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Date/Time • February 4(Wed), 16:30-17:10
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Plenary Speech 1

Ultra-Precision Flexible Polishing

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The work proposes a novel ultraprecision flexible shear-thickening polishing method to meet the stringent requirements of hard and brittle materials for high-precision surface integrity and subsurface damage (SSD). By precisely regulating the non-Newtonian rheological behavior of the polishing slurry, shear thickening (ST) or gradient/chain thickening (GT/CT) effects are induced under shear fields, leading to the formation of a dynamic quasi-solid flexible abrasive tool. This enables a fundamental transition of the material removal mechanism from purely mechanical wear to a flexible physicochemical synergistic process. Parameter optimization demonstrates that, through control of the critical shear rate, abrasive characteristics, and chemical medium activity, sub-nanometer surface roughness, nanoscale SSD (< 5 nm), and sub-micrometer form accuracy can be simultaneously achieved on various difficult-to-machine materials, including lithium niobate (LN), KDP crystals, silicon carbide (SiC), and 9Cr18 bearing steel. It reveals a new pathway for efficient, low-damage material removal through the coupling of rheological control and interfacial reactions, providing an innovative technological approach and theoretical foundation for ultraprecision or atomic-scale manufacturing in optical, semiconductor, and precision device applications.

Keywords: Flexible Polishing; Shear-thickening Polishing; Material Removal; Subsurface Damage

Acknowledgement: This work has been supported by National Natural Science Foundation of China (Excellent Young Scientists Fund-2023-Overseas-Min Li; General Program No. 52475446) and Anhui Provincial Natural Science Foundation (No. 2308085ME170) and Key Science & Technology Project of Anhui Province (No. 202423i08050035 and No. 2024jyjxggyjY058).

Plenary Speech 2

3D Printing for Advanced Manufacturing: Multi-Functional and Multi-Materials Voxels

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3D Printing or additive manufacturing has already been applied in various advanced manufacturing processes, enabling new product design and new workflow in a spectrum of industrial and research applications. In this talk, we would like to discuss further the potential of 3D printing as a new design paradigm for the fabrication of multi-materials and multi-functional parts. From metal printing to microstructure alignment of nanoparticles, we will share examples of different 3D printing techniques in enabling new design and materials for innovations in manufacturing.

Keywords: 3D Printing; Advanced Manufacturing; Additive Manufacturing

Acknowledgement: This research is supported by the National Research Foundation, Singapore, under its NRF Investigatorship (NRFI Award No. NRF-NRFI07-2021-0007). The research is also supported by the National Research Foundation, Prime Minister's Office, Singapore, under its Medium-Sized Centre funding scheme.

Plenary Speech 3

Additive Manufacturing of Functional Metamaterials with Three-Dimensionally Repeating Internal Architectures

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Additive manufacturing (AM) processes enable the facile fabrication of products with complex internal geometries that are difficult to produce using conventional manufacturing processes. As a result, the advent of AM process has led to a significant increase in research on the design and fabrication of metamaterials featuring three-dimensionally repeating internal architectures for enhanced and controllable functionalities. The functionalities intended in the design of the metamaterial can be effectively improved by the application of a functional material coating to the additively manufactured metamaterial frame. The objective of this study is to propose design and fabrication methods for functional metamaterials with three-dimensionally repeating internal architectures through the application of functional coating and micro-nano processing to additively manufactured frames. The influence of frame design and coating material on the functionality of the metamaterial is investigated using computer-aided design (CAD) and computer-aided engineering (CAE) softwares. In addition, novel experimental methods are discussed to evaluate the performance and characteristics of the functional metamaterial. Finally, the applicability of the metamaterial is examined through several case studies.

Keywords: Metamaterial; Multifunction; Repeating Internal Architecture; Additive Manufacturing

Acknowledgement: This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. RS-2023-00219369, RS-2025-00562459)

Keynote Speech

Keynote Speech 1

Date/Time • February 3(Tue), 10:55-11:20
Session Chair • Young Tae Cho (Changwon National University, Korea)

Keynote Speech 2

Date/Time • February 3(Tue), 11:20-11:45
Session Chair • Young Tae Cho (Changwon National University, Korea)

Keynote Speech 3

Date/Time • February 4(Wed), 10:55-11:20
Session Chair • Bong-Kee Lee (Chonnam National University, Korea)

Keynote Speech 4

Date/Time • February 4(Wed), 11:20-11:45
Session Chair • Bong-Kee Lee (Chonnam National University, Korea)

Keynote Speech 1

Algorithm of Sustainability: Engineering Additive Manufacturing with Printing Materials and Artificial Intelligence

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The keynote examines how the convergence of advanced materials science, simulation, and intelligent algorithms can support the development of new printing material with recycled waste, while improving the efficiency of additive manufacturing (AM) processes. Two main research thrusts define this approach. The first investigates the development of high-performance, recyclable materials derived from sustainable or post-consumer feedstocks, particularly recycled high-density polyethylene (rHDPE). To qualify new composite systems such as rHDPE/PTFE blends, a multi-scale simulation framework based on the CFD–DEM method is applied. This method systematically links feedstock characteristics, including particle size, with printing performance, supporting data-driven material qualification. The second research thrust introduces an AI-based optimization framework for metal additive manufacturing, demonstrated through the Laser Engineered Net Shaping (LENS) process using a dataset of 90 samples. By combining a physics-informed Liquid Neural Network (LNN) with reinforcement learning, the framework enables adaptive control through real-time thermal stress feedback, effectively reducing the risk of cracking. Experimental results confirm improvements in microhardness and dilution, validating the approach's multi-objective optimization capability. These developments lessen the dependence on extensive experimental trials and establish a scalable, verifiable pathway toward sustainable, resource-efficient additive manufacturing processes and materials.

Keywords: Additive Manufacturing; Recycled Plastic; CFD-DEM Simulation; Metal Additive Manufacturing; Liquid Neural Network(LNN)

Keynote Speech 2

Ultrafast Photonics for Precision Manufacturing of Semiconductors and Secondary Batteries

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This presentation will introduce how we have utilized a frequency comb for multi-scale high-precision dimensional measurements, ranging from sub-nanometer-scale thermo-plasmonic motions to kilometer-scale inter-satellite-distances. The frequency comb of a femtosecond pulse laser provides a repetitive pulse train in the time domain and millions of evenly spaced optical laser modes in the frequency domain; these features enabled the endowment of Nobel Prize in Physics to frequency comb in 2005. Over the recent two decades, all the fields in precision metrology have benefited from this frequency comb technology; high-precision dimensional metrology was not an exception. In large scales, we reported nanometer-precision time-of-flight measurement for large-scale engineering and future space missions. In medium scales, precision stage positioning and dimensional inspection required in semiconductor and display industries were proven to get precision improvement from the frequency comb. In small scales, we reported that frequency comb can successfully maintain core performances in photon-plasmon conversion by exploiting plasmonic extraordinary transmission through a subwavelength plasmonic hole array, so it can be used for high-resolution phase spectroscopy in the field of plasmonics for realizing picometer resolution plasmonic ruler. These series of demonstrations prove that the frequency comb will be the key technology to open the new vista of future precision metrology.

In recent years, we also have witnessed a tremendous demand of electronic devices that leads to a massive amount of e-waste and rapid exhaustion of non-renewable resources. Consequently, green electronics become a promising area to produce eco-friendly devices from natural materials using sustainable fabrication methods. Graphene, a two-dimensional material, exhibits exceptional electrical, mechanical, physical, and thermal properties which make graphene highly attractive for numerous applications. Up to now, graphene can be synthesized via several routes such as liquid-phase exfoliation, mechanical exfoliation, chemical vapor deposition, and reduction of graphene oxide. However, to realize the full potential of graphene, there is an urgent need to develop a cost-effective, scalable, and green fabrication pathway. We have developed a one-step approach to the preparation of arbitrary graphene patterns on various precursor materials, for example, polymers, fabrics, papers, and biomass using femtosecond laser pulses in ambient conditions. The formation of laser-induced graphene (LIG) has been confirmed and characterized using scanning electron microscopy (SEM), transmission electron microscopy (TEM), Raman spectroscopy, and electrical measurement. Owing to excellent electrical conductivity and highly porous structures, this LIG can be utilized in diverse applications such as supercapacitors, pseudo capacitors, and various types of sensors.

Keywords: Ultrafast Photonics; Direct Laser Writing; Optical Metrology; Non-destructive Testing; Precision Manufacturing

Keynote Speech 3

Experimental Investigation of the Mechanical and Magnetic Properties of Metal 3D-Printed Parts

Do Qui Duyen[1], Tran Huu Anh Huy[1], Nguyen Duy Hung[1], and Nguyen Quoc Hung[2,#]

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Metal Additive Manufacturing (AM), or metal 3D printing, has transitioned from a rapid prototyping tool to a primary manufacturing method for complex, high-value components across the aerospace, medical, and energy sectors. This presentation will begin with a concise review of prevailing metal AM technologies, such as Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Binder Jetting, and Bound Metal Deposition (BMD) - also known as metal Fused Deposition Modeling (FDM). The core of the presentation will then focus on a detailed experimental investigation into the mechanical and magnetic properties of parts fabricated via PBF and metal FDM. The study systematically characterizes critical mechanical properties, including tensile strength and yield strength, and correlates them with the unique microstructural features such as porosity, grain morphology, and the presence of residual stresses. Furthermore, the research delves into the often-overlooked functional property of magnetism, examining the magnetic permeability, coercivity, and saturation magnetization of 3D-printed soft magnetic materials like iron-silicon and nickel-iron alloys. Ultimately, this work provides essential insights for selecting the appropriate AM technology and post-processing route to meet specific mechanical and functional requirements for advanced applications.

Keywords: Metal Additive Manufacturing(AM); Metal 3D Printing; Powder Bed Fusion(PBF); Bound Metal Deposition(BMD); Mechanical and Magnetic Properties

Keynote Speech 4

Skin-Conformable Sensors and Displays by Soft Electronic Materials

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Wearable healthcare devices realize reliable monitoring of physiological signals in the long term, which helps us find or prevent diseases in the early stage. However, current wearable devices, such as watches or rings, have poor skin contact, degrading signal integrity. This is due to the huge mechanical mismatch between rigid wearables and soft human skin In this presentation, we show skin-like soft sensors and displays formed with stretchable electronic materials. For example, we developed high-resolution patternable stretchable conducting polymers which allowed us to fabricate skin-conformable sensors. We fabricated an ultrathin and stretchable electrochromic display, which can be used as an information display for signals obtained by skin-attached sensors. Furthermore, our stretchable piezoelectric sensor has a modulus of ~10 MPa and thickness of less than 10 μm, which allows us to form a highly conformal contact to the skin. The sensor allowed us to record the deformation of skin while minimizing the discomfort of wearing. We envision such unperceivable designs would be one of the next steps of wearable devices.

Keywords: Wearable Devices; Stretchable Electronics; Conducting Polymers

Acknowledgement: This work was supported by Daicel, JST FOREST (JPMJFR234E), Murata Foundation, and JKA Foundation.

The 7th International Conference on
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Technical Session

Technical Session 1

Date/Time • February 3(Tue), 08:30-09:45
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Date/Time • February 3(Tue), 08:30-09:45
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Technical Session 3

Date/Time • February 3(Tue), 14:00-15:15
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Technical Session 4

Date/Time • February 3(Tue), 14:00-15:00
Session Chair • Sang-in Park (Incheon National University, Korea)

Technical Session 5

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Date/Time • February 3(Tue), 15:30-16:45
Session Chair • Yongho Jeon (Ajou University, Korea)

Technical Session 7

Date/Time • February 4(Wed), 08:30-10:00
Session Chair • Hyun-Joon Kim (Kyungpook National University, Korea)

Technical Session 8

Date/Time • February 4(Wed), 08:30-10:00
Session Chair • Hyoungsoo Kim (KAIST, Korea)

Technical Session 9

Date/Time • February 4(Wed), 14:00-15:15
Session Chair • Jungchul Lee (KAIST, Korea)

Technical Session 10

Date/Time • February 4(Wed), 14:00-15:15
Session Chair • Sang Min Park (Pusan National University, Korea)

An Experimental Analysis of Surface Quality and Dimensional Shrinkage in Bound Metal Deposition Additive Manufacturing

Tran Huu Anh Huy[1], Do Qui Duyen[1], Do Huu Minh Hieu[1], and Nguyen Quoc Hung[2,#]

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This study presents an experimental investigation into the surface characteristics and dimensional shrinkage of stainless steel 316L parts fabricated via Bound Metal Deposition (BMD), an emerging additive manufacturing technology. The research systematically examines how critical printing parameters—specifically, layer height and print orientation—influence the resulting surface roughness and anisotropic shrinkage behavior during the subsequent debinding and sintering stages. A series of test specimens were manufactured under varying conditions, with surface topography analyzed using contact profilometry. Dimensional accuracy was quantified by measuring critical features before and after sintering to calculate linear shrinkage percentages in the X, Y, and Z axes. Results indicate that surface roughness is predominantly governed by layer height, while print orientation significantly affects the magnitude and uniformity of shrinkage. This work establishes quantitative correlations between process parameters and final part quality, providing essential data for optimizing BMD processes to achieve improved geometric fidelity and surface finish, thereby enhancing the manufacturability of functional, net-shape metal components.

Keywords: Additive Manufacturing; 3D Printing; Bound Metal Deposition; Shrinkage; Surface Roughness

Acknowledgement: This research was fully funded by the HUTECH University under grant number D- TTD- -2025-01.

A Data-Driven Digital–Physical Hybrid Framework for Predicting Surface Deformation in Metal Binder Jetting

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Metal binder jetting (MBJ) often exhibits significant sintering-induced deformation; however, existing studies primarily focus on shrinkage trends rather than surface-shape evolution. This work develops a data-driven surrogate framework for predicting post-sintering surface geometry in MBJ parts. Bridge and cantilever structures were parameterized using Latin hypercube sampling, allowing for a systematic exploration of deformation-sensitive design variables. Densification behavior was simulated using the finite element method (FEM) with pressure- and temperature-dependent creep subroutines, generating digital deformation data. Cross-sectional surface curves were extracted from binarized and edge-processed images, followed by curve normalization and resampling to create consistent geometric datasets. ImageJ overlap analysis was used to evaluate agreement between predicted and actual deformation profiles. A Gaussian Process Regression (GPR) model was constructed to predict surface curves from design parameters and provide 95% confidence intervals for uncertainty quantification. The integrated approach reduces trial-and-error fabrication, supports compensation design, and improves predictive reliability for sintering-driven deformation in MBJ applications.

Keywords: Metal Binder Jetting(MBJ); Sintering Deformation Prediction; Digital–Physical Hybrid Surrogate Modeling; Finite Element Method

Acknowledgement: This research is conducted by the Industrial Technology Innovation Program (KEIT project no. 20024344, Development of AI-based high carbon steel alloy design and sintering-based additive manufacturing technology for 7.0 L/Hr-level high-speed production of powertrain components with tensile strength over 1.0 GPa in the next-generation mobility) funded by the Ministry of Trade, Industry & Energy of the Republic of Korea, and K-Labs Inc.

Material Property Prediction in L-DED: A Physics-Based Hardness Prediction Framework Using In-Situ Thermal Data

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Ensuring the mechanical integrity of components fabricated via Laser-Directed Energy Deposition (L-DED) is challenging due to complex, non-equilibrium thermal histories. While data-driven machine learning and high-fidelity simulations address this, they often lack physical interpretability or suffer from prohibitive computational costs. This study presents a fully physics-based framework for real-time Vickers hardness prediction in 316L stainless steel using in-situ infrared (IR) thermal data. Unlike "black-box" models, this framework explicitly establishes a Process-Structure-Property (PSP) linkage. By extracting cooling rates from IR monitoring, the model estimates key microstructural parameters—solidification cell size and dislocation density—to predict hardness through segregation, Orowan, and dislocation strengthening mechanisms. A key innovation is the development of a track-by-track dislocation density model that quantifies the competition between generation and dynamic recovery induced by repetitive thermal cycling. Experimental validation confirms the framework's ability to predict hardness distributions accurately without extensive pre-labeled datasets. This work effectively bridges the gap between real-time monitoring and physical metallurgy, offering a robust, interpretable tool for L-DED quality assurance.

Keywords: Additive Manufacturing; Directed Energy Deposition; In-situ Thermal Monitoring; Physics-based Modeling; Process-structure-property Relationships

Acknowledgement: This research was supported by Korea Basic Science Institute (National research Facilities and Equipment Center) grant funded by the Ministry of Education. (grant No. 2021R1A6C101A449) and the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT)(No. RS-2023-NR076859).

Adaptive AI for Bioprinting

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The accelerating progress of bioprinting technology demands robust and flexible methods for both bioink characterization and printing optimization. Conventional artificial intelligence (AI) models used in additive manufacturing often lack adaptability, requiring new models to be trained for every notable change, including new bioink, or real-world variability such as subtle differences in formulation, printer units, batch quality, or ink aging. In this work, we present an adaptive AI framework that combines a pre-trained base model with an adaptation model. This design enables efficient transfer of prior knowledge, allowing for rapid recalibration to new bioink formulations or evolving printing conditions while minimizing the need for additional experimental data. For smaller, incremental variations, such as batch-to-batch or printer-to-printer differences, as well as temporal changes in material properties, integration of reinforcement learning enables real-time fine-tuning, greatly reducing the need for repeated manual adjustments. Our results demonstrate that this adaptive approach maintains its performance across different bioink compositions and can even be extended to predict various physical properties of a single bioink. This streamlines experimental workflows and supports automated, data-driven decision-making. When combined with reinforcement learning, our methodology offers increased resilience and scalability in bioprinting and accelerates the translation of innovative bioink designs into consistent and practical manufacturing solutions.

Keywords: Bioprinting; Artificial Intelligence; Adaptive Machine Learning; Reinforcement Learning; Process Optimization

Technical Session 1 TS1-5

Experimental Study on Surface Interaction for Multi-Process Additive Manufacturing

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Additive Manufacturing (AM) consists of vast range of processes which are capable of processing diverse materials. While the adoption of individual AM technologies by industries, researchers and hobbyists is well established, integration of multiple AM processes within a single platform can further expand material combinations and part functionality. In particular, combining direct ink writing (DIW) of high-viscosity materials with material jetting of low-viscosity inks offers a pathway to deposit precise functional features onto or within DIW-printed structures. This study focuses on the interaction between low-viscosity jetting inks and high viscosity DIW inks, with an emphasis on wetting and interfacial bonding. In addition, the influence of surface energy of a substrate on droplet spreading and adhesion is investigated using surfaces with different surface energies. The insight from this work is intended to guide the design of hybrid DIW-inkjet systems and process windows for multi-material AM.

Keywords: Hybrid Additive Manufacturing; Direct Ink Writing(DIW); Material Jetting/ Inkjet Printing; Multi-Material 3D Printing; Surface Energy and Wetting; Droplet Spreading; Interfacial Bonding; Functional Ink Deposition

Ultra-Precision Mechanical Machining Approach for Efficient Manufacturing Approach of Shaping Piezoelectric Single Crystal

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Piezoelectric single crystal is one of the promising energy transduction material which are widely used for various sensors and actuators applications. In order to shape the piezoelectric single crystal, brittle characteristics of it should be required to be considered. According to crystal orientation, ductile and brittle behavior showing different characteristics. Also, mechanical machining parameters such as cutting depth, feed, and laser assistance required to be optimized. In this research, we demonstrate and optimize the ultra-precision mechanical machining approach as an efficient shaping process for novel piezoelectric single crystal material. Firstly, lens like curvature fabrication results will be presented with the according focused ultrasound performance evaluation results. In this project, we fabricated ultra-precision concave and convex shaped piezoelectric single crystal. Secondly, step fabrication results will be presented for future applications of vortex transducer. As controlling the chipping and crack propagation in brittle material, efficient manufacturing approach which enable to fabricate complex geometry of single crystal was developed and optimized.

Keywords: Piezoelectric Single Crystal; Mechanical Machining; Focused Ultrasound; Crack; Chipping

Acknowledgement: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2023-00210764)

Atomic-Scale Laser-Assisted Polishing of Gallium Oxide

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Gallium oxide (β-Ga_2O_3) exhibits excellent physical properties and is considered a highly promising material for semiconductor and microelectronic applications. This poses significant challenges for its ultra-precision machining with minimal damage. Compared with conventional polishing, laser-assisted polishing (LAP) offers distinct advantages, yet its material removal mechanisms remain insufficiently understood. In this study, machine learning-driven molecular dynamics simulations are employed to atomistically investigate material removal behavior and subsurface damage mechanisms of β-Ga_2O_3 with and without laser assistance. The results show that laser assistance markedly affects the polishing force, temperature, potential energy, phase transformation, dislocation activity, friction coefficient, material removal rate, and subsurface damage. LAP significantly reduces the polishing force, average friction coefficient, and subsurface damage depth. Moreover, material removal in LAP involves both abrasive interaction and laser ablation, resulting in a substantial increase in the removal rate. Plastic deformation in β-Ga_2O_3 primarily occurs through amorphization, dislocation motion, stacking faults, and oxygen atom phase transitions. This work enhances the fundamental understanding of β-Ga_2O_3 damage mechanisms and provides theoretical insights for atomic-scale laser-assisted polishing.

Keywords: Atomic-scale Polishing; Material Removal; Subsurface Damage; β-Ga_2O_3

Acknowledgement: This work has been supported by National Natural Science Foundation of China (Excellent Young Scientists Fund-2023-Overseas; No. 52475446) and Anhui Provincial Natural Science Foundation (No. 2308085ME170) and Key Science & Technology Project of Anhui Province (No. 202423i08050035 and No. 2024jyjxggyjY058).

Study on Temperature and Vibration Integrated Sensor Based on Fiber Bragg Grating

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In response to the lack of fiber Bragg grating (FBG) sensors capable of simultaneously monitoring temperature and vibration in mechanical equipment, this paper presents the design, simulation, and experimental validation of a novel integrated temperature–vibration FBG sensor. The sensor features reliable performance, broadband response, and high sensitivity, offering strong potential for intelligent equipment health monitoring. A theoretical analysis and modal simulation of the hinge, the core sensing component, were conducted to optimize its structural parameters. The first-order natural frequency of the hinge was determined as 481.92 Hz, ensuring stable sensing performance within the operational range of 0–160 Hz, where frequency variation has negligible influence on vibration sensitivity. Experimental evaluations further verified the sensor's capabilities. Temperature calibration demonstrated a stable response from 30 °C to 130 °C with a sensitivity of 10.87 pm/°C. The measured first-order natural frequency was approximately 500 Hz, consistent with simulation results. Vibration calibration confirmed broadband and high-acceleration sensing performance, yielding a sensitivity of 86.36 pm/g within 0–160 Hz and 0–9 g. These results validate the feasibility and effectiveness of the proposed integrated FBG sensor, providing a reliable and efficient solution for real-time health monitoring of mechanical systems.

Keywords: Fiber Bragg Grating Sensor; Temperature–vibration Sensing; Monitoring

Acknowledgement: The authors extend their appreciation to the Yeungnam University Research Grant for 2025, Natural Science Foundation of Hubei Province (No.2024AFB376).

Study on the Influence of Green Dielectric and Process Feasibility in Electrical Discharge-Assisted Milling of Nickel-Based Alloy 718

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Electrical Discharge Assisted Milling (EDAM) proves to be a highly effective and viable process for machining nickel-based alloy 718. The use of EDM oil as the dielectric fluid for machining nickel-based alloy 718 generates hazardous by-products, posing serious risks to laboratory personnel and the environment. To mitigate the environmental and safety hazards associated with conventional EDM oil, this study employs green plant-based dielectric fluids (Canola oil, Peanut oil) as alternative media in the electrical discharge assisted milling process. Through comparative experiments on the designed system, key performance indicators such as surface microhardness, surface chemical composition, surface morphology integrity, electrode wear rate, and cutting force after workpiece machining were evaluated to comprehensively investigate the feasibility of green dielectric fluids in this composite machining technology. Experimental results indicate: Green dielectric fluid is an effective alternative to EDM oil; During machining in EDM oil, Canola oil, and Peanut oil media, the cutting force amplitudes were 323.4 N, 302.6 N, and 281.5 N, respectively. Compared to EDM oil, Canola oil and Peanut oil reduced cutting forces by 6.4% and 12.9%, respectively. Surface roughness first decreases and then increases with increasing capacitance, reaching its optimal value at 1 μF. The roughness under Peanut oil medium is reduced by 26.5% and 21.1% compared to EDM oil and Canola oil, respectively; At a capacitance parameter of 1 μF, optimal machined surface quality is achieved, with Peanut oil as the dielectric fluid yielding the best surface integrity of the workpiece.

Keywords: Nickel-based Alloy 718; Electrical Discharge Assisted Milling; Green Dielectric Fluids; Process Feasibility; Surface Quality

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An Inverse Modeling Algorithm for Form Grinding of Spiral Grooves in Tap Production Lines

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The tap's spiral groove is the key geometric feature to realize efficient chip removal and cutting stability, and its groove machining accuracy directly affects tool life and cutting quality. However, in non-fully automated production lines, this process often requires multiple test cuts and manual compensation, resulting in low efficiency and poor stability. To address these challenges, this study proposes an inverse-modeling algorithm for determining the grinding wheel profile. First, a 3D point cloud representing the designed spiral groove geometry is constructed. Next, the grinding wheel profile is obtained by numerically solving the contact-curve equations and converting the solution into a format compatible with machine inputs. Experimental verification on a tap production line demonstrated that the proposed method could reproduce the designed groove shape in a single pass, significantly reducing debugging time and improving machining accuracy and productivity. Finally, several factors that are often overlooked but may affect the final groove shape during the grinding process are summarized and analyzed. The proposed solution provides a feasible approach for achieving high-precision, single-step spiral-groove forming, offering strong potential for wider industrial adoption.

Keywords: Cutting Tool; Tap; Spiral Groove; Form Grinding; Grinding Wheel Profile

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Technical Session 3 TS3-1

Optically Engineered Materials for High-Efficiency Dielectric Metasurface

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Metasurfaces are planar optical devices that manipulate light (phase, amplitude, polarization) using periodic nanoscale structures, enabling ultrathin, high-efficiency components for displays, sensors, cameras, and AR. However, scaling to large-area, low-cost fabrication while preserving nanoscale precision and optical efficiency remains challenging.

This study presents an integrated fabrication platform combining nanoimprint lithography and PECVD. Nanoimprint lithography enables rapid, low-cost large-area patterning via mold replication; we optimized an in-house mold and resin to improve fidelity, uniformity, and transfer efficiency, achieving scalable pattern precision from sub-mm to full wafer. These imprinted templates were used to realize complex metalenses and beam-steering devices.

For PECVD, a-Si:H and a-SiOx:H films were deposited and their optical constants were engineered by tuning hydrogen/oxygen content, plasma power, and substrate temperature, thereby controlling refractive index (n) and extinction coefficient (k). This reduced absorption in amorphous Si and expanded visible-wavelength phase control. XPS and FTIR linked optical-constant changes to hydrogen bonding configurations.

Using imprint-based patterning plus material property engineering, we demonstrated high-efficiency, low-loss, large-area metasurfaces with cost advantages over conventional methods and strong agreement between experiments and electromagnetic simulations. The platform supports practical metasurface commercialization and is extendable toward continuous, scalable industrial production.

Keywords: Nano-manufacturing; Metasurface; Optical Materials; Imprinting; Nano-photonics

Acknowledgement: Y.Y. acknowledges that this research was supported by Regional Innovation Alliance Center for Mid-tier Companies (Ministry of Trade, Industry and Energy (MOTIE)).

Bioinspired Tubular Porous Polylactic Acid Microneedle Array Patch with Enhanced Mechanical Strength and Interstitial Fluid Extraction

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Porous polymer microneedles (MNs) have emerged as a promising platform for minimally invasive transdermal sampling and therapy. Although various porous polymer MNs have been demonstrated, they typically rely on randomly distributed or isotropic pores, and the critical effects of pore-structure on mechanical performance and interstitial fluid (ISF) transport remain insufficiently understood. To address these limitations, we investigate pore-structure engineering as a strategy to overcome the current performance bottlenecks.

The microstructure of conifer trees, characterized by anisotropic tubular channels that enable highly efficient water transport, inspired our design. We implemented a tubular pore architecture in porous polylactic acid (PLA) MNs fabricated using an ice-templating method. By employing directional freezing, we successfully fabricated a PLA MN array patch (MAP) with tubular pore structures, uniform pore distribution, and vertically aligned continuous channels. The resulting MNs exhibit tunable pore diameters around 10 μm and a porosity range of 45–85%. The fabricated PLA MNs retained sufficient axial strength to exceed the minimum insertion threshold of the human skin (~0.058 N) and penetrate porcine skin reliably. Moreover, the pronounced pore anisotropy greatly facilitates rapid liquid transport via capillary flow, yielding an uptake rate of 5.35–11.41 $\mu L \cdot min^{-1}$ per array. The developed MAPs combine enhanced mechanical strength with efficient extraction and offer clear potential for integration with point-of-care testing (POCT) systems for minimally invasive biomarker diagnostics.

Keywords: Porous Microneedle; Polylactic Acid; Ice-templating; Liquid Extraction; Structure–performance

Acknowledgement: This work was supported by JST SPRING, Grant Number JPMJSP2108 and by the WINGS-QSTEP Program, The University of Tokyo.

Programmable Stiffness and Shape Control in Soft Magnetic Muscles Using a Hybrid Cross-Linked Matrix

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Soft artificial muscles offer transformative potential for robotics, wearable electronics, and biomedical devices, yet their broader application is frequently restricted by an intrinsic trade-off between mechanical compliance and energy output. This limitation often results in actuators that are flexible but lack the work density required for practical, load-bearing tasks. In this work, we present a high-performance magnetic composite actuator designed to overcome these challenges through a novel material architecture. The system utilizes an optimized dual cross-linked polymer network—integrating stable covalent bonds with reversible dynamic physical interactions—embedded with surface-functionalized magnetic microparticles. This hybrid design enables precise, on-demand stiffness modulation and reprogrammable actuation. Mechanically, the composite demonstrates exceptional deformability with an elongation at break of 1274% and a massive programmable stiffness range from 213 kPa to 292 MPa (a switching ratio of 1.37×10^3). Furthermore, it achieves a shape fixation efficiency exceeding 99%. In terms of actuation performance, the device delivers a high actuation strain of 86.4% and a work density of 1150 kJ m^{-3}. Notably, it supports loads exceeding 4000 times its own weight, providing a robust, reconfigurable platform that successfully bridges the gap between soft adaptability and high-power output.

Keywords: Dual Cross-linking Networks; High Work Density; Magnetic Soft Actuators; Programmable Stiffness; Shape Memory Polymers

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Liquid-Borne Particle Measurement with Aerosolization and Data Processing Algorithm

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In chemical mechanical polishing, even a small fraction of oversized or agglomerated particles in slurry can trigger micro-scratches, making precise particle size monitoring indispensable. However, optical methods such as liquid particle counters and dynamic light scattering suffer from refractive-index and calibration biases, optical coincidence at high concentrations, and intensity-weighting that distorts PSDs in polydisperse slurries. By aerosolizing the slurry and classifying particles by electrical mobility with SMPS, aerosol metrology avoids refractive-index dependence and optical coincidence while resolving multimodal populations with high fidelity. We present a liquid-particle monitoring approach combining an aerosol atomizer and SMPS with a data-processing pipeline that isolates non-volatile residue (NVR) and inverts aerosol size distributions (ASDs) to hydrosol size distributions (HSDs). Using monodisperse PSL standards (50–700 nm) at multiple concentrations, we establish empirical calibration after multi-mode lognormal fitting (≤4 modes; R2 > 0.99) and NVR–particle mode assignment via 10% diameter-proximity merging or slope-based cutoff. The calibrated inversion with dilution-factor (DF) correction reconstructs HSDs from measured ASDs. Applied to ceria (~140 nm, 6 wt%) and silica (~150 nm, 20 wt%) slurries, the NVR-subtracted HSDs show consistent mode peaks across DFs, with minor concentration-dependent shifts only for silica. DF-corrected particle concentrations agree across DFs. Reconstructed mean sizes align with SEM references (ceria ≈ 103–114 nm; silica ≈ 115–121 nm), confirming inversion fidelity. Overall, the integrated A-SMPS + NVR subtraction + ASD→HSD inversion + DF correction enables quantitative liquid-phase PSDs for CMP slurries, supporting inline/edge-of-line process monitoring.

Keywords: Aerosol; Atomizer; Hydrosol Size Distribution; Non-volatile Residue; Aerosol to Hydrosol Inversion

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Technical Session 3 TS3-5

Scalable In Situ Synthesis of Cu_2O/ZnO Heterojunction UV Photodetectors through Joule-Heated Nanofiber Templates

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Ultraviolet (UV) photodetectors are essential for applications in environmental monitoring, biomedical sensing, and optical communication. Zinc oxide (ZnO), a wide-bandgap (3.37 eV) n-type semiconductor, is attractive for UV photodetector fabrication due to its excellent photochemical stability and low cost; however, single-ZnO devices exhibit poor charge collection and slow response. To overcome these drawbacks, this study introduces a novel fabrication strategy for Cu_2O/ZnO heterojunction UV photodetectors. The method integrates electrospinning, electroless copper deposition, and Joule-heating-assisted ZnO synthesis. First, palladium-containing polymer nanofibers are electrospun onto a substrate to form a Pd seed layer for subsequent Cu deposition. Second, electroless deposition forms a conductive Cu nanowire (CuNW) network, in which resistance and transparency can be adjusted by deposition time. By applying a direct current voltage to the CuNW-based electrode, localized Joule heating (~60 °C) occurs. Simultaneously, when a ZnO precursor solution is dropped, Cu oxidation and hydrothermal ZnO growth begin, thereby forming a conformal Cu_2O/ZnO p–n heterojunction. The resulting device exhibits outstanding performance, with a photosensitivity of 36.51 % and ultrafast response times of 51.94 ms—over 18 times higher sensitivity than single-ZnO devices. The enhancement arises from a strong built-in electric field at the heterojunction, which promotes efficient electron–hole separation and rapid carrier transport. This scalable, low-temperature process enables precise control of heterojunction formation and offers strong potential for flexible, transparent, and wearable optoelectronic systems.

Keywords: Ultraviolet Photodetector; Cu_2O/ZnO Heterojunction; Joule Heating

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Thickness Optimization and Energy Absorption Performance Comparison of Extruded Aluminum Beams

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This study aims to balance vehicle lightweighting and crash safety by experimentally comparing advanced high-strength steel (AHSS) and 7xxx-series extruded aluminum beams with wall thicknesses of 2.5, 3.0, and 3.5 mm. Quasi-static three-point bending tests were conducted under identical jig and support conditions. While maintaining the same cross-sectional geometry, only the wall thickness was varied, and performance was evaluated using load–displacement curves, initial stiffness, energy absorption over the deformation range, and mass-normalized efficiency as an integrated index. The results show that the 3.0 mm aluminum beam provides the most favorable balance among crash performance, weight, and manufacturability, as it stably sustains the target load range while minimizing the increase in mass. The 3.5 mm beam offers a larger safety margin in terms of absolute load capacity, but its higher mass and process burden reduce overall efficiency, whereas the 2.5 mm beam fails to secure sufficient margin in maximum load. These findings confirm that, even within the same cross-sectional family, appropriate tuning of wall thickness alone can substantially improve the mass efficiency of crash response.

Keywords: Extrude Aluminum Beam; Thickness Optimization; Three-point Bending; Energy Absorption Efficiency; Vehicle Lightweighting

Acknowledgement: This work was supported by the Technology Innovation Program (RS-2024-00405428, Development of High Energy Absorbtion Materials and Parts Manufacturing Technology to Improve Crash Performance) funded By the Ministry of Trade, Industry & Resources(MOTIR, Korea)

Fixed-Grid-Based Optimization of a Vibration Test Fixture for Automotive Headlamps to Increase Natural Frequency

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The vehicle component is exposed to continuous vibration in driving environments. To ensure its durability, a vibration test is essential in the product development process. In particular, a vibration test fixture is used to secure the test target to the vibration tester during the testing procedure. This fixture is designed to protect the test target from the impact and vibration it experiences. However, when the natural frequency of the test fixture matches the test frequency range, resonance occurs, which limits the accuracy of the durability evaluation. Therefore, there is a need for a design approach that maximizes the natural frequency of the test fixture. This study proposes an optimization method to maximize the natural frequency of the vibration test fixture. The proposed method consists of two steps. Firstly, a finite element model is constructed based on a fixed grid. Secondly, optimization is performed using the constructed model. The design variables are the height and the existence of a rib. The objective function is to maximize the natural frequency, with a constraint on the mass of the test fixture. A genetic algorithm was used to update each design variable. Additionally, the optimized model was quantitatively compared with the conventional optimized model. As a result, the study derived a domed form of the vibration test fixture for a single optimization process. The optimized model improved the natural frequency by approximately 2.30% and reduced the mass by approximately 25.45% compared to the conventional optimized model.

Keywords: Optimization; Fixed Grid; Vibration Test Fixture; Genetic Algorithm

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A Dual-Axis Rotational Molding Machine: Design, Fabrication, and Experimental Testing

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This study focuses on the design and fabrication of a rotational molding machine for producing hollow plastic products with high durability, eliminating the need for assembly and improving processing efficiency and recyclability. A square-shaped dual-axis rotational molding structure was selected due to its simplicity, low cost, and ease of operation. The machine applies a chain and bevel gear drive system capable of achieving mold rotation speeds of 10–20 rpm. Forming performance was evaluated under four resin volume conditions (Factor A) with product wall thickness measured at three rotational speeds (Factor B). A two-factor ANOVA without replication revealed a significant effect of resin volume ($F(3,6)=13.67$, $p=0.0043$) and rotational speed ($F(2,6)=30.33$, $p=0.00073$). Bonferroni-adjusted pairwise comparisons indicated that A3 (42 mL) produced significantly lower thickness values than A2 (40 mL), while B1 (16 rpm) resulted in significantly higher thickness uniformity than B2 (18 rpm) and B3 (20 rpm), establishing the trend B1 > B2 > B3. Practical testing further confirmed that the system operates safely and reliably, with convenient disassembly and maintenance. While additional experiments with broader processing parameters are recommended, the developed machine demonstrates strong potential for application in small and medium-scale plastic manufacturing and laboratory environments.

Keywords: Rotational Molding; Dual-axis Drive; Hollow Plastic Products; Square-frame Structure; Bonferroni-adjusted Pairwise Comparison

Acknowledgement: This work was carried out at the X3.14 Scientific Research Room, Faculty of Mechanical Engineering, Industrial University of Ho Chi Minh City, Vietnam.

Technical Session 4 TS4-4

Molecular Dynamics Study on PEGDE-Modified Electrochemically Debondable Epoxy Systems Containing EMIM-TFSI Ionic Liquid

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Electrochemically Debondable Adhesives (EDA) are emerging epoxy-based materials that exhibit strong adhesion under normal conditions but allow reversible debonding upon electrical stimulation, providing a promising solution for sustainable recycling and repair of electronic and energy devices. In this study, molecular dynamics (MD) simulations were conducted to investigate the structural and ionic transport behavior of diglycidyl ether of bisphenol A (DGEBA) epoxy systems cured with an amine-based hardener and modified with polyethylene glycol diglycidyl ether (PEGDE) in the presence of the ionic liquid 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide (EMIM-TFSI). Crosslinked networks were generated using a distance-based xlink.pl protocol within the COMPASSIII force field, targeting a 60% degree of conversion at 300 K to represent room-temperature curing conditions. The incorporation of PEGDE effectively enhanced the dispersion of ionic liquids, suppressed ionic cluster formation, and significantly improved ionic conductivity. The system containing 10 wt% PEGDE showed the highest ionic conductivity, indicating the most efficient ion transport pathways and suggesting the fastest electrochemical debonding behavior under reduction conditions. These results demonstrate that the PEGDE content and ionic network distribution play a crucial role in tuning the electro-responsive performance of EDA epoxy systems, providing molecular-level insights into the design of recyclable and energy-efficient adhesive materials for next-generation applications.

Keywords: Epoxy Resin; PEGDE Modifier; EMIM-TFSI; Electrochemically Debondable Adhesives; Molecular Dynamics Simulation

Automated CAD-to-Manufacturability Analysis: A Relational GNN Framework for Metal Powder Bed Fusion

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The increasing deployment of metal powder bed fusion (PBF) in low-volume automotive production requires accurate early prediction of design and manufacturability complexity directly from native computer-aided design (CAD) data. Conventional learning approaches based on geometric descriptors or image-based neural netowkrs were unable to model the complex relationships among features that govern PBF build time, energy demand, material usage, and overall difficulty. In response, a relational, geometry-aware graph neural network (GNN) is developed to provide manufacturability assessment directly from feature graphs extracted from native CAD models without slicing or mesh conversion.

Each CAD model is first decomposed into HybridCAD-level manufacturing features, and a feature graph is constructed where nodes represent individual features and edges represent adjacency, containment, and interface relationships. A three-layer relational graph convolution network is developed to model higher-order interactions among features by utilizing relation-specific linear operators. Prototype-based and bilinear decoders are then developed to perform node classification and graph-level regression, respectively. Node-level feature recognition and graph-level prediction of PBF build time, energy demand, and material usage are predicted after the decoders. Additional prediction heads are implemented to estimate design complexity, manufacturability complexity, and overall printability difficulty, which produces an interpretable CAD-native mechanism for PBF complexity estimation.

Experiments conducted on a large STEP-based dataset demonstrate improved prediction accuracy relative to image- and point-based baselines. This study provides a foundation for automated part categorization and design-for-PBF decision support in industrial applications.

Keywords: Graph Neural Network(GNN); Powder Bed Fusion(PBF); Design for Additive Manufacturing(DfAM); Relational Graph Learning

Acknowledgement: This research is conducted by the Industrial Technology Innovation Program (KEIT project no. 20024344, Development of AI-based high carbon steel alloy design and sintering-based additive manufacturing technology for 7.0 L/Hr-level high-speed production of powertrain components with tensile strength over 1.0 GPa in the next-generation mobility) funded by the Ministry of Trade, Industry & Energy of the Republic of Korea, and K-Labs Inc. It is supported by Singapore Centre for 3D Printing (SC3DP), the National Research Foundation, Prime Minister's Office, Singapore under its Medium-Sized Centre funding scheme.

Physics-Aware Reinforcement Learning for Design of Mechanical Interlocking Interfaces in Additively Manufactured Metal-Polymer Parts

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Lightweight structures are increasingly demanded across engineering industries, accelerating the adoption of hybrid metal-polymer joining technologies. However, conventional bonding approaches, such as adhesive bonding or mechanical fastening, often struggle to overcome the intrinsic chemical and physical incompatibility between metals and polymers. Mechanical interlocking has therefore emerged as a promising alternative, and additive manufacturing (AM) plays a pivotal role by enabling precise fabrication of highly complex and customizable interlocking geometries. Recent advances in machine learning have further expanded the design space of engineered structures, with reinforcement learning (RL), grounded in the Markov decision process (MDP), offering powerful capabilities for automated exploration and optimization of complex geometries. Building on this perspective, we propose a physics-aware RL framework for the systematic design of metal-polymer interlocking interfaces. The design problem was formulated as an MDP in which states, actions, rewards, and the environment guide the generation of novel interface patterns. Physical fidelity was embedded directly into the reward function by incorporating a fracture-mechanics-based stress-concentration metric, enabling the RL agent to evaluate and maximize interlocking strength according to mechanically meaningful criteria. The RL-generated designs were validated through numerical simulations and experimental testing using additively manufactured specimens. The results confirm that the proposed RL-driven methodology can effectively discover mechanically efficient interlocking architectures, outperforming conventional design heuristics. This framework provides a new pathway for optimizing heterogeneous material interfaces and offers broad potential for applications involving hybrid metal-polymer components across multiple industrial sectors.

Keywords: Physics-aware Reinforcement Learning; Mechanical Interlocking Design; Joining of Metal-polymer; Additive Manufacturing

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Vision-Based Semantic Segmentation System for Real-Time Monitoring and PID Control of Coaxial Electrospinning

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Electrospinning is an effective method for generating ultrafine polymer fibers and has been widely adopted in biomedical engineering, filtration, and energy-related applications. Among various configurations, coaxial electrospinning enables the fabrication of core–shell fibers by simultaneously electrospinning two different materials. Although this approach offers strong industrial potential, large differences in material properties often induce interfacial instability and irregular core–shell formation, making stable operation challenging. Therefore, a real-time monitoring and control system is essential for ensuring process stability and fiber consistency. In this study, we developed a vision-AI-based real-time monitoring framework for coaxial electrospinning. A semantic segmentation model was employed to perform pixel-level identification of the core and shell regions at the nozzle tip, enabling precise tracking of Taylor cone and jet morphology. The extracted morphological indicators allowed quantitative evaluation of solution fluctuations and provided a reliable basis for determining initial operating conditions. Since Taylor cone shape is closely associated with fiber defects and uniformity, maintaining its stability is critical for consistent fiber formation. To achieve stable long-term operation, a closed-loop PID controller was integrated to automatically adjust process parameters based on real-time morphology variations. This approach effectively suppressed unstable Taylor cone behavior and improved fiber uniformity. The developed framework is applicable to a broad range of nozzle-based manufacturing processes and provides a platform for real-time monitoring and adaptive process control. By ensuring stable and continuously regulated operation, the system strengthens the practicality of electrospinning and supports its transition from a laboratory-scale technique to a robust, industry-ready manufacturing technology.

Keywords: Electrospinning; Real-Time Monitoring; Autocalibration; PID-Controller; Semantic Segmentation

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Integrated Data-Driven and Experimental Assessment of Long-Term Durability in Electric and Conventional Passenger Vehicles: Evidence from Vietnam

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Electric vehicles are expanding rapidly in Vietnam, yet their long-term durability under local driving and maintenance conditions remains unclear. This study assesses the durability of battery electric vehicles (BEVs) and internal combustion engine vehicles (ICEs) using international reference data, large-scale maintenance records, and controlled on-road tests conducted under comparable driving conditions. First, global studies using two-parameter Weibull models are reviewed to outline typical patterns of early failures and long-term stabilization, serving solely as conceptual benchmarks rather than fitted models for the Vietnamese dataset. Second, maintenance records from 1,047 BEVs and 4,620 ICE vehicles across four brands in Vietnam are analyzed to estimate failure intensity across mileage intervals. Given differences in models and usage, the analysis uses only recurrent, service-verified failures to ensure consistency rather than comparing specific models. Third, two representative mid-size SUVs-one BEV and one ICE are driven on the same route and schedule to collect brake temperature and suspension load data, with the aim of validating physical mechanisms that may correspond to the statistical patterns observed in the dataset. Results indicate that BEVs show slightly higher failure intensity during the first 20,000 km but stabilize at 0.021–0.029 failures per 1,000 km after 40,000 km, whereas ICE vehicles stabilize at 0.025–0.034 under comparable usage contexts. BEV brake temperatures increase only slightly on downhill segments, and suspension loads remain within similar ranges but with lower peaks under urban operating conditions. Overall, the findings indicate that BEVs in Vietnam achieve competitive long-term durability under the operating conditions examined.

Keywords: Electric Vehicle; Durability; Reliability Analysis; Brake Wear; Suspension Stress

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Artificial Intelligence for the Design of Next-Generation Mechanical Metamaterials

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Recent advancements in additive manufacturing have enabled the realization of complex architectures that were once unattainable using conventional fabrication techniques. This technological progress has further accelerated research on mechanical metamaterials, whose mechanical behavior arises not only from the intrinsic properties of their constituent materials but also from their architected geometries. However, traditional design strategies, such as bio-inspired or heuristic design approaches, are limited in their ability to capture the intricate, high-dimensional design spaces required for diverse functional demands. To overcome these challenges, a range of computational design methodologies has been developed. Among them, artificial intelligence (AI)-driven approaches have emerged as particularly powerful, offering the capability to discover novel geometries and accelerate the design process for metamaterials with tailored properties.

In this study, we review recent technological trends and AI-based design strategies for mechanical metamaterials. These methods encompass both two-dimensional and three-dimensional architectures and employ a variety of geometric representations, including pixel-based encodings, graph-based topologies, and point-cloud descriptions. We discuss their effectiveness in addressing both forward design problems—predicting mechanical responses from known structures—and inverse design problems—generating structures that achieve target mechanical properties. Furthermore, we analyze the influence of data noise on model performance and introduce strategies to improve robustness. Finally, we outline emerging research directions aimed at enhancing generalizability, uncertainty awareness, and cross-domain adaptability, which are essential for realizing scalable, autonomous, and multifunctional metamaterial design frameworks.

Keywords: AI-driven Design; Mechanical Metamaterials; Generative AI; Inverse Design

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Exceptional Properties of Materials Additively Manufactured with Novel Laser Sheet Fusion Technique

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Metalworking often serves two functions. Firstly, it shapes the material into the desired morphology and secondly, it imparts mechanical properties to the part through the microstructures it generates. The advent of additive manufacturing, therefore, has not only allowed true 3D metallic structures with overhangs to be fabricated, but also introduced extreme strength to these parts by making ultrahigh cooling rates possible (~ 10^3 – 10^6 K/s). At present, however, all mainstream metal additive manufacturing methods utilize metal powders, which are expensive, flammable, toxic and introduce porosity, as well as stochastic variations to the final print. To circumvent these limitations, Laser Pulsed Integration of Sheets (LAPIS) was developed to make use of metal foil as precursor materials. Our results show that stainless steel parts can be made with ⩾ 99% relative density with high reliability under ambient conditions. Moreover, the self-supporting nature of the metal foil also allows tortuous enclosed channels to be fabricated easily, making them suitable for heat exchangers. Biocompatibility results from rat bone mesenchymal stem cells indicate that the surface of these metal parts render them suitable for use as dental and bone implants. Lastly, the ability to define different microstructures spatially, with different laser parameters, allow novel metametals to be realized for studies.

Keywords: Additive Manufacturing; Metamaterials; Microstructure; Sheet Lamination; 3D Printing

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Improving Cyclic Fatigue Performance of Stainless Steel-Welded Joint through Pulsed Electric Current Treatment: Application to Landing Gear

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The fatigue perspective of landing gear focuses on how repeated takeoff and landing loads affect its structure. Even small, repeated stresses can cause internal cracks that grow over time, potentially leading to sudden failure. Engineers use fatigue analysis and inspections to predict service life and ensure safety. This study investigates the influence of High-Density Pulsed Electric Current (HDPEC) on the fatigue behavior of austenitic stainless steel through quantitative analysis of fatigue-damage evolution. Using a cumulative fatigue damage model, the research compares untreated and HDPEC-treated specimens to clarify how pulsed current modifies fatigue performance under various loading conditions. HDPEC was found to induce significant fatigue-damage recovery across Low Cycle Fatigue(LCF), High Cycle Fatigue(HCF), and Very High Cycle Fatigue(VHCF) regimes, with the most substantial improvements occurring in HCF and VHCF, where subsurface microstructural stability governs failure. These results indicate that HDPEC contributes to defect healing and enhanced microstructural integrity, effects not easily achieved through conventional treatments. Comprehensive fatigue tests confirmed that HDPEC delays crack initiation and reduces propagation rates, resulting in markedly increased fatigue life. Continuum damage mechanics analysis demonstrated measurable reductions in accumulated damage, supporting HDPEC's role as an electromechanical rejuvenation mechanism.

Keywords: Structural Analysis; Electric Current; Fatigue; Welded Joint; Damage Mechanics

Acknowledgement: This research was financially supported by the Ministry of Small and Medium-sized Enterprises(SMEs) and Startups(MSS), Korea, under the "Regional Specialized Industry Development Plus Program(R&D, S3452055)" supervised by the Korea Technology and Information Promotion Agency for SMEs(TIPA).

Damage-Tolerant Structural Materials for Energy Transition through Additive Manufacturing

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Structural materials that can withstand extreme environments are crucial, especially for aerospace, hypersonic, nuclear, and sustainable energy applications. Historically, the selection and design of materials for these extreme environment applications have been challenging because of the conflict between their strength and fracture resistance, i.e., their overall damage tolerance. However, additive manufacturing, a bottom-up process similar to how nature builds structures, has improved the designability of structural materials. The microstructure of the materials can be tailored in a range of length scales, i.e., cellular structures (~0.5-6 μm), grain morphology (~10-1000 μm), texture gradient (~10-500 μm), melt-pool structures (~50-3000 μm) and compositional gradients. Such microstructural freedom during additive manufacturing provides an opportunity to introduce hierarchical structures inside the materials to increase their strength without affecting their fracture resistance, i.e., improving their overall damage tolerance. This presentation will highlight the opportunities and challenges of discovering damage-tolerant structural alloys using additive manufacturing.

Keywords: Additive Manufacturing; Structural Alloys; Fracture Resistance; Damage Tolerance; Multiscale Modeling; Alloy Design

Morphology Study and Printability of Recycled HDPE/PTFE Filament for Material Extrusion Process

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The rise of affordable 3D printers has greatly expanded filament variety while also increasing plastic waste, driving urgent demand for high-performance materials that can be fully recycled. This study develops recycled high-density polyethylene (rHDPE) reinforced with polytetrafluoroethylene (PTFE) for filament based material extrusion process (MEX). Six rHDPE/PTFE mass ratios were melt-extruded at temperature between 180–200 °C using a custom single-screw extruder operated at a fixed feed rate through a 3 mm nozzle with air cooling. The process yielded 1.75 ± 0.2 mm filament. Morphology of each rHDPE/PTFE filament was compared with pure rHDPE and virgin HDPE (vHDPE) by optical microscopy where surface roughness, porosity, and PTFE dispersion were quantified. Printability of the rHDPE/PTFE filament was also systematically assessed using a Taguchi orthogonal method. Three printing temperatures and three print speeds were tested. Square specimens were printed via single-layer and multi-layer deposition on a 0.4 mm nozzle. Surface finish, dimensional accuracy, corner warping, and inter-layer adhesion were quantified for every trial. The investigation establishes a printable processing window that balances surface quality and dimensional accuracy. The work advances sustainable FFF in Malaysia by utilising locally sourced post-consumer HDPE and provides a scalable route toward industrial deployment of fully recyclable filament blends.

Keywords: Recycled HDPE(rHDPE); Polytetrafluoroethylene(PTFE); Material Extrusion(MEX); Filament Morpohology; Printability

Technical Session 6 TS6-5

Accelerated Field Enhancement by Laser Beam Irradiation in Extreme Gap

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We investigate the phenomenon of field enhancement–driven electric discharge in extremely small gaps subjected to high electric potentials under laser irradiation. When a laser beam is incident on the gap, the optical field locally amplifies the electric field, effectively lowering the breakdown threshold and triggering discharge. Using computational simulations, we demonstrate that the laser-induced field enhancement is highly localized at the gap edges, leading to a significant increase in the peak electric field intensity. These results provide key insights into the synergistic effects of laser excitation and high-voltage biasing, offering a potential pathway for controlled discharge initiation and applications in microelectronics, high-precision switching, and next-generation pulsed-power devices.

Keywords: Field Enhancement; Laser Beam Irradiation; Surface Plasmon Polaritons

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Design and Experimental Validation of a Rotary Seal Based on Magnetorheological Grease

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This study presents the design and experimental validation of a novel rotary seal utilizing magnetorheological grease (MRG) to achieve active sealing control. Conventional seals often struggle to adapt to varying pressures and rotational speeds, leading to potential leakage or excessive wear. The proposed MRG seal addresses this by leveraging the MRG's rapid and reversible change in yield stress upon the application of a magnetic field, enabling real-time adjustment of sealing performance. The seal's structural design and magnetic circuit are optimized via finite element analysis. A prototype is fabricated and tested on a custom-built rotary seal apparatus. Experimental results demonstrate that the sealing pressure capacity increases significantly with the applied magnetic field intensity, effectively containing higher internal pressures. The findings confirm that the MRG-based seal provides a dynamically controllable sealing solution, offering a promising alternative for advanced rotary systems requiring adaptive performance.

Keywords: Magnetorheological Grease(MRG); Active Sealing; Rotary Seal; Magnetorheological Seal

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Tribology Behaviour of Mild Steel Carburized Using Na_2CO_3-NaCl under Lubrication

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The tribological behavior of carburized mild steel under oil lubrication was investigated. 2 types of carburized steel specimens were used in this study. The surface of the first type of the carburized steel was rich in retained austenite. Towards the core, the amount of austenite reduced and the amount of martensite increased. In contrast, the surface and subsurface of the second type carburized steel was rich in martensite. In the sliding of carburized steel, the COF was found to reduce with increased load before boundary lubrication occurred at loads above 150 N. Under boundary lubrication at 1000 N, the martensite in the carburized layer reacted with the hydrocarbon and oil additive to form a lubricant film consisting of C-C, C=O, C-P, and C-O. This resulted in reduced COF and wear rate, if fracture did not take place. The average COF and wear rate obtained at this load was 0.085-0.096 and 1.69 - 0.94 x 10-11 mm3/Nm, respectively, lower than those that obtained at 600 N which were 0.108-0.109 and 2.89-4.86 x 10-11 mm3/Nm, respectively. The lubricant film formed on the retained austenite, which involved only reaction with the hydrocarbon, did not produce any such beneficial effect. These results showed that the presence of the retained austenite made the worn surface less favorable to form an effective anti-wear lubricant film.

Keywords: Carburization; Friction; Lubricant; Microstructure; Wear

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Study on Electrochemistry Assisted Magnetorheological Polishing of Cemented Carbide Based on Halbach Magnetic Array and Textured Surface

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After precision grinding, cemented carbide cutting tools are often accompanied by burrs, microcracks, and excessive sharpness. These defects lead to stress concentration and early tool failure, so machining quality and tool life are reduced. Traditional methods (mechanical grinding, sandblasting) are characterized by poor controllability, low efficiency, and inconsistent surface quality. A novel composite process was proposed, which integrates magnetorheological and electrochemical polishing with the introduction of a Halbach magnetic array and a textured surface. Based on the "electrochemical softening-mechanical removal" mechanism, an experimental platform was built, which was equipped with a five-axis machine tool, a magnetorheological polishing tool, a pulse power supply, and a sodium hydroxide NaOH-based electrolyte. Cemented carbide specimens (matching the tool matrix) were pre-ground with diamond sandpaper; the effects of key parameters (working gap, polishing time, revolution speed of polishing tool, current) on the polishing quality were studied, and with/without textured surface of polishing tools were compared based on polishing force and polished surface. Results showed that the shear force was increased by ~160% and surface roughness was reduced from Sa 8 nm to 4 nm via the textured surface. When the working gap ranged from 0.4 to 0.8 mm, material removal depth was decreased from 3.2 μm to 2.2 μm, while roughness was increased from Sa 19 nm to 30 nm. Under optimal parameters (0.4 mm in working gap, 5 min in polishing time, 0.05 A in current), surface was smoothed from the initial surface roughness Sa 130 nm to 4 nm.

Keywords: Cemented Carbide; Halbach Magnetic Array; Magnetorheological Polishing; Electrochemical Polishing; Surface Quality

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Effects of h-BN on the Microstructure, Mechanical Properties and Tribological Performance of WC-Ni_3Al Cemented Carbides

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WC-10wt.%Ni_3Al cemented carbides with varying h-BN contents were fabricated via vacuum sintering technology. The effects of h-BN content on the microstructure, mechanical properties, and tribological behavior of the alloys were systematically investigated, and the underlying mechanisms of h-BN in reducing friction and wear in WC-10wt.%Ni_3Al cemented carbides were thoroughly explored. The results demonstrate that the incorporation of h-BN significantly enhances the alloy properties through mechanisms such as heterogeneous nucleation and fine-grain strengthening. However, excessive h-BN content results in non-uniform distribution within the alloy, leading to a deterioration in mechanical properties. The WC-10wt.%Ni_3Al-0.1h-BN alloy exhibited optimal overall performance when sintered at 1450°C, achieving peak values in relative density, hardness, and strength. Tribological tests revealed that the addition of h-BN markedly reduced the friction coefficient and wear rate of the alloys. Specifically, the sample containing 0.1 wt.% h-BN displayed the most favorable tribological properties, primarily attributed to the lubricating effect of the h-BN-derived transfer film formed during the friction process.

Keywords: WC; Ni3Al; Microstructure; Mechanical Properties; Tribological Properties

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Digitized Experimental Data Extracted from Hardcoded Graphical Data for Verification of Cutting Force Predictions in Endmilling

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Experimental verification of empirical cutting force model predictions, for any type of a milling operation, is best accomplished if the data are available in digitized (tabulated) form. Predicted and experimentally observed force patterns can be printed on the same plot using the same scale for easy visual comparison. This is the usual procedure. Experiments incur time and cost. If historically generated experimental data were available in digitized form, it would enable the modeler to avoid experimentation altogether, saving time and expense. Significant amounts of such data are available in journal publications, thesis publications, and commercial catalogs, many of which are published in hardcoded graphical form. In many cases, the original authors can no longer be contacted, nor can the original data be obtained for use by future researchers. We demonstrate a procedure for extraction of data in digitized form from published graphical plots using open software. Data was recovered by us in sufficiently faithful form as demonstrated by graphical comparisons of the results. This exercise was conducted by us using a data set generated in helical endmilling experiments in which cutting force measurement signals were recorded using a dynamometer. Our study was motivated when we lost our own original digitized data to computer related mishaps and faulty back-ups, leaving us holding our data merely in graphical form. The demonstrated procedure is quite general, and universally applicable. Hardcoded, graphically displayed experimental data from any historical publication can be extracted and used for comparison with model predictions incurring no violation of copyright.

Keywords: Digitized Experimental Data; Cutting Force; End Milling; Empirical Model

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Ultrasonic Non-Destructive Evaluation for Quality Assessment of TRISO-Based Pebble Nuclear Fuels

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TRistructural-ISOtropic (TRISO) particle-based pebble nuclear fuels are increasingly recognized as a promising fuel form for pebble-bed reactors (PBRs), one of the leading next-generation nuclear systems for small modular reactors (SMRs). These fuels consist of a spherical graphite matrix embedding thousands of TRISO particles, offering inherent safety, high thermal efficiency, and continuous refueling capability. However, ensuring the structural integrity and manufacturing quality of fuel pebbles remains a critical challenge. During the multi-step manufacturing process—including particle coating, layering, and pebble compaction—manufacturing-induced defects, such as escaped particles, coating non-uniformities, and surface damage can occur. These defects can adversely affect efficiency and safety, necessitating reliable nondestructive evaluation (NDE) methods. Currently employed NDE techniques have notable limitations: resonant ultrasonic spectroscopy (RUS) provides only global defect sensitivity without localization, while X-ray computed tomography (XCT), although highly accurate, is costly, time-intensive, and impractical for large-scale manufacturing inspection. Moreover, the highly attenuative and compositionally complex structure of TRISO pebbles restricts the effectiveness of conventional ultrasonic methods. To address these challenges, this study proposes an ultrasonic NDE approach integrating an optimized triangular sensor network with machine-learning-based signal analysis. Representative manufacturing-induced defects—escaped particles, surface cracks, and shell non-uniformities—were fabricated and simulated for validation. The results demonstrate the feasibility of the proposed approach as a scalable and efficient NDE solution for in-line quality assessment of TRISO-based pebble fuels in advanced nuclear fuel manufacturing.

Keywords: TRISO Particle-based Pebble Nuclear Fuels; Pebble-bed Reactors; Small Modular Reactors; Ultrasonic Nondestructive Evaluation; Machine Learning

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Technical Session 8 TS8-1

Cooling Paint for Glass with Solar Selectivity and High Emissivity

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Under the combined pressures of global warming and urban heat island intensification, global cooling demand is rising exponentially. Passive radiative cooling—leveraging thermal emission through the atmospheric window (8–13 μm) without external energy input—has emerged as a promising energy-saving strategy. However, most existing studies focus on opaque white coatings that are unsuitable for glass, despite glass being one of the most energy-intensive components in buildings. Current transparent radiative-cooling solutions remain limited by high cost, excessive haze, or insufficient outdoor durability.

In this work, we develop a low-cost, easy-to-apply, and spectrally selective transparent radiative-cooling coating composed of water glass and cesium tungsten bronze (Cs0.33WO3) nanoparticles. The coating features ultralow haze, strong mid-infrared emissivity within the atmospheric window, and excellent adhesion, hardness, and water resistance on glass substrates. Even with a very small amount of functional nanoparticles and a thin coating layer, it effectively blocks ultraviolet and near-infrared radiation while maintaining desirable visible-light transparency. By tuning the modulus of alkali metal silicates, the early-stage water resistance is significantly enhanced, while lithium-modified bentonite improves the coating's leveling and flow properties. The abundant Si–O bonds within the silica network impart strong emissive capability in the atmospheric window after room-temperature curing. Benefiting from the inherent stability of Si–O bonds, the coating exhibits remarkable outdoor durability under high temperature and intense UV conditions. Field exposure tests further show that its heat-blocking performance remains essentially unchanged over time.

Keywords: Transparent Passive Cooling Paint; Solar-selective; Alkaline Metal Silicate; Cesium Tungsten Bronze

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Technical Session 8 TS8-2

Solar-Driven Integrated Device for Simultaneous Atmospheric Water Harvesting and Direct Air Capture

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The demand for freshwater production and achieving carbon neutrality has become a global challenge for human society. Herein, an integrated device is proposed for simultaneous atmospheric water harvesting and direct air capture (AWH-DAC device). During nighttime, ambient air with CO_2 flows into the AWH-DAC device, followed by adsorption of moisture and CO_2. During daytime, water production and CO_2 desorption are driven by sunlight and natural convection cooling from condenser, resulting economic energy efficiency. The AWH-DAC device demonstrates notable performance of water production in the outdoor experiments, exhibiting water harvesting productivity of 0.89 $L \cdot m^{-2} \cdot day^{-1}$ and consumption of energy input per water production of 5.77 $kWh \cdot L^{-1}$. Moreover, the AWH-DAC device demonstrates stable CO_2 desorption in the outdoor experiments without electrical heat compared with conventional plants. The estimation of the total cost shows \$82–204$\cdot t^{-1}_{CO2}$ to operate the AWH-DAC device for DAC applications, achieving an average cost reduction of 12% for adsorption-based DAC and 84% for absorption-based DAC compared to the total cost of conventional plants. In greenhouse applications, the AWH-DAC device can provide the cost savings of \$1–3$\cdot t^{-1}_{sorbent} \cdot day^{-1}$ for water irrigation and \$22–65$\cdot t^{-1}_{sorbent} \cdot day^{-1}$ for CO_2 enrichment. This suggests cost-effective advantages of the AWH-DAC device for industrial applications without additional energy consumption. This work establishes an approach for freshwater production and CO_2 mitigation simultaneously, thereby alleviating not only water scarcity and global warming but also energy shortages by mainly utilizing renewable energy.

Keywords: Amine-functionalized adsorbent; Atmospheric water harvesting; Direct air capture; Industrial application; Metal-organic framework

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Engineering the Interphase for Lithium Metal Batteries

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Since their commercialization in the early 1990s, lithium-ion batteries (LiBs) have been the dominant power source for portable electronics, electric vehicles, and large-scale energy storage. Yet, LiBs are now approaching their practical energy density ceiling. Meeting the growing demand for safer and higher-energy storage systems requires advancing beyond current chemistries, with lithium metal batteries (LMBs) emerging as a leading candidate. LMBs promise up to twice (or even more) the energy density of LiBs, but their deployment has been limited by short cycle life and safety challenges. These issues stem from uncontrolled solid-electrolyte interphase (SEI) growth and inadequate electrolytes inherited from LiBs. Among various strategies, engineering inorganic-rich SEIs through electrolyte design has proven particularly effective in stabilizing lithium metal anodes. In this talk, I will highlight the pivotal characteristics of inorganic SEI components, explain their role in establishing durable interphases, and briefly outline my research contributions in this area.

Keywords: Lithium; Interphase; Electrolyte; Battery

Acknowledgement: This work was supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Office under the Battery Materials Research Program and the Battery500 Consortium. Additional support was provided by the Nanyang Technological University Start-Up Grant and the School of Mechanical and Aerospace Engineering.

Ultrafast LIG-on-CPI Electro-Thermal Actuators for High-Resolution Active Optics

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We demonstrate a high-performance, flexible electro-thermal micro-actuators fabricated through a facile, single-step femtosecond laser direct writing (FsLDW) process. This maskless technique directly converts regions of a colorless polyimide (CPI) substrate into laser-induced graphene (LIG), creating an integrated monolithic device. The actuation mechanism is rooted in the stark mismatch of thermo-mechanical properties between the two materials. Specifically, this approach leverages LIG's exceptional thermal conductivity—over two orders of magnitude greater than the pristine CPI—combined with the substrate's inherent optical transparency, flexibility, and high thermal stability. When electrically stimulated, the LIG layer generates highly localized heat, inducing a differential thermal expansion that results in rapid and controllable out-of-plane deflection. The resulting LIG actuators enable precise thermal cycling of optically reflective surfaces at frequencies up to an impressive 2 kHz. Furthermore, by structuring the LIG into an optically diffractive configuration, we achieve high-resolution beam steering with a 0.5-millidegree precision and a 0.9-second response time, effectively transitioning the device from a quasi-static to a fully active operational regime. This powerful combination of high-speed, high-precision actuation and a simple, cost-effective, and scalable fabrication process highlights its significant potential for next-generation lightweight, flexible, and integrated optoelectronic systems, focus-tunable lenses, LiDAR beam-steering devices, and advanced optical switches.

Keywords: Laser-induced Graphene(LIG); Electro-thermal Actuator; Colorless Polyimide(CPI); Femtosecond Laser Direct Writing(FsLDW); Beam Steering

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Femtosecond Laser Pulses Enable Graphene-Based Smart Textile Applications

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We demonstrate a maskless fabrication route to multifunctional smart textiles by converting aramid textile into laser-induced graphene (LIG) through femtosecond direct writing. Applicable to nonwoven, knit, and woven types, the process yields porous, conductive LIG (sheet resistance 2.86 Ω/sq) while maintaining mechanical durability and breathability. On the same textile, multimodal devices are patterned: temperature sensors with a temperature coefficient of resistance of −0.068%/°C (30–60 °C), strain sensors exhibiting a maximum gauge factor of 454 at 4.8–5.4% strain, and micro-supercapacitors achieving 36.17 mF/cm2 areal capacitance with 96.3% retention after 6000 cycles; five cells in series power LEDs. Double-sided LIG coatings provide broadband absorptance up to 97.57% (190–2500 nm) and through-thickness thermal diffusivity of 6.376 mm^2/s (in-plane 2.554 mm^2/s), corresponding to a thermal conductivity of 18.6 W/m·K at 25 °C. Devices remain functions after thermal-vacuum cycling at 10^{-3} Torr between −20 and 60 °C, confirming space-environment compatibility.

Femtosecond laser writing minimizes unnecessary ablation compared to continuous-wave laser. By integrating sensing, energy storage, stray-light suppression, and heat spreading into a single lightweight system, the platform meets the requirements of astronaut monitoring and telescope baffles. The demonstrated electrical, thermal, and mechanical functions exceed typical textile electronics and validate a pathway toward space-qualified, multifunctional smart textiles capable of active thermal control, in-suit health diagnostics, and low-reflectance shielding on deployable optical structures.

Keywords: Femtosecond Laser; Laser Direct Writing; Laser-induced Graphene; Smart Textile

Acknowledgement: Korean National Research Foundation (Nos. NRF-2020R1A2C 210233813, NRF-RS-2024-00401786 Ministry of Agriculture, Food and Rural Affairs (No. MAFRA: RS-2024-00401642) R&D Program for Forest Science Technology (Project No. 2023488B10-2325-AA01) provided by Korea Forest Service (Korea Forestry Promotion Institute).

Microwave-Assisted Hydrothermally Carbonized Waste Sawdust as Photothermal Conversion Material for Solar Vapor Generation

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Waste sawdust, a low-cost and abundant byproduct, can be effectively valorized into carbon-rich hydrochar through an eco-friendly carbonization process, offering a sustainable alternative for photothermal conversion materials in solar vapor generation. Despite its potential, limited studies have explored this utilization and application. This study aimed to investigate the potential of sawdust hydrochar for solar vapor generation. In this study, hydrochars were synthesized from waste sawdust using microwave-assisted hydrothermal carbonization at 170, 200, and 230 °C for 30 minutes. The hydrochar produced at 230 °C (H-230) exhibited the best photothermal properties, retaining its fibrous structure, rough surface morphology, high carbon content (around 79 %), and strong light absorption (400–800 nm). The hydrochars were effectively and uniformly coated onto cotton substrate via a modified dip-coating method, creating solar absorbers for use in solar vapor generation. These solar absorbers were evaluated in an outdoor system using seawater under direct solar radiation (1.17 kW/m^2). The solar absorber containing H-230 (SA-230) demonstrated the highest evaporation rate of 1.08 kg/m2/h and an efficiency of 62.5 %. These results demonstrated the potential of waste sawdust as a resource for producing hydrochar-based solar absorbers for efficient solar vapor generation. This study also contributes to achieving multiple Sustainable Development Goals (SDGs), particularly SDG6: Water and Sanitation (ensuring the availability of clean water) and SDG13: Climate Action (using renewable energy and green technology).

Keywords: Waste Sawdust; Microwave-assisted Hydrothermal Carbonization; Hydrochar; Solar Vapor Generation

Acknowledgement: This research was supported by the Ministry of Higher Education, Malaysia, under the Fundamental Research Grant Scheme (FRGS/1/2023/STG05/UMS/02/1).

Design and CFD Evaluation of a Water-Based Single-Phase Natural Circulation Loop

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Single-phase Natural Circulation Loop (NCL) or thermosyphon systems rely on buoyancy-driven flow without pumps and are widely applied in passive cooling, including nuclear safety systems. In this study, water was selected as the working fluid, and its temperature-dependent density and viscosity variations were considered because they significantly affect the buoyancy driving head, Reynolds number (Re), and friction factor, which are key determinants of thermo-hydraulic stability. An engineering design procedure for the heating and cooling sections is presented to maintain stable single-phase flow under a prescribed heat load. For the heated section, pipe dimensions were determined to preserve the required Re range and prevent excessive friction losses by compensating for the reduction in effective flow area due to heater insertion. For the cooling section, a shell-and-tube configuration was adopted to achieve an appropriate balance between heat removal capability and pressure drop. Three-dimensional CFD analysis incorporating temperature-dependent water properties was performed to evaluate local temperature rise around the heaters, overall loop friction losses, circulation flow rate, and general thermo-hydraulic behavior. The results confirm that the proposed design methodology maintains a sufficient single-phase operating margin and ensures thermo-hydraulic stability. This approach provides a systematic framework for early-stage NCL design and supports broader applications in energy and nuclear engineering.

Keywords: Thermosyphon; Buoyancy-Driven Flow; Single-Phase Flow; Loop Stability Analysis; Thermal-Hydraulic Characteristics

Acknowledgement: This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant (No. RS-2024-00398425 and RS-2024-00401705) funded by the Ministry of Trade, and the Glocal University 30 Project fund of Gyeongsang National University in 2025.

Evaporative Pre-Cooling in Hot–Humid Climates

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Tropical air-cooled condensers operate under elevated condensing temperatures, which significantly diminish energy efficiency and increase peak electricity demand. Evaporative pre-cooling (EPC), leveraging latent heat transfer during water evaporation is a practical retrofit strategy to reduce condenser inlet air temperature. However, the performance of EPC systems in hot and humid climates has received comparatively limited attention. This is due to small wet-bulb depression and concerns regarding water consumption and fouling. This review synthesises recent advancements in EPC applications for humid environments. It focuses on psychrometrics constraints, cooling effectiveness, and potential energy savings. It also critically examines experimental and computational studies addressing temperature reduction, saturation efficiency, and improvements in the coefficient of performance (COP). As enabling tools for predictive design and optimisation, computational fluid dynamics (CFD) methods for modelling porous media and coupled heat-mass transfer are discussed. Despite promising outcomes, there are still gaps in integrated evaluation of condensate reuse. Some examples such as sustainable water source, validated CFD frameworks for humid psychrometrics, and climate-specific geometry tuning. Future researches should prioritise reliable CFD models for tropical climates, optimising pad geometry and operating conditions, and long-term field studies on fouling and water treatment. These directions support EPC system deployment for cost-effective, water-efficient HVAC improvement in hot-humid regions.

Keywords: Evaporative Pre-cooling; Air-cooled Condensers; Tropical Climate HVAC; Psychrometrics Limitations; Saturation Efficiency

Acknowledgement: The authors wish to convey sincere gratitude to Universiti Malaysia Sabah (UMS) for supporting the current research work.

Performance Evaluation of a Passive Chimney-Ventilated Solar Dryer under Varying Loading Density and Outlet Geometry

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Drying is an important process for agricultural and marine products to prevent microbial and chemical spoilage, and it reduces the volume and weight of products for efficient storage and transportation. This paper evaluates and optimizes the performance of a passive chimney-ventilated solar dryer using synthetic sponge as a surrogate for seaweed. In this study, a prototype was made with a 2.5 m × 1.5 m × 2.3 m dryer fitted with three vertical drying columns and five trays per column. Four different loading densities (8, 12, 16, and 20 sponges per tray) and multiple outlet cross-sectional areas were studied in order to find the best configuration that provides optimum airflow and drying performance under tropical conditions in Sabah, Malaysia. A preliminary smoke test confirmed uniform airflow with minimal leakage. Among all configurations, 16 sponges per tray combined with an outlet area of 1.5 m × 0.5 m produced the highest drying rate (1.41-1.49 kg/h) and the most uniform moisture removal. Under optimized setup, full-load testing removed 8.99 kg of water within 6 h, giving a drying efficiency of 28%, a specific energy consumption (SEC) of 8.3 MJ/kg, and a specific moisture extraction rate (SMER) of 0.11 kg/MJ. The passive dryer demonstrated superior heat retention, improved drying uniformity, and more stable drying kinetics compared to open sun drying. The results confirm the suitability of the passive greenhouse solar dryer for seaweed drying applications and identified loading density and outlet geometry as key influential parameters for improving natural-convection drying performance.

Keywords: Passive Solar Dryer; Loading Density; Outlet Geometry; Drying Performance; Natural Convection Airflow

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Technical Session 9 TS9-4

Effect of Porous Transport Layer Thickness in Proton Exchange Membrane Water Electrolysis

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Among various hydrogen production technologies, the proton exchange membrane water electrolyzer (PEMWE) is considered a key technology for green hydrogen generation due to its efficient operation at low temperatures and high current densities. The porous transport layer (PTL), a major component of PEMWE, is responsible for supplying water and releasing oxygen while maintaining stable two-phase flow. For PEMWE commercialization, it is essential to achieve stable operation at high current densities for large-scale hydrogen production. This requires effective oxygen removal from the PTL to prevent gas accumulation. In this study, the effect of PTL thickness on PEMWE performance was experimentally investigated using titanium felt PTLs of 0.25, 0.3, and 0.5 mm in thickness. A single cell with an active area of 25 cm2 was operated at 50 °C with a water flow rate of 200 mL/min. Electrochemical performance was evaluated over a current density range of 0–3.0 A/cm^2, and the high-frequency resistance was measured using electrochemical impedance spectroscopy. At 3.0 A/cm^2, the cell voltages were 2.89 V, 2.92 V, and 3.08 V for 0.25, 0.3, and 0.5 mm PTLs, respectively, demonstrating superior performance with the thinnest PTLs. The mass transport overpotential increased with PTL thickness, measured as 0.73, 0.87, and 1.06 V at 3.0 A/cm^2. Thicker PTLs hinder gas release, leading to increased transport losses, highlighting the importance of optimizing PTL thickness to minimize resistance and enhance overall PEMWE efficiency.

Keywords: Porous Transport Layer; Proton Exchange Membrane Water Elecrolyzer; Bubble Behavior; Two-phase Flow; Mass Transport Overpotential

Acknowledgement: This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. RS-2023-00208497, RS-2023-00219369).

Development of Capacitive Sensor for Measuring Adsorption Capacity

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We designed an advanced measurement method to measure the adsorption capacity in condition of ammonia. As the sensor was designed specifically for ammonia environments, we adopted the capacitive measurement method which is widely used for accurate and stable measurements. A pair of parallel electrodes was vertically aligned, where the upper electrode functioned as an active component capable of vertical displacement, leading to measurable changes in capacitance. A specimen, such as balance weight or an adsorbent, was placed on the upper electrode so that the applied mass could induce measurable displacement. The capacitance was measured to be 28.2 pF at 0.0 g and 31.5 pF at 1.4 g, indicating that the designed sensor could detect a capacitance change of approximately 2.36 pF per gram of mass variation. Repeatability tests demonstrated consistent capacitance measurements for identical mass loads. After the performance verification test, the validation test was conducted under the ammonia conditions. We utilized the adsorbent which can adsorb the ammonia easily for the active mass change during the test and check the capacitance change simultaneously. During the validation test, the capacitive sensor successfully measured the capacitance change and was calibrated for mass measurement using the result of the verification test. The measurement results may vary depending on the sensor design. Nevertheless, the prototype sensor developed in this study successfully demonstrated its capability to detect mass changes of specimens even under ammonia conditions, suggesting its potential applicability in industrial fields that require precise monitoring of mass variations.

Keywords: Adsorption; Ammonia; Capacitance; Instrumentation; Precise

Acknowledgement: This work was supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP), which is funded by the Korean government (MOTIE) (No. 20212050100010, Chemisorption heat pump system using electrochemical compressor), and the Glocal University 30 Project Fund of Gyeongsang National University in 2025.

Zynthesis: Zero-Shot Synthetic-to-Real Assembly Inspection

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Procedural inspection of mechanical assemblies remains predominantly manual, requiring engineers to verify whether components were installed in the correct sequence, orientation, and configuration. This work introduces Zynthesis, a proof-of-concept framework that combines domain-randomized synthetic data with video–language reasoning to automate assembly-procedure understanding with minimal real-world supervision. We generate a synthetic segmentation corpus from CAD components using a fully scripted Blender pipeline that randomizes lighting, backgrounds, materials, poses, occlusions and distractors. A YOLO v11 segmentation model trained solely on this synthetic data is applied directly to real assembly footage and provides part-level overlays without requiring real-image annotation or retraining. These overlays, together with a small schema describing the part dictionary and expected interactions, are passed to a vision–language model, which infers an ordered step sequence and flags qualitative deviations such as missing, misoriented, or out-of-order operations. While we demonstrate the pipeline on a single real assembly example, results show that synthetic-to-real transfer is sufficient for basic part localization, and that Vision Language Models can produce coherent, interpretable step narratives from noisy segmentation cues. Zynthesis highlights a lightweight path toward automated procedural inspection and motivates further quantitative study across broader assembly domains.

Keywords: Procedural Anomaly Detection; Synthetic-to-real Transfer; Domain Randomization; Video–language Model

Acknowledgement: This research was supported by Korea University (fund number: K2528941, K2531821).

Reinforcement Learning Based on Digital Twin with Data Augmentation for Autonomous Robotic Assembly

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The fast adoption of Generative AI in industrial workflows is accelerating design cycles and increasing the demand for product diversity and customization. This shift places new requirements on assembly systems, which must now support levels of flexibility that traditional methods cannot provide. However, current industrial practice still relies heavily on rigid, manually programmed robot operations, where the time-consuming reconstruction of assembly data is required for every new product. This dependence creates significant operational burden whenever process changes are introduced. To address these limitations, this research proposes a robust pipeline for automated assembly by synthesizing CAD geometry, simulation-based learning, and real-world execution. In the perception phase, synthetic datasets are automatically generated from CAD files with randomized lighting and pose parameters to maximize domain generalization; the resulting object detection model is rigorously validated using detection quality in real world. For control, this paper presents automatic construction of the virtual environment using CAD model and assembly instructions to support reinforcement learning. Within this simulated setting, agents learn assembly strategies, driven by a reward function that is based on positional accuracy and task completion. Crucially, strategies acquired through reinforcement learning are subsequently translated into feasible kinematic trajectories through a dedicated off-line programming, allowing for the control of the real robot system. Policy convergence, speed, and action diversity are analyzed as key performance indicators during training. Final validation on a physical prototype confirms that integrating these path-generated strategies with perception outputs achieves stable transfer and successful task execution.

Keywords: Assembly; Synthetic Dataset; Domain Randomization; Object Detection; Reinforcement Learning

Acknowledgement: This work was supported by Institute for Information & communications Technology Promotion(IITP) grant funded by the Korea government(MSIP) (RS-2025-02219563, Step by Step Autonomous Manufacturing: From Dataset Construction to Generative AI Utilization) and supported by Korea Institute for Advancement of Technology(KIAT) grant funded by the Korea Government(MOTIE) (P0028468, Development of Manufacturing On-Device AI and Dataspace Technology)

Integration of Advanced Materials with MEMS Fabrication Technology for a Miniaturized Portable VOC Analysis Platform

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Miniaturized gas analysis systems for low concentrations of complex volatile organic compounds (VOCs) have been actively developed using MEMS technology. These systems typically combine a preconcentrator (PC) chip, a gas chromatography (GC) column chip, and a compact detector, but their deployment remains limited by cost, size, and power constraints. To address these issues, we designed a hybrid GC platform that provides compactness, low power operation, and cost-efficient manufacturing by integrating a MOF-coated MEMS hybrid chip with a miniaturized photoionization detector (PID). The hybrid chip enables both preconcentration and chromatographic separation within a single device, simplifying system design. It was developed through MEMS fabrication combined with metal–organic frameworks (MOFs), which offer high surface area, tunable adsorption, and chemical selectivity for VOCs pretreatment. The hybrid GC platform delivered excellent analytical performance within a 0.62 L volume, the smallest among reported GC-based systems. Its simplified architecture ensured low power consumption (average 2.65 W) and supports up to 35 hours of continuous operation on a single battery. The platform achieved ppb-level detection of representative VOCs and enabled analysis of alkanes, alcohols, aldehydes, and ketones. These results demonstrate the potential of combining advanced materials with MEMS fabrication to realize a compact and capable platform for comprehensive VOCs monitoring in environmental, industrial, and medical applications.

Keywords: Volatile Organic Compound; VOC Analysis System; Preconcentrator; Gas Chromatography; Metal-organic Framework

Acknowledgement: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) [grant number: RS-2025-02223634 & RS-2025-00518573].

Design, Optimization and Experimental Validation of a Magnetorheological Impact Damper with an Annular-Radial Valve

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This study introduces a newly designed Magnetorheological Impact Damper (MRID) and evaluates its performance. The damper is equipped with an externally mounted MR valve for controlled energy dissipation under high-intensity impact loads. This addresses limitations of previous designs with valves integrated inside the piston, which include a restricted dynamic range, lower output force, and more complicated assembly and maintenance. The proposed annular-radial MR valve enhances damping force and provides a faster response. The MRID's design and modeling are based on an extensive review of existing research, employing the Bingham plastic model and the finite element method (FEM). Analytical formulations are developed for the damper's damping force and frictional torque. A PSO-based optimization approach is applied to determine optimal design parameters, improving damping performance while reducing manufacturing costs. These parameters are used for prototype fabrication and experimental testing, with the results compared against the simulation predictions.

Keywords: Magnetorheological Fluid(MRF); MR Valve; MR Impact Damper; Optimal Design; Valve-mode; PSO

Acknowledgement: This research was fully funded by the HUTECH University under grant number D- TTD- -2025-01

The Forklift Logistics Design Considering Both Operational Efficiency and Environmental Sustainability from a Textile Manufacturing System

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With the advancement of manufacturing automation and the push for corporate sustainable development, the efficiency of internal factory logistics and environmental sustainability are becoming increasingly crucial. Forklifts, as core material handling equipment, have their configuration and operational efficiency directly impacting corporate operating costs and greenhouse gas emissions. However, most enterprises generally lack systematic strategies for forklift operational zone partitioning and resource allocation, often leading to equipment idleness or overload, which increases energy consumption and environmental impact. This study aims to enhance forklift efficiency and consider sustainability by proposing a two-stage logistics system design method. The first stage optimizes the location of pickup and delivery points within the factory. The second stage introduces a novel integrated similarity coefficient, combined with an improved hierarchical clustering method, to partition optimal operational zones; this is followed by load balancing adjustments and flexible forklift allocation to boost efficiency and prevent idleness. Validated through a textile factory case study and discrete event simulation, the results indicate that the proposed method significantly improves logistics performance. Compared to the current state, forklift utilization increased by approximately 36%, total transport trips decreased by 26%, and carbon emissions were effectively reduced by about 11%. This study contributes significantly to ESG development with empirical support, particularly by achieving remarkable environmental benefits through optimized resource allocation, enhancing workplace social well-being through streamlined processes, and providing a systematic forklift logistics design solution for enterprises that supports efficiency improvement, cost savings, and environmental sustainability.

Keywords: Forklift Allocation; Material Handling Optimization; Zone Partitioning; Discrete Event Simulation; Environmental Sustainability

Acknowledgement: The authors thank the anonymous company for providing the case study. Work was supported in part by the National Science and Technology Council of Taiwan, under Grant NSTC112-2221-E-006-154-MY3.

Poster Session

Poster Session 1

Date/Time • February 3(Tue), 13:00-14:00
Organizer • Jung Jin Kim (Keimyung University, Korea),
Seungho Han (Dong-A University, Korea),
Sungmin Yoon (Changwon National University, Korea)

Poster Session 2

Date/Time • February 3(Tue), 17:00-18:00
Organizer • Sung-Uk Zhang (Dong-Eui University, Korea),
Younghwan Yang (Changwon National University, Korea),
Dong-Bin Kwak (Seoul National University of Science and Technology, Korea)

Poster Session 3

Date/Time • February 4(Wed), 13:00-14:00
Organizer • Jun Sae Han (KIMM, Korea),
Hae Woon Choi (Keimyung University, Korea),
Hyunseop Lee (Dong-A University, Korea)

Poster Session 4

Date/Time • February 4(Wed), 15:30-16:30
Organizer • Youngho Jeon (Ajou University, Korea),
Jongkyeong Lim (Gachon University, Korea),
Sung Yong Jung (Chosun University, Korea)

Poster Session 1 CAD/CAM/CAE, Optimization PP1-1

Optimization of Vibration Test Fixture Design Using a Variable Grid-Based Approach

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A vibration test fixture supports the test specimen during vibration testing and enables accurate transmission of applied excitation. To achieve effective vibration transfer and avoid resonance, the fixture must maintain a sufficiently high natural frequency while minimizing structural mass. However, as test specimens grow in size, conventional experience-based finite element design approaches have become inadequate for simultaneously satisfying frequency and mass requirements. This study proposes a variable grid–based optimization framework to address this limitation. In the proposed method, rib height is defined as a discrete design variable instead of the density used in fixed-grid topology optimization, and grid spacing is additionally treated as a variable to control rib distribution. A genetic algorithm is employed to minimize mass, with the first natural frequency imposed as the governing constraint. The approach was applied to the design of an automotive headlamp vibration test fixture, where design complexity increases significantly with structural enlargement. The effectiveness of the proposed method was evaluated through comparison with a traditional experience-based design. The optimized fixture achieved up to 37.5% mass reduction while preserving global modal behavior, and the optimization exhibited stable convergence with a total computation time of less than eight hours. These results demonstrate that the variable grid–based automated optimization strategy enhances both structural performance and design efficiency, providing a practical and scalable alternative to empirical design processes for vibration test fixtures.

Keywords: Variable Grid; Vibration-Test Fixture; Genetic Algorithm; Manufacturability Constraints; Natural Frequency

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Leveraging Large Language Model for Sustainable Manufacturing Process Recommendation

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Selecting an appropriate manufacturing process in the early design phase remains a challenging task due to the need to simultaneously consider productivity, efficiency, and environmental impact. Conventional experience-driven and rule-based methods either lack consistency due to expert subjectivity or are limited in systematically comparing productivity and efficiency. This study proposes an integrated framework combining a large language model (LLM) and machine learning (ML) to support sustainable and explainable manufacturing process recommendation. The framework evaluates additive manufacturing, subtractive manufacturing, injection molding, and others through part validation, geometric assessment, producibility evaluation, and efficiency analysis. Part validation examines file integrity and component type, geometric assessment evaluates manufacturability from 3D models, producibility evaluation recommends processes using production variables, and efficiency analysis employs ML to predict processing time, cost, and CO2 emissions. Concurrently, the LLM module explains assessment results at all stages and provides reasoning-based recommendations by referencing manufacturing standards through Retrieval-Augmented Generation. The framework enables designers to systematically evaluate trade-offs among process alternatives and select sustainable manufacturing strategies based on explainable rationale.

Keywords: Large Language Model; Sustainable Manufacturing; Process Recommendation; Machine Learning

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Poster Session 1 CAD/CAM/CAE, Optimization PP1-3

Semantic-Aware Part Decomposition for Additive Manufacturing via Reinforcement Learning

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Additive Manufacturing (AM) has enabled the manufacture of highly complex geometries. However, several constraints remain for industrial adoption, including increased build time and manufacturing costs due to support structures, surface quality degradation, and printer build volume limitations. To mitigate these constraints, Part Decomposition (PD) has emerged as an effective redesign strategy. While previous research has optimized AM design considerations through PD, such as build orientation optimization, support structure minimization, and surface quality improvement, it faces limitations in reflecting the sequential and planned decomposition strategies required for complex geometries. Furthermore, most existing research does not incorporate semantic information into the decomposition process, resulting in limited ability to achieve structurally coherent decomposition that preserves geometric structural consistency. To address these two limitations, this study proposes a Reinforcement Learning (RL)-based PD framework. In the proposed framework, AM design considerations are mathematically defined as reward functions, and recursive PD is performed within an RL environment, where the agent learns to maximize cumulative rewards. Moreover, additional rewards are provided when decomposition maintains semantic consistency, encouraging the agent to perform semantically coherent decomposition while satisfying AM objectives. The proposed method simultaneously achieves manufacturability and semantic-aware decomposition, presenting a novel decomposition strategy that encompasses the core objectives of design for AM.

Keywords: Additive Manufacturing; Part Decomposition; Reinforcement Learning; Semantic Segmentation; Design for Additive Manufacturing

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3D Printed Partial Reinforcement CF Composite Co-Analysis

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Recently, interest in composite materials with high specific strength and specific stiffness has been increasing across various applications such as aerospace, defense, and automotive industries. In addition, continuous fiber-reinforced composites shows superior mechanical properties as compated to those reinforced by short fiber, so it can be well suited for structural components. Unlike conventional manufacturing proceed for continuous fiber-reinforced composite structures such as Compression molding and autoclaving, the composite 3D printing technique proposed by Markforged Inc. can offers design flexibility and especially allows for partial reinforcement in the whole structures. According to the above research background, this study focused on the design methodology of the 3D printed composite structures, and the mechanical behavior of partially reinforced composite parts were experimentally/numerically investigated. For the experimental works, some cases of tensile specimens were considered to compare the influence of continuous fiber content on the mechanical behaviors of the printed part. The speed of the tensile test was setted 5 mm/min, and five specimens were considered in every case. For the numerical analysis, a finite element model of the tensile specimen was constructed by Abaqus. In the process of finite element analysis, material properties were derived through reverse engineering based on the experimental data and local orthotropic properties due to the filament orientation was mapped in the finite element model by using Digimat. The reliability of the proposed analysis method was verified by comparing the numerical results with experimental data. Consequently, it was confirmed that the proposed method provided meaningful solutions and reinforcement in the tensile direction can be significantly improved the mechanical behavior of the tensile specimen.

Keywords: 3D Printing; Composites; Continuous Fiber; FEM

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Injection–Structural Coupled 2D Analysis Model Considering Characteristics of 3D Fiber Orientation

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In recent years, the use of composite materials in the automotive and aerospace industries has increased significantly to achieve lightweight designs while maintaining high strength and stiffness. Unlike conventional isotropic materials, composite structures exhibit local anisotropic mechanical properties that depend on manufacturing processes and fiber orientation. In particular, for short-fiber reinforced composites, the fiber orientation along the thickness direction has a strong influence on local anisotropic behavior, so consideration of local fiber orientation is essential for reliable structural analysis. However, finite element modeling that consider through-the-thickness anisotropic properties requires a large number of elements, leading to excessive computational cost for numerical simulation of the full 3D model. To overcome this limitation, this study proposes an efficient injection–structural coupled analysis method that approximates the through-the-thickness anisotropic properties of a 3D short-fiber composite structure using a 2D model. Fiber orientation data were obtained from Moldex3D and mapped onto a 2D model using Digimat to derive reliable local through-the-thickness anisotropic properties. A 12-layer 2D model was constructed to reproduce the typical skin–core–skin fiber orientation pattern. The results confirm that mapping 3D fiber -orientation data onto a 2D structural model enables efficient and reliable coupled analysis while significantly reducing computational resources. The proposed method is highly effective for analyzing short-fiber composite structures with large aspect ratios.

Keywords: Fiber Orientation Tensor; Injection Molding; CAE; Coupled Analysis

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Numerical Analysis of Flow and Heat Transfer Characteristics in a CO_2–Water Based Chiller Heat Exchanger

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This study presents a comprehensive numerical investigation of the flow characteristics and heat transfer performance of a CO_2–water based chiller heat exchanger intended for data-center and industrial cooling applications. The geometry of the heat exchanger was generated using CATIA and further refined in SpaceClaim by separating the CO_2 and water flow channels. A steady-state CFD simulation was conducted using ANSYS Fluent with the SST k–ω turbulence model. Polyhedral meshes were generated with approximately 15.2 million cells, and mesh orthogonality and near-wall resolution ($y^+ \approx 0.9$) satisfied the requirements for accurate turbulence modeling.

Boundary conditions were applied with CO_2 and water entering at 60 m/s, with inlet temperatures of 3 °C and 12 °C, respectively. The outlet pressure for both fluids was set to 0 Pa. The results showed that the CO_2 velocity increased from 60 m/s to a peak of 81.68 m/s as it passed through the inner tube. The CO_2 temperature increased from 3 °C to 10.99 °C due to heat absorption from the water, whereas the water temperature decreased from 12 °C to 10.54 °C. The maximum pressure, approximately 9,000 Pa, occurred at the junction where the CO_2 and water channels interacted.

The study demonstrates that the CO_2–water configuration exhibits high heat-transfer effectiveness, showing strong potential for application in eco-friendly cooling systems. The numerical results provide essential baseline data for future optimization of chiller heat-exchanger geometries and subsequent experimental validation.

Keywords: Carbon Dioxide; Chiller; Heat Exchanger; CFD Simulation; Thermal Performance

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Contact Behavior and Durability Assessment of a Hydrogen Pneumatic Valve under Full-Pressure Operation Cycling Conditions

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Hydrogen refueling valves sustain sealing performance and structural integrity under full-pressure operation cycling conditions specified in ISO 19880-3. According to the standard, valves are required to withstand 102,000 full-pressure operation cycles, in which the valve is repeatedly opened and closed under its component pressure rating, without exhibiting leakage or mechanical damage. In this study, the mechanical response, contact behavior, and durability of a hydrogen pneumatic valve were evaluated through FEM analysis and experimental test. The FEM analysis was performed using ANSYS Workbench base on Chaboche kinematic hardening model, which considered material behaviors such as plastic deformations due to cyclic loading. The analysis simulated cyclic opening and closing up to 16,000 cycles, corresponding to the seal replacement interval defined by the standard. The obtained results indicated progressive deformation of the plunger and reduction in contact area due to repeated mechanical loading. However, the circumferential contact pressure remained sufficiently uniform to maintain sealing performance. To verify the numerical results, a full-scale 102,000-cycle operation test was conducted under the full-pressure load required by ISO 19880-3. No leakage or structural damage was observed throughout the test, confirming that the valve satisfies the regulatory durability and leakage criteria.

Keywords: Contact Behavior; Durability Assessment; Hydrogen Pneumatic Valve; Leak-prevention

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Estimation of Boil-Off Gas Generation in Liquid Hydrogen Storage Vessels Using Phase Change Model Based on Intermolecular Interaction

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Boil-off gas (BOG) generated during the storage of liquid hydrogen, causes pressure rise in the storage vessel and increases the risk of explosion. One of the major causes of the BOG generation is the vaporization at the interface between the liquid hydrogen and the storage vessel wall. At the interface, the vaporization regime transitions from natural convection boiling to nucleate boiling as the heat ingress in the storage vessel increases, resulting in a significant increase in the BOG generation. In this study, a phase change model considering the vaporization regime depending on heat ingress was proposed and applied to estimate the amount of BOG generated in liquid hydrogen storage vessels. The proposed model was based on the Lennard–Jones potential energy, which accounts for intermolecular interactions and the Maxwell–Boltzmann speed distribution. It could estimate the significantly increasing mass transfer rate in the vaporization regime where natural-convection boiling transitions to nucleate boiling. To validate the proposed model, multi-phase fluid flow analysis for the self-pressurization experiments conducted at NASA GRC (Glenn Research Center) on small- and large-scale liquid hydrogen storage vessels with heat ingress of 22 and 48 W, respectively, was performed. The commercial software of ANSYS Fluent was used to perform the multi-phase fluid flow analysis, and the pressure rise rates and the amount of BOG generated were evaluated. The pressure rise rates obtained for the small- and large-scale storage vessels were 440 and 6.24 Pa/s, respectively, and agreed well with the experimental data within a relative error of 5 %. In addition, the amounts of BOG generated in the small- and large-scale storage vessels were 6.1×10^{-6} and 5.8×10^{-8} kg/s, respectively, indicating that BOG generation in the small-scale storage vessel was approximately 100 times that in the large-scale vessel. This is because, although the total heat ingress into the small-scale storage vessel was lower, the corresponding heat flux was as high as 238 W/m^2, which induced active nucleate boiling at the vessel wall.

Keywords: BOG(Boil-Off Gas); Intermolecular Interaction; Liquid Hydrogen; Phase Change Model

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Poster Session 1 CAD/CAM/CAE, Optimization **PP1-9**

Size Optimization of Metal Disc for Leak Prevention in Cryogenic Pilot-Operated Safety Relief Valve

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In storage tanks and piping for cryogenic fluids such as LNG and liquid hydrogen, boil-off gas (BOG) generated by heat ingress can significantly raise internal pressure. To mitigate pressure buildup, pilot-operated safety relief valves (POSRVs) are employed in cryogenic applications. Although POSRVs provide superior sealing performance compared with conventional spring-actuated relief valves under ambient temperature and normal-pressure conditions, cryogenic environments induce material contraction and embrittlement, altering the contact mechanics between the metal seat and disk. Consequently, the reduced contact pressure can increase the likelihood of leakage at the metal-to-metal contact interface. In this study, the contact pressure and contact area between the metal seat and disk of POSRV during flow-path closure were numerically evaluated using FEM analysis. Based on Persson's percolation theory and Kazeminia's concentric-cylinders model, a new leakage prevention criterion was proposed, suggesting that leakage can be avoided if non-contact pathways are eliminated and continuous contact region exceeding the operating pressure of working fluids is established within the same effective radius. In addition, an angular contact-pressure ratio (ACR) was introduced to quantify the circumferential distribution of contact pressure. Under cryogenic conditions, the ACR was found to be below an allowable limit, indicating a high probability of leakage at the contact interface. To overcome this, a parametric study of disk geometries was conducted, followed by size optimization to identify design parameters that maintain the ACR above the allowable limit. Through optimization, the POSRV disk geometries were improved, ensuring the leakage prevention at the metal-to-metal contact interface under cryogenic operating conditions.

Keywords: Cryogenic Environment; Leak Prevention; Metal-to-Metal Contact; Pilot-Operated Safety Relief Valve; Size Optimization

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A Method for Reconstructing Triangular Elements from Large-Scale 3D Point Cloud

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Point clouds obtained from terrain measurements are typically large-scale and contain substantial noise. In addition, certain regions may not be measured at all. Conventional approaches such as Delaunay triangulation, voxel-based structures, or Poisson surface reconstruction often require considerable processing time under these conditions, and the presence of noise may hinder accurate shape reconstruction. This paper proposes a fast method for reconstructing three-dimensional terrain surfaces from large-scale point clouds using an element offset approach. The element offset method constructs a two-dimensional grid that encloses the point cloud and identifies the points contained within each grid cell. For all points, the distances to the corresponding grid plane are calculated, and the average distance value is computed for each grid cell. Outliers deviating significantly from the mean can be excluded to remove noise. In cases where a grid cell contains no points, interpolated values from neighboring cells are used instead. Finally, for each grid node, the average distance of adjacent grid cells is determined, and the node is offset along the normal direction by the corresponding distance, thereby reconstructing the surface geometry.

Keywords: Point Cloud; Mesh Reconstruction; Mesh Offset

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A Study on Casting Analysis for the Development of Optimized Process Technology for Base Cartridges

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As modern transportation environments become more complex and vehicle technology is evolving into cutting-edge technologies like autonomous driving. Existing safety devices need to be integrated with new technologies to become more efficient and intelligent. A seat belt pretensioner is a device that rapidly tightens a belt when a collision is detected. Usually, these devices utilize gunpowder. The resulting explosive gas pushes a piston, tightening the belt. A small cartridge-shaped component located inside the pretensioner that is ignited by a sensor signal and explodes or generates high-pressure gas to push the piston. The base cartridge functions as a pretensioner when combined with a spark plug, gunpowder or propellant gas outlet, or connecting passage. With the rapid growth of the unmanned and autonomous vehicle industry, demand for smart seat belt is expected to increase. The base cartridge, a key component of these smart seat belts, requires high strength and high-quality specifications. In this die-casting process, overflow and gate runner play a role in reducing the casting defect rate, but if the area increases, it affects the yield and cost. Therefore, the optimal runner size and shape were derived through casting analysis.

Keywords: Die-casting; Zinc Alloy; Base Cartridge; Casting Analysis; Optimization

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Comparison of Noise Removal Methods for Scanned Ship Block Data Using CAD Models

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Research on noise removal from scanning data has been actively conducted in recent years. During the fabrication and assembly of ship blocks, point cloud data collected by scanners are used for virtual simulations, and noise removal is essential for accuracy. This study proposes and compares three methods for point cloud denoising using CAD models and 3D scanned ship block data. The first calculates the shortest distance from each point to the CAD mesh, removing points exceeding a threshold. The second generates virtual rays from the scanner to each point and removes those not intersecting the mesh. The third obtains distance information from the scanner to both the CAD model and point cloud, converting it into equirectangular images of equal resolution for pixel-based comparison. Two methods are applied: pixel-comparison removes points corresponding to pixels with large value differences, while edge-comparison deletes edges and interiors existing only in the point cloud image. The distance-based method showed the best performance but required threshold adjustment according to shape. The ray-casting-based method produced non-intersecting regions depending on scanner position, requiring an offset on the mesh surface. The image-based methods faced difficulties due to pixel distribution changes from differences between maximum and minimum distance ranges and incomplete edge extraction. All methods were affected by registration accuracy. To improve performance, additional alignment divided the block's bounding box into grids and applied the Iterative Closest Point algorithm locally, but it showed lower accuracy than the previously registered state and had limitations in complete noise removal.

Keywords: Denoising; Point Cloud; Distance; Ray Casting; Equirectangular Image

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Dual-Invariance Self-Supervised Learning for Conceptual to Detailed Design Retrieval

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In today's rapidly evolving market, strategies for shortening development cycles and reusing existing design knowledge are essential for securing a competitive edge in product development processes. In particular, retrieving detailed design models from a database using conceptual design CAD models created in the early design stages can significantly enhance development productivity. However, a geometric gap exists between the conceptual and detailed design models owing to their different levels of abstraction. This prevents conventional retrieval techniques, which rely on low-level geometric features, from capturing semantic similarities between the two model types. To overcome this gap, this study proposes a novel self-supervised contrastive learning strategy that uses multi-view images converted from 3D shapes as input and jointly learns two types of invariance: viewpoint and augmentation. This is implemented by defining a composite contrastive loss based on the relationship between two views sampled from a single model and their corresponding augmented views. This approach compels the model to effectively encode essential semantic features shared across shapes with different levels of abstraction into an embedding space. To validate the proposed model, experiments were conducted on the ModelNet40 dataset, achieving an NMI score of 0.78. This result quantitatively demonstrates that our model constructs a robust embedding space capable of effectively retrieving relevant detailed models using only abstract information from conceptual designs. Consequently, designers can shorten development times and improve design quality by rapidly referencing relevant design cases in the early stages of development.

Keywords: 3D Shape Retrieval; Contrastive Learning; Metric Learning; Multi-view Learning; Self-supervised Learning

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Shape-Based Viewpoint Optimization for Bottom-Side Measurement of Ship Blocks

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Ships and offshore plants are built in block units, with the final structure completed by welding the blocks together at the yard. Fabrication errors in the underside of blocks can cause serious problems during assembly. To prevent this, three-dimensional measurements using terrestrial laser scanners are essential. However, the underside area presents challenges such as confined workspaces, limited accessibility due to supporting structures, and safety risks. Moreover, the absence of clear criteria for selecting viewpoints forces operators to rely on experience, often leading to redundant measurements to avoid omissions. This increases work time in hazardous zones and causes inefficiency from excessive data processing.

To address these issues, this study proposes an automated optimal viewpoint selection method for measuring the underside of blocks. The method projects the underside region of a 3D CAD model onto a 2D plane, extracts feature points from the projection, and applies Delaunay triangulation to form triangular regions. Initial viewpoints are placed at the circumcenters of these triangles. A visibility matrix is then calculated to identify unmeasured areas, and additional viewpoints are added to cover them. Scanning simulations using the block's CAD model are also performed to detect unmeasured regions accurately. Finally, a greedy algorithm determines the minimal combination of viewpoints required. The proposed method was implemented and tested on an actual block CAD model, verifying its effectiveness.

Keywords: Shape Analysis; Ship Block; Terrestrial Laser Scanning; Viewpoint Optimization

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Detailing 3D Shapes Using a Generative Model

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Recently, research on generative AI based on large language models (LLMs) has attracted considerable attention. However, a challenge in applying LLMs to 3D shape generation is their tendency to produce overly simplistic forms that lack fine-grained geometric details. To address this limitation, this study proposes a generative framework that refines coarse shapes into detailed mesh- based representations. For training, we first tokenized the 3D geometries. The coarse input shape was converted into a point cloud and encoded into tokens, whereas the corresponding detailed shape was represented as a mesh and tokenized using its vertices. Tokens from both coarse and detailed representations were concatenated and used to train the transformer model. Our trained model demonstrated the ability to generate diverse shapes with rich geometric and topological variations while maintaining consistency with the original input shape. Because the generative model outputs the mesh directly, it minimizes information loss and produces more detailed geometries than voxel or point cloud methods. Notably, the model effectively preserves the sharp edges and angular features that are characteristic of CAD models. Moreover, we confirmed that even when simple shapes of different types were trained together as inputs, the model generated outputs distinct for each input shape.

Keywords: Transformer; Shape Generation; Shape Detailing

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Automated Generation of CAD Models from Text Input for Circular and Intelligent Industry 4.0/5.0 Systems

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The rapid development of digital technologies within Industry 4.0 and the emerging era of Industry 5.0 introduces new approaches to product design and manufacturing. One of these innovations is the automated creation of CAD models based on text input, which enables the generation of 3D geometry through natural language. The aim of this article is to analyze the principles and benefits of automated CAD model generation in an environment utilizing language-driven modeling and rule-based geometry control. The research focuses on the interconnection between text input, parametric modeling, and design process automation in the context of digital engineering and sustainable development. The study highlights the potential of this approach for modern manufacturing environments that are evolving toward interconnected, intelligent, and circular forms of Industry 4.0/5.0. Such systems emphasize efficient resource utilization, design adaptability, and error reduction throughout the product life cycle. The article also presents practical examples of creating simple geometric entities and their subsequent parameterization through textual instructions. Furthermore, technical limitations and the possibilities of integrating language-driven systems into modern CAD environments are discussed, with the aim of increasing the level of automation, repeatability, and efficiency of the design process.

Keywords: Automation; Text-to-CAD; Digital Engineering; CAD Systems; Circular and Intelligent Industry

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Poster Session 1 CAD/CAM/CAE, Optimization **PP1-17**

CAE-Based Degradation Mapping and Constitutive Model Selection for NBR Seals under Thermal Aging

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This study presents a design-oriented framework for predicting and compensating the degradation of nitrile-butadiene rubber (NBR) seals used in high-temperature industrial and energy systems. The objective is to integrate accelerated aging experiments, Arrhenius-based lifetime estimation, and finite element analysis (FEA) to establish a quantitative guideline for selecting appropriate hyperelastic models according to the material degradation state. The activation energy was determined to be 131 kilojoules per mole using the Flynn–Wall–Ozawa method, enabling equivalent service-life prediction at 70 to 90 degrees Celsius. Mechanical and thermal characterizations, including tensile, dynamic mechanical, and thermogravimetric analyses, revealed that the crosslink density increased linearly from 2.0×10^3 mol·m^{-3} to 6.8×10^3 mol·m^{-3}, while the elongation at break decreased from 273 percent to 4 percent. Hyperelastic parameters were extracted from experimental data and validated through ANSYS Workbench 2024 R2 simulations using an L2-norm error evaluation. The Neo-Hookean model provided optimal accuracy at the early degradation stage, whereas the five-parameter Mooney–Rivlin model was more accurate after embrittlement occurred when the crosslink density exceeded 3.3×10^3 mol·m^{-3}. Based on these results, a degradation map was developed to correlate service temperature and time with the appropriate constitutive model. The proposed framework enhances the predictive reliability of CAE-based design and supports digital twin applications for optimizing polymer seal performance in advanced manufacturing environments.

Keywords: Nitrile-Butadiene Rubber; Accelerated Aging; Hyperelastic Model; Finite Element Analysis; Design Optimization

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Definition of Functional Requirements for the Development of a Design Parameter Calculation System

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Design parameters are key elements that define the geometric and functional characteristics of a product during the design process, representing design requirements such as length, width, and angle in numerical form. In the detailed design verification stage, it is necessary to calculate and verify the major parameters of design features included in the boundary representation (B-rep) model to evaluate whether the CAD model accurately reflects the intended design requirements. This study aims to develop a system that automatically calculates the design parameters required for detailed design verification based on the reference topological elements of the B-rep model and defines the functional requirements necessary for its implementation.

Keywords: Boundary Representation Model; Design Parameters; Design Verification; Parameter Calculations

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Point Cloud-Based Automatic Detection of Welding Lines for Mechanical Structures

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This study proposes a method for recognizing planar and curved surfaces of mechanical structures from point cloud data acquired by a 3D scanner, and for automatically extracting welding lines based on the identified surfaces. Structural components such as ship curved blocks are composed of thin steel plates assembled by welding. A three-dimensional grid is first constructed over the entire point cloud, and any grid cell containing a sufficient number of points with an RMS error below a specified threshold is classified as a plane. Similar planes are then merged based on the angular difference of their normal vectors and the distances between their centroids. In the case of curved surfaces, even a single continuous surface may be erroneously divided into multiple planes due to variations in normal directions at the grid level. To address this, neighboring grid cells are sequentially examined, and those with normal vector differences within a tolerance are grouped together into a unified curved surface. Finally, surfaces with small areas or low point densities are removed. Welding lines correspond to the boundaries where steel plates meet, and are defined as the intersections between planar and curved surfaces.

Keywords: Curved Surface Recognition; Point Cloud; Scan Data; Welding Line Recognition

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Design Feature Recognition in Mechanical Parts Based on Graph Neural Network

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After product design, design verification is crucial to ensure that the design meets the specified requirements. This process involves identifying issues, making corrections, and repeating the verification. In typical design workflows, the STEP neutral model is used for compatibility reasons. However, STEP models only contain geometric and topological information, lacking high-level information such as design features, which are necessary for comprehensive verification. As a result, design verification is often performed manually, requiring significant time and effort, and increasing the risk of human error. To address the issue of automating design verification, this study proposes a method to automatically recognize design features during the verification process. The proposed method first converts 3D CAD models, represented in boundary representation (BREP), into graph structures, which are then processed using a graph attention network (GAT). Specifically, by using a multi-head attention mechanism, the system can effectively capture more complex and high-dimensional design features and verify them. This technique greatly reduces manual intervention and minimizes the risk of human error.

Keywords: Boundary Representation; Graph Neural Network; Mechanical Part; Multi-head Attention

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GUI for CAD Detailed Design Modeling Using XML-Defined Features

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3D CAD models used in industrial practice serve not only as geometric representations but also play a critical role in verifying manufacturability and product performance. To ensure machinability, enhance structural stability, and improve product quality, the application of elements such as fillets and chamfers is an essential step. However, in conventional commercial CAD environments, users must manually select geometric entities and repeatedly input detailed parameters for these operations, which is time-consuming even for experienced engineers and poses a significant barrier for beginners. In this study, these elements are collectively defined as "Detail Design Elements." A Detail Design Element refers to an auxiliary modeling step applied to a base shape, intended to reflect manufacturing requirements and design rules. The system developed in this study takes a STEP model file and an XML file in which Feature information is predefined, and applies the detail design elements specified in the XML sequentially to the CAD model with a single button click. The GUI provides functions such as model loading, XML loading, and modeling execution, while the applied results can be intuitively verified through a Feature Tree and highlighted visualization. In addition, an Undo function is provided to enhance reproducibility and stability of the workflow. The proposed system operates on the premise of 1:1 compatibility between the XML and STEP files, thereby guaranteeing consistent results for a given pair. This allows not only researchers and engineers but also CAD beginners to perform modeling tasks easily, and it offers the potential to be extended to other detail design elements such as Draft and Rib in the future.

Keywords: Detail Design Elements; Graphical User Interface (GUI); XML-Defined Features

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User-Friendly GUI for Realistic Rendering of Industrial CAD Models

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In Industrial 3D CAD models, realistic rendering plays a critical role in various fields such as digital twins, smart manufacturing, and simulation. However, when performing realistic rendering with commercial rendering software such as Blender or Unreal Engine, the process requires repetitive manual operations, and complexity of integrated functions makes it difficult for non-expert users. This study aims to overcome these limitations by developing a user-friendly GUI(Graphical User Interface) that supports part-type-based texture mapping. The proposed GUI provides buttons for key functions such as UV map generation, HDRI configuration, texture assignment, part-type-to-texture mapping through a combo box, and realistic rendering. Through this GUI, users can perform realistic rendering with intuitive manipulation and immediate visualization of results, without complex parameter adjustments. In addition, users can save and load the part-type-to -texture mapping data through XML format, which eliminates repetitive mapping process when handling models that have same part types. The developed GUI can simplify the realistic rendering workflow of large-scale 3D CAD models compared to existing commercial rendering tools. Consequently, researchers, engineers, and non-experts who are not familiar with professional rendering software can generate virtual models for digital twin applications easily and efficiently

Keywords: Realistic Rendering; Graphical User Interface(GUI); Industrial 3D CAD Models; Digital Twin Applications; Texture Mapping

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Development of Laboratory Data Lifecycle Management System for Proton-Based Ceramic Electrolysis Cells

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Recent advances in artificial intelligence and robotics have accelerated research on autonomous and unmanned laboratories, where experiments are executed and analyzed with minimal human intervention. As laboratory automation progresses, the volume and complexity of data generated during experiment or manufacturing workflows have increased substantially. Laboratory data include materials information, equipment information, process parameters, and analysis results, all of which must remain interpretable and reusable across experiments. This study aims to develop a laboratory execution system (LES) to automate the fabrication of protonic ceramic electrolysis cells. The target fabrication process involves the production of the anode, electrolyte, and cathode layers. This requires custom-built devices to cut raw materials, apply thin layers of electrolytes onto the specimens, laminate the fabricated layers, and sinter the functional layers. To build the Laboratory Execution System, the database schema includes tables for materials, equipment, process, work orders, and real-time monitoring for process data. To enable semantic consistency and cross-stage data integration, an ontology-based database was implemented on PostgreSQL by mapping domain concepts and definitions into a structured relational schema. This work presents the development of a Laboratory Data Lifecycle Management System for PCEC fabrication, integrating an ontology-based database with lifecycle data management to support automation-ready laboratory research.

Keywords: Laboratory Execution System; Protonic Ceramic Electrolysis Cell; Ontology-based Database

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Manufacturability- and Performance-Aware Generative Design for Additive Manufacturing

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Additively manufactured (AM) heat exchangers offer unprecedented geometric freedom for achieving high thermal efficiency, reduced weight, and compact form factors. However, designing high-performance structures that are simultaneously manufacturable remains a major challenge due to complex thermal–hydraulic interactions and AM-specific limitations such as minimum feature sizes, overhang angles, and enclosed cavities. This paper presents a manufacturability- and performance-aware generative design framework that integrates surrogate modelling and generative modelling to automate the creation of high-performing AM heat exchangers. The proposed workflow begins by generating a large, diverse dataset of parameterized heat exchanger geometries, each evaluated in terms of surface-to-volume ratio and manufacturability metrics. Surrogate models are then trained to approximate these performance and manufacturability results with near real-time speed while maintaining high predictive fidelity. These models are incorporated as guidance modules within a diffusion-based generative model, enabling performance-aware generation of novel heat exchanger designs. Manufacturability constraints are embedded through geometry-aware filters and gradient-based penalties to ensure AM feasibility. Results demonstrate that the proposed framework can (i) generate geometries with significantly improved surface-to-volume ratio and manufacturability, and (ii) support multi-objective optimization. Comparative studies show substantial improvements over unguided generative baselines and traditional parametric design. This work provides a generalizable AI-driven approach for the scalable, manufacturable, and high-performance design of heat exchangers, offering a new pathway toward next-generation thermal management solutions.

Keywords: Generative Design; Design Exploration; Manufacturability; Design for Additive Manufacturing; Diffusion Model

Hybrid CFD–ML Surrogate Modeling and Multi-Objective Optimization for PEMFC Performance and Operating Strategy Design

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Proton exchange membrane fuel cells (PEMFCs) require accurate performance prediction and systematic optimization to ensure high power output, durability, and efficient operational control. This study presents an integrated framework that combines high-fidelity 3D CFD simulation, experimentally validated machine-learning surrogate modeling, and multi-objective optimization (MOO) with post-Pareto decision analysis. A detailed CFD model of a realistic 25 cm^2 PEMFC was developed and validated against polarization measurements, achieving strong agreement across operating conditions. Using this dataset, five surrogate models: RF, GB, SVM, ANN, and XGBoost were trained and rigorously evaluated. XGBoost demonstrated the highest accuracy (R^2 > 0.989 for power density (PD), 0.996 for system efficiency (SE), and 0.94 for oxygen distribution uniformity (ODU)), allowing the surrogate model to replace time-consuming CFD simulations. The NSGA-III optimization targeted three conflicting objectives : PD, SE, and ODU. The Pareto analysis clearly showed that improving one often reduces the others. To transform the Pareto solutions into clear and useful operating guidelines, a post-Pareto regime-based decision strategy was applied across voltage bands from 0.9 to 0.4 V. Using VIKOR, balanced operating points were extracted, showing that moderate-voltage operation (0.5–0.7 V) provides optimal compromise values (PD ≈ 0.65–1.0 Wcm^{-2}, SE ≈ 32–46%, ODU ≈ 1–2). In contrast, low-voltage operation (0.4–0.5 V) produced only marginal PD gains but suffered substantial efficiency loss and reactant maldistribution. Overall, this combined CFD–ML–MOO decision framework offers a robust pathway for high-accuracy PEMFC prediction and provides physically interpretable, application-oriented operational guidelines for improving long-term fuel-cell performance.

Keywords: Proton Exchange Membrane Fuel Cell; Machine Learning Surrogate; Multi-Objective Optimization; Operating Conditions; Post-Pareto

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A Study on the Definition and Cases of Manufacturability Conflicts in Design–Manufacturing Processes

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Industry 4.0 has accelerated the separation of design and manufacturing roles, thereby increasing the need for structured and effective collaboration. In product development, designers and engineers often work with different priorities, which leads to repeated design revisions, extended development cycles, increased costs, and reduced product quality. A major source of these inefficiencies is manufacturability conflict. This occurs when the designer's intent does not match the capabilities, limitations, or constraints of the manufacturing process, resulting in design choices that are difficult or inefficient to produce. This study explains the concept of manufacturability conflict that arises during the product design stage, with a focus on key manufacturing processes such as injection molding, pressing, die casting, and machining. Representative conflict scenarios include improper draft angles, undercuts, tooling inaccessibility, springback, and material-related defects. These cases are analyzed to demonstrate how certain design decisions unintentionally create technical barriers during production. Based on these documented cases, we propose a preliminary set of manufacturability rules intended to guide designers toward more production-feasible decisions early in the design process. These rules are developed from expert interviews, literature reviews, and process-specific operational constraints, and serve as actionable criteria for predicting and preventing common design–manufacturing mismatches.

Keywords: Manufacturability; Design-Manufacturing Conflict; Design for Manufacturability; Design Rule

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Multi-Sensor Based In-situ Warping Detection and Feedback Control for Super Engineering Plastic 3D Printing Using a Conditional LSTM-VAE Model

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Polyether ether ketone (PEEK) is a super engineering plastic (SEP) with high strength, thermal resistance, and biocompatibility and is widely applied in aerospace and medical fields. However, due to its high melting point, material extrusion of PEEK requires high nozzle temperatures above 400°C which often leads to severe warpage. Warpage arises from the cooling induced shrinkage of extruded material, affecting dimensional accuracy or even causing part detachment from the build platform. This issue is particularly prominent in open type 3D printers, so a monitoring and feedback system is essential to minimize warpage. While many studies employ vision based machine learning monitoring, these methods are sensitive to light conditions and suffer from blind spots. To address these limitations, we utilized unsupervised learning based anomaly detection method using extrusion force time series data. Printing was performed with longitudinal, transverse, and grid toolpaths, and normal data patterns differed according to each toolpath condition. To incorporate this pattern into the model, nozzle position data was used to generate toolpath images. These images were dimensionally reduced via an autoencoder and provided as condition for a conditional LSTM-VAE. This allowed the model to learn normal extrusion force patterns for different toolpaths. Upon defect detection, feedback was executed by adjusting nozzle height and applying localized heating with an IR heater depending on the printing layer. Consequently, the system demonstrated partial suppression of warpage progression during the process.

Keywords: Super Engineering Plastic; Warpage; Extrusion Force; Real-time Process Monitoring; Feedback Condtrol

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Optimization of Laser-Assisted Wafer-Level Carrier Debonding Based on Physics-informed Neural Network for Advanced Semiconductor Packaging

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Temporary carrier bonding–debonding is a key unit process in advanced wafer-level packaging for HBM and 3D integration, where ultrathin wafers are vulnerable to thermomechanical damage. Laser-assisted debonding provides localized energy input and a wide process window, but systematic optimization remains challenging because debonding force, defect formation, and throughput are controlled by coupled thermomechanical fields and a high-dimensional laser parameter space. In particular, the combined influence of laser power, scan speed, and line gap on debonding force has not been quantitatively established. In this work, we develop a physics-informed neural network framework that simulates and learns the laser debonding process. Heat conduction, stress equilibrium, and Beer–Lambert absorption equations are embedded into the loss function so that the network predicts temperature distribution, interfacial stress, and debonding force in a physically consistent manner. Data generated by these physics-based simulations are combined with wafer-level experiments, in which debonding force and damage indicators are measured under systematically varied laser power, scan speed, and line gap. This hybrid simulation–experiment training allows the surrogate model to reconstruct thermomechanical states while quickly mapping laser conditions to debonding force and damage risk. Using the trained model, we perform a multi-objective optimization to minimize debonding force and predicted damage probability under a throughput requirement and to identify optimal combinations of laser power, scan speed, and line gap. The proposed physics-informed machine learning framework provides a data-efficient and physically interpretable design tool for carrier laser debonding that can be extended to various temporary bonding materials and next-generation heterogeneous integration.

Keywords: Laser-assisted Debonding; Wafer-level Packaging; Physics-informed Neural Network; Thermomechanical Behavior; Process Optimization

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Emotion Recognition and HRV-Based Multimodal Mental Health Assessment Integrated with an AI Chatbot

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Despite growing attention to mental health in older adults and active seniors, assessment tools have not progressed as rapidly as physical health monitoring technologies. To address this gap, we propose a multimodal stress-monitoring framework centered on an AI-based conversational chatbot equipped with emotion recognition and heart rate variability (HRV) analysis. The system integrates chatbot dialogue with video, audio, and heart rate signals to extract facial expressions, speech emotions, and HRV indicators, which are then used to estimate users' stress levels and classify them into corresponding stress categories. Negative emotional cues are quantified and combined with HRV metrics to produce an overall stress score. For emotion analysis, facial and vocal recognition models were trained using the RAVDESS, CREMA, and TESS datasets, expanded to 21,000 samples through data augmentation and optimized with a BiLSTM architecture. In parallel, a deep learning–based HRV model trained on smartwatch data enhances stress prediction accuracy. By employing fusion of facial, vocal, and HRV features, the system generates an integrated stress index that assigns individuals to stable, cautionary, at-risk, or high-risk groups. This framework supports continuous home-based monitoring and holds promises for early detection, preventive interventions, and more informed clinical decision-making.

Keywords: Mental Health Monitoring; Multimodal Stress Detection; AI Chatbot; Emotion Recognition; Heart Rate Variability

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Fourier Transform–Based Mark-Free Alignment via Deep Learning for Heterogeneous Pattern

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Alignment marks often act as surface defects, degrading not only the functional performance but Alignment marks often act as surface defects, degrading not only the functional performance but also the aesthetic completeness of microstructured devices. In this study, we propose a mark-free alignment method that leverages the rotational invariance of the Fourier Transform combined with deep learning to achieve precise alignment of periodic micro-patterns with heterogeneous geometries. The rotational invariance implies that when the original image is rotated, its Fourier spectrum rotates by the same angle. By converting the Fourier spectrum into Cartesian coordinates, the radial (r) and angular (θ) components were analyzed to quantify the shift corresponding to rotational misalignment, simplifying the rotation estimation into a vertical displacement problem. Angular integration was then performed to produce one-dimensional time-series data, which were used to train a deep learning model. Various weighting functions—linear, inverse, and Gaussian—were compared to correct coordinate distortion, and the Gaussian weighting yielded the best performance. A graph neural network (GNN) model with quadrupled convolutional layers achieved a mean absolute error (MAE) of 0.039°, demonstrating high rotational prediction accuracy. The proposed framework enables precise alignment between heterogeneous patterns without alignment marks, offering significant potential for large-area nanoimprint lithography, multilayer stitching, and next-generation micro/nanofabrication processes.

Keywords: Fourier Transform; Mark-Free Alignment; Deep Learning; Rotational Invariance; Graph Neural Network

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A Study on Injection Molding Conditions for Producing Target-Quality Products Using ANN

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The quality of the products produced by the injection molding process is greatly influenced by the process variables applied to the injection molding machine. It is very difficult to determine process variables considering all of the variables because the process variables affect complexly the quality of the injection molded product. In this study, we determined injection molding process variables to manufacture the product of the desired quality using Artificial Neural Network (ANN) method known to have high accuracy in the field of analyzing the problem of nonlinear relationship. In order to train the ANN model, the experimental plan based on the combination of orthogonal sampling and random sampling which can represent various and robust patterns with s small number of experiments was performed. According to the plan, the injection molding experiments was conducted to generate the training data and the data was separated into training data group, validation data group and test data group to optimize the structure of the ANN model and evaluate the predicting performance. First, the Multiple Input Single Output (MISO) model in which the output is the mass of the injection molded product predicted the process variables that satisfies the target mass. Second, Multiple Input Multiple Output (MIMO) model predicted 8 process variables to manufacture the specific x, y, z dimensional length of the LEGO shaped product. The predicted process variables were applied to the injection molding machine to validate the predicting accuracy of the ANN model. As a results, it was confirmed that the length of the products all satisfy the dimensional tolerance of polypropylene products.

Keywords: Injection Molding; Part Quality; Artificial Neural Network; Multiple Input Single Output (MISO) Model; Multiple Input Multiple Output (MIMO) Model

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Real-Time On-Device Vision on Embedded NPUs: Lightweight Deployment of Object Detection and Semantic Segmentation Models

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This study aims to enable real-time crack detection at the edge by leveraging on-device AI NPUs and deploying both object detection and semantic segmentation models on embedded hardware. Two edge AI platforms were evaluated: DeepX DX-M1 and Rockchip RK3588, with an RTX 3060 ONNX environment used as a baseline for accuracy and performance comparison. YOLOv8L was adopted for crack object detection, trained using a crack dataset provided by the Roboflow platform to ensure robust recognition of crack patterns across diverse surfaces. For pixel-level crack segmentation, BiseNetV2 was employed and trained on the CrackSeg9k dataset from Harvard Dataverse to achieve fine-grained crack boundary extraction. Experimental results demonstrated that YOLOv8L achieved an mAP@0.5 of 0.9285 on ONNX, while DX-M1 and RK3588 recorded 0.9061 and 0.9065 respectively, indicating less than a 2 percent accuracy reduction after NPU deployment and model optimization. In terms of inference speed, DX-M1 achieved approximately 29.9 FPS, validating its suitability for real-time deployment. For BiseNetV2, the ONNX mIoU was 0.8003, with DX-M1 and RK3588 reaching 0.7995 and 0.7942. Segmentation speed also remained practical for edge deployment, achieving 27.5 FPS on DX-M1 and 34.2 FPS on RK3588. These results confirm that both crack detection and segmentation models can maintain high accuracy on embedded NPUs while achieving real-time or near-real-time performance. Furthermore, the successful on-device execution of both tasks demonstrates the feasibility of constructing a fully integrated edge-based crack inspection system without reliance on cloud computing.

Keywords: On-device Artificial Intelligence; Machine Vision; Neural Processing Unit (NPU); Model Quantization; Edge Computing

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On-Device Sleep Stage Classification on the RK3588 NPU Using Quantized EfficientNet for Edge AI Applications

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This study presents an on-device sleep stage classification model implemented on the Rockchip RK3588 Neural Processing Unit (NPU) to enable real-time, power-efficient, and privacy-preserving sleep monitoring without reliance on cloud computation. The objective of this research is to evaluate the feasibility of deploying a deep learning model for three-class sleep stage recognition—Wake, REM, and NREM—directly on embedded hardware. The proposed model is based on EfficientNet-B0 and was converted from the ONNX format to the RKNN format using RKNN-Toolkit2 v2.3.2. To enhance inference efficiency, INT8 quantization was applied using the Minimum Mean Square Error (MMSE) algorithm. Experiments were conducted on an RK3588 board running Buildroot Linux 5.10, and inference performance was compared between FP32 and INT8 models. The quantized INT8 model achieved an overall accuracy of 75.2%, with class-wise accuracies of 77.2% for Wake, 51.7% for REM, and 96.6% for NREM. Despite a negligible 0.2% accuracy loss compared with the FP32 baseline, the quantized model exhibited a 42% reduction in model size and was approximately 1.8 times faster in inference speed. These results demonstrate that the RK3588's NPU can effectively perform multi-class sleep stage classification with low latency and high computational efficiency. The findings highlight the strong potential of integrating on-device artificial intelligence into next-generation wearable and standalone medical systems for continuous, real-time sleep monitoring and personalized healthcare applications.

Keywords: On-device Artificial Intelligence; Sleep Stage Classification; Neural Processing Unit (NPU); Model Quantization; Edge Computing

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Digitization and Content Refinement of Engineering Documents

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Engineering documents encapsulate critical information across diverse domains and are often written in descriptive form to facilitate understanding by engineers, contractors, and other stakeholders. Owing to their unstructured nature and considerable volume, identifying relevant information from such documents is costly and inefficient. While parsing techniques for extracting text from unstructured PDF documents have been widely studied, their direct application to engineering documents is limited. Revisions introduced during project execution are typically embedded through annotations or strikethroughs, resulting in redundant text and diverse formal expressions. Moreover, the inherent structural complexity of engineering documents often leads to distortion of document hierarchy and inaccurate element matching when conventional parsing methods are applied.

To address these limitations, this study proposes a methodology that utilizes XML specifications to represent user-defined structural features of documents as a basis for text extraction. The method independently recognizes text, tables, and strikethroughs, integrates them in document order, and removes extraneous elements such as strikethroughs and company names, thereby generating refined digital text. Through this approach, users can obtain cleaned and structured text simply by defining the document structure in advance. The approach was validated using three control narrative documents with distinct structures and expression styles, demonstrating robustness across heterogeneous document types. This work contributes to the efficient management of engineering documents and provides a foundation for subsequent research on information extraction with language models.

Keywords: Digitization; Engineering Document; Unstructured Document; Parsing

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Detection of Unrecognized Objects in Engineering Drawings

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Piping and Instrument Diagrams (P&IDs) represent equipment and control system connections within plants. Due to the characteristics of the plant industry, P&IDs often exist as unstructured paper documents, which leads to inefficiencies in maintenance and operation management. To address this issue, many studies have focused on the digitization of P&IDs. Among them, object recognition based on deep learning is widely used to convert graphical information into digital form. However, this process inevitably involves unrecognized objects and recognition errors. Thus, manual correction by human experts is required to achieve a complete digital representation, which is time-consuming and prone to human errors. To mitigate this limitation, this study proposes a human-in-the-loop (HITL) method that assists manual correction by detecting unrecognized objects. The proposed approach first divides the entire P&ID into patches of fixed size, followed by preprocessing. Since objects within symbols may be hidden in these patches, additional patches focusing on composite symbols are generated. These patches are then fed into a classification-based deep learning model to determine whether they contain unrecognized objects. Patches predicted to include such objects are filtered and presented to the user for review. Experimental evaluation using three P&ID drawings achieved a recall of 100%, successfully detecting all unrecognized objects within the patches. Furthermore, by integrating the proposed detection method with a HITL-based support tool, the time required for object detection and correction was reduced by approximately 50%.

Keywords: P&IDs; Deep Learning; Digitization; Unrecognized Objects

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Robot Pushing and Grasping Learning in Dense Environments Using Harris Corner Detection-Based Corner Masks

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To enable a robot to stably grasp objects without collision in a dense environment, space must be secured for the gripper to access. To achieve this, a pushing action must be performed to separate closely packed objects and create space. Selecting an appropriate pushing point is necessary to efficiently separate objects. Accordingly, this study proposes a corner mask pushing method that predicts the optimal pushing point based on Harris Corner Detection to improve robot operation success rate and efficiency. It also proposes a center mask-based reward function to determine whether an object has been separated, thereby judging the success of the pushing action. The proposed method was tested in both simulation environments and complex real-world settings. Experimental results demonstrated improvements of approximately 20% or more compared to existing studies in task completion rate, grasping success rate, and action efficiency.

Keywords: Deep Reinforcement Learning; Robot Arm Control; Pushing; Grasping

Acknowledgement: This work was supported by the National Research Foundation(NRF), South Korea, under project BK21 FOUR (Smart Robot Convergence and Application Education Research Center).

A Study on the Automation Model of Food Service Facilities Using Digital Twin-Based Cooking Simulation

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Food service facilities performing mass cooking—such as those in educational, industrial, military, and medical institutions—are confronted with numerous challenges. These include critical shortages of cooking personnel, high industrial accident rates, inefficient cooking processes, food safety vulnerabilities, high energy consumption, and extended waiting times. As a solution, cooking automation technology is gaining prominence, with smart cooking systems utilizing digital twin technology emerging as a highly effective approach. A digital twin framework allows for the real-time monitoring and simulation of the cooking process, which is critical for maximizing operational efficiency, ensuring consistent food quality, and improving safety. Furthermore, the integration of cooking robots and automated devices aims to reduce the physical burden on staff, optimize energy usage, prevent industrial accidents, lower operating costs, and enhance service quality. In this study, we model the mass cooking process based on a digital twin. By utilizing cooking simulations, we propose a method for automating and optimizing this process. This study is expected to contribute significantly to the adoption of smart cooking systems and the development of future operational strategies for mass cooking environments.

Keywords: Food Tech; Digital Twin; Foodservice Industry; Cooking Robot; Cooking Automation

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Robot-Based Preprocessing Framework for Automated Inspection and Repair of CFRP Structures

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Carbon fiber reinforced polymer (CFRP) is widely used in aerospace and future mobility because of its high specific strength and low weight. However, its laminated structure makes it vulnerable to internal delamination and impact damage, requiring reliable nondestructive inspection and accurate repair. The tap test is simple, but manual tapping depends on operator skill and angle, which reduces repeatability and accuracy on complex surfaces. Existing CFRP repair research has also focused mainly on flat specimens, limiting applicability to real components with curved shapes. To overcome these issues, this study proposes a robot-based preprocessing framework that integrates surface scanning, tap-test inspection, and damage-site drilling for CFRP repair. The 3D scanning process digitalizes complex geometries and generates robot trajectories that maintain consistent contact conditions. A robotic tap-test system enables automated tapping and stable signal acquisition, allowing reliable defect detection regardless of curvature. Finally, a robot-assisted drilling module creates resin-inlet and vent holes for resin-injection repair, and posture optimization improves stiffness and reduces vibration-induced secondary defects. This framework shows the feasibility of using industrial robots for automated preprocessing of CFRP repairs on complex structures and provides a basis for future autonomous composite repair systems.

Keywords: CFRP; Surface Scanning; Tap Test; Drilling Process

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AI-Based Intelligent Digital Machining System for Titanium Alloy Using Smartphone Sensor

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This study proposes a fully integrated smartphone-centric intelligent manufacturing framework that unifies mobile sensing, cloud-based data streaming, digital-twin simulation, and AI-driven tool-wear prediction. The system utilizes built-in smartphone sensors—such as accelerometers, audio, and vibration signals—to acquire multi-modal machining data during milling operations. These signals are transmitted in real time through an MQTT messaging protocol and stored in an InfluxDB time-series database, enabling high-resolution, low-latency data collection without the need for expensive industrial sensors. A Unity-based digital-twin environment is developed to visualize the machining process, tool–workpiece interaction, and material removal behaviors. The digital twin continuously synchronizes with real machining data, allowing users to observe dynamic machining states through a mobile-connected interface. Furthermore, a deep-learning model, including a multi-scale convolutional architecture, is trained to predict tool wear from smartphone-acquired signals, capturing nonlinear temporal–spectral patterns. Experimental results demonstrate that the proposed framework provides accurate tool-wear estimation and reliable state monitoring. This approach introduces a practical paradigm in smart manufacturing where data acquisition, monitoring, and AI inference are performed.

Keywords: Artificial Intelligence; Digital Twin; Deep Learning; Tool Wear; Smartphone Sensor

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Physical AI-Driven Smart Gripper System for Adaptive Bin-Picking of Irregular Objects in Autonomous Manufacturing

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The application of AI in manufacturing is emerging as an effective solution to labor shortages and the growing demand for higher productivity. This paradigm integrates AI and robotics to minimize human intervention and ultimately enable fully unmanned production environments. Traditional automation systems perform predefined repetitive tasks; however, in scenarios involving small-batch, multi-variety production or non-uniform products, process complexity increases and bottlenecks arise, making worker involvement unavoidable. Conventional robotic automation systems also face limitations in handling irregular items. For example, robots struggle with "bin-picking" tasks, where products on conveyors vary in position and orientation which reduce gripping performance. To address these issues, a smart robotic gripper is developed to change bin-picking coordinates such as X,Y,Z and delta by applying Hexapod Platform structure using 3 linear actuator. In addition, a 3D depth camera and ICT sensors such as IMU and pneumatic sensors are attached on smart gripper. These devices capture the object's three-dimensional position, surface orientation, and physical characteristics of smart gripper status, enabling an AI model to determine grasp feasibility and automatically adjust the gripper structure by controlling PWM value of linear actuator and position of servo motor in real time. This approach provides significant technical value by allowing robots to locate and grasp items without modifying pre-defined motion trajectories. Finally, an AI-based smart gripper combining 3D depth and ICT sensors was developed for incasing and de-packaging tasks involving irregular objects. Compared to manual operations in flexible, small-batch packaging processes, the technology improves work efficiency by 18% and productivity by 23%.

Keywords: Physical AI; Smart Robot Gripper; IoT Sensor; 3-Axis Hexapod Platform; Deep Learning

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Digital Twin–Based Robotic Automation and Performance Evaluation for Meal-Kit Packaging Processes

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The meal-kit packaging process requires the highest labor input among the manufacturing stages, highlighting the need for advanced automation solutions. This study aims to develop a detailed 3D simulation model of the primary packaging inspection and box-incasing process and to evaluate the key performance indicators (KPIs) associated with robotic automation. Using high-resolution 3D scanning, the existing production environment was digitized to create accurate models of the facility layout, equipment, and workflow. Based on these models, two robot-based automation scenarios—one using a single SCARA robot and the other using an industrial articulated robot—were constructed and analyzed. The simulation included all major sub-processes such as tray feeding, desiccant insertion, powder and noodle supply, product alignment, and automated pick-and-place operations for carton loading. The baseline manual scenario revealed consistently high worker utilization levels, suggesting significant physical workload and fatigue accumulation, with a throughput of 2,012 units per hour. In contrast, the SCARA-based automation scenario produced a cycle time of 2.36 seconds and a throughput of 1,894 units per hour, indicating a reduction in productivity relative to manual operations. The industrial robot scenario demonstrated the most substantial improvement, achieving a reduced cycle time of 1.42 seconds and an increased throughput of 2,493 units per hour. These findings confirm that industrial robotic automation offers clear productivity advantages compared to both manual processes and SCARA-based automation. The study provides quantitative evidence supporting the feasibility, benefits, and expected performance gains of implementing industrial robots in meal-kit packaging operations.

Keywords: Meal-kit Packaging; Robotic Automation; 3D Simulation; Industrial Robot; Productivity Analysis

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A Study on the Application of a Multivariate Data-Based LSTM-Attention-VAE Model for Anomaly Detection in Ion Piston Hydrogen Compressors

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This paper proposes an unsupervised anomaly-detection framework for an ionic piston hydrogen compressor based on a multivariate LSTM-Attention-VAE model. The compressor uses an ionic-liquid piston driven hydraulically to compress highly flammable hydrogen gas, so early fault detection is essential for safety and predictive maintenance. The monitoring system acquires pressure, temperature, flow-rate, current, and voltage signals via Serial, MQTT, and Modbus-TCP at 7 Hz and streams them to a central server for preprocessing and real-time analysis. The model is trained only on normal operating data. Sliding windows of 20 samples are first encoded by LSTM layers to capture temporal evolution and cross-channel dependencies. A multi-head attention block then focuses on informative time steps and inter-sensor interactions, producing a compact latent distribution. A VAE decoder reconstructs the original window, and the reconstruction error is converted into a composite anomaly score. To evaluate performance, artificial anomalies are injected into four sensor channels around window 100,000 using a Westgard-rule strategy on long multivariate records (about 25,000–400,000 samples per hour). The proposed method accurately reconstructs normal periodic patterns, preserves sharp transients, and reveals meaningful correlations among sensors. During anomaly periods, the composite score rises sharply and crosses both static and adaptive dynamic thresholds, enabling precise localization with high sensitivity and few false alarms by excluding warm-up noise and adapting to recent trends. The authors plan to integrate this framework into an online monitoring platform for safer, more reliable hydrogen refueling-station operation in real industrial environments.

Keywords: Hydroge; Compressor; Anomaly Detection; LSTM Autoencoder

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Thermal Anomaly Detection for Hydraulic Components Using Image Motion Compensation and One-Class SVM

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Thermal imaging is a practical tool for noncontact and nondestructive fault diagnosis in construction machinery. The need for rapid assessment and improved maintenance efficiency has increased the demand for such techniques. However, real operating environments often limit camera placement, and operators frequently rely on handheld infrared imaging. This introduces camera shake and frame instability, which must be corrected for reliable thermal analysis. This study proposes an anomaly detection framework that stabilizes handheld infrared video and analyzes thermal behavior in hydraulic components. Thermal images of pumps, valves, and radiators were acquired under normal operating conditions. A frame alignment technique was applied to compensate for minor motion between frames and ensure temporal consistency. After stabilization, the region with the highest temperature gradient was identified as the region of interest. From this area, statistical temperature features were extracted, including maximum, minimum, and mean temperature, along with skewness and kurtosis. These features were used as inputs to a One-Class Support Vector Machine (OC-SVM). The model was trained exclusively on normal data to construct a decision boundary for detecting abnormal thermal patterns. The proposed method effectively corrected motion artifacts from handheld imaging and enabled consistent extraction of region of interest guided features. As a result, the framework confirmed effective anomaly detection using a model trained solely on normal-state thermal data. Future work will focus on achieving consistent performance across excavator models with different manufacturers and specifications to improve applicability in actual operating environments.

Keywords: Thermal Imaging; Hydraulic Systems; Frame Alignment; Anomaly Detection; One-Class SVM

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Real-Time Multi-Robot WAAM of Dissimilar Metal Via a Virtual Environment Platform

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Wire Arc Additive Manufacturing (WAAM) is a metal deposition technique that employs an arc heat source to melt and solidify metal wire in a layer-by-layer process, making it suitable for producing large components. This approach is especially relevant to aerospace, nuclear, and defense industries, where components must endure extreme thermal and mechanical conditions. However, applying high-performance materials uniformly across an entire part can lead to excessive performance in low-stress regions, reducing manufacturing efficiency and increasing costs. As a solution, this study explores dissimilar metal WAAM using multi-robot control. Industrial environments often utilize heterogeneous robots from different manufacturers, introducing challenges due to variations in coordinate systems, control languages, and software platforms. We developed a real-time, virtual environment-based integrated robot control platform using RoboDK to synchronize heterogeneous robots, detect collisions in advance, and directly apply virtual robot motions to physical robots. Using this platform, dissimilar metal beads were fabricated by precisely controlling the wire distance between Inconel 718 and STS 316L. To assess the effect of inter-wire spacing, Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) were used to analyze microstructures and Nb distribution at the dissimilar metal interface, addressing issues related to abrupt material transitions.

Keywords: WAAM; Dissimilar Metal; GMAW; Virtual Environment

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A Basic Study on CNN-Based Anomaly Detection Using Infrared Thermography in Directed Energy Deposition

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Directed energy deposition (DED) is an additive manufacturing process used for localized repair and dissimilar-materials deposition, in which a focused high-power heat source melts and deposits metal powder delivered at a controlled feed rate. Heat input variations directly affect the thermal history, inducing temperature gradients and thermal non-uniformity. Such thermal non-uniformity causes defects such as microstructural heterogeneity, porosity, and cracking, compromising build quality and reliability. Hence, real-time monitoring for anomaly identification is important in DED. This study presents a basic feasibility investigation of CNN-based anomaly detection using infrared (IR) thermography. To develop and evaluate the proposed approach, an off-axis monitoring system was employed to acquire IR thermal images during deposition. The acquired images were classified into three heat input conditions—insufficient, nominal, and excessive—based on the applied energy input. A YOLO-based CNN detector was trained using the labeled dataset. The performance of the trained model was evaluated using precision, recall, and detection accuracy. From the test results, the developed system achieved a detection accuracy exceeding 90%, demonstrating the ability to identify non-nominal heat-input conditions. These findings support the feasibility of the proposed CNN-based approach as a foundation for online monitoring and quality assurance in DED.

Keywords: Additive Manufacturing; Directed Energy Deposition; In-situ Monitoring; Anomaly Detection; Infrared Thermography

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High-Pressure, High-Density Powder Spreading Method for Refractory Metal Additive Manufacturing

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Materials such as tungsten, molybdenum, and tantalum, possessing melting points exceeding 2,400°C, are classified as refractory metals. They are generally processed into products by producing ingots through metallurgical methods, followed by machining. Therefore, exclusively depending on subtractive processes posed constraints in design and manufacturing, and numerous research initiatives are underway to address these limitations through additive manufacturing techniques. However, because the melting point exceeds both room temperature and cost-effective heating ranges, employing additive manufacturing techniques such as L-PBF leads to the formation of a melt pool. Even when a melt pool is established, issues such as cracking or porosity persist due to rapid temperature fluctuations during fusion with the base material following melting. In this investigation, a powder metallurgy approach was employed at the powder deposition region of L-PBF to establish a layered manufacturing process for materials with high melting points. We will demonstrate through experimental results and sample manufacturing that by compressing metal powder to decrease the gaps between particles, we can reduce cooling shrinkage and address issues related to rapid cooling by minimizing interparticle gaps to the greatest extent possible.

Keywords: Refractory Metals; Additive Manufacturing; Tungsten 3D Printing; Hybrid Manufacturing; L-PBF

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Study on Breakaway Support for Polyetheretherketone in High-Temperature Material Extrusion

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Material extrusion (MEX) of high-performance polymers such as polyetheretherketone (PEEK) presents challenges due to high processing temperatures reaching approximately 450°C, which precludes the use of common soluble supports. This study aims to identify an optimal breakaway support material that provides stable support without adhering too strongly. Using the MEX, polyarylate (PAR), polysulfone (PSU), and a high-temperature polycarbonate (PC) are evaluated as candidate breakaway support materials for PEEK. The industry-standard combination of ULTEM and its dedicated Support is established as the control group for comparison. Interfacial adhesion is quantified by measuring the breakaway force, and support performance is visually assessed. The results showed that the high-temperature PC lacked sufficient thermal stability. PSU exhibited an excessive breakaway force of 1135 N, indicating a high probability of part damage during removal. In contrast, PAR demonstrated excellent thermal stability and a low breakaway force of 297 N, comparable to the industry-standard ULTEM/Support combination of 314 N. This indicates that PAR achieves an optimal balance between stable support and ease of removal, suggesting it is an ideal breakaway support material for PEEK-MEX.

Keywords: Material Extrusion; Polyetheretherketone; Polyarylate; Breakaway; Support

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In-situ Control of Melt Pool Temperature for Material Properties Characterization in Customized DED System

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In Directed Energy Deposition (DED), thermal accumulation significantly affects microstructure homogeneity and geometric accuracy. Commercial systems often lack the open architecture required to implement high-frequency custom feedback loops. This study presents a real-time closed-loop control strategy implemented on "ALOHA-DED," a customized open-source DED platform. The objective is to stabilize the manufacturing process by maintaining a constant melt pool temperature despite changes in heat dissipation. The experimental setup integrates a 1500W Raycus fiber laser with a Dynomotion KFLOP controller, which executes the control logic. A SWIFT 350 FO PL pyrometer serves as the primary feedback sensor, monitoring melt pool temperatures within the 350°C to 3500°C range. The methodology involves reading the pyrometer's analog signal directly into the motion controller, where a custom C-language algorithm dynamically modulates the laser power output to compensate for thermal deviations. Comparative tests between open-loop and closed-loop deposition of thin-wall structures demonstrate that this control framework effectively mitigates heat buildup. The results indicate improved consistency in layer width and height, validating the use of accessible, open-source hardware for advanced thermal control in additive manufacturing.

Keywords: Closed-loop Control; Melt Pool Monitoring; Directed Energy Deposition(DED); Pyrometer Feedback; Process Stability

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Simulation of HDPE Particle in a Single-Screw Extrusion Process

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This study proposes a simulation method centered on the coupled computational fluid dynamics and discrete element method (CFD-DEM) to address the lack of systematic analysis on the impact of recycled high-density polyethylene (HDPE) particle characteristics on 3D printing filament production through a single-screw extrusion process. The mechanical properties of recycled HDPE particles, including size distribution, shape, and density were inputted as for the CFD-DEM simulation. The discrete element method (DEM) module first simulates particle motion, collision, granular heat transfer, and melting processes in processing equipment, then statistically analyzes furnace data to generate mass and energy source terms reflecting melting behavior. These source terms are transmitted to the computational fluid dynamics (CFD) module, which solves governing equations to simulate complex melt flow, extracts eigenvalues of key field variables, and realizes seamless simulation from solid particle transport to molten flow. Particle sizes ranging from 0.5 mm to 1.0 mm show the optimal melt homogeneity, stable extrusion, and the highest interlayer bonding strength. This flow-based simulation method effectively reveals the intrinsic link between particle size and printing performance, reducing reliance on traditional trial-and-error experiments, and provides technical support for the high-value application of recycled plastics in additive manufacturing.

Keywords: Recycled High-density Polyethylene; Particle Size; 3D Printing; Computer Simulation; Mechanical Performance

A Study on the Effects of Manufacture of CNT Coated TPMS Filters on EMI Shielding Performance Using Electromagnetic Analysis

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This study investigates the EMI (Electromagnetic Interference) shielding performance of CNT (Carbon Nanotube)-coated filters designed with various TPMS (Triply Periodic Minimal Surface) structures. Diamond, Gyroid, and Primitive geometries were modeled and converted into specimen forms compatible with the Coaxial Transmission Line Method. To enhance electrical conductivity and improve shielding characteristics, a CNT coating layer was applied to the surface of each TPMS-based filter. Electromagnetic behavior within the 30 MHz–1.5 GHz frequency range was analyzed using simulated S-parameters (S_{11}, S_{21}), from which reflection loss (SE_R), absorption loss (SE_A), and total shielding effectiveness (SE_T) were derived. The results indicate that both the intrinsic geometric complexity of TPMS structures and the conductive CNT coating significantly influence the attenuation mechanisms. Structures with more continuous internal pathways and enhanced surface conductivity promoted stronger multiple reflections and energy dissipation, resulting in improved shielding efficiency. This work highlights the combined impact of TPMS geometry and CNT coating on EMI shielding performance, providing design guidelines for next-generation lightweight and high-efficiency shielding materials.

Keywords: EMI Shielding; Carbon Nanotube; Filter; Triply Periodic Minimal Surface

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Effect of Warm Isostatic Press Process on Additive-Manufactured Parts in Binder Jetting and Powder Bed Fusion

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Due to the inherently deposition mechanism of the additive manufacturing (AM) process, the parts fabricated by powder-based polymer AM exhibit significant porosity. This study investigates the effect of warm isostatic press (WIP) post-processing on parts fabricated by two distinct powder-based polymer additive manufacturing (AM) methods/ materials: binder jetting (BJT)/polymethylmethacrylate (PMMA) and powder bed fusion (PBF)/ polyamide 12 (PA12). By applying heat and pressure together via a WIP process, we directly compared the resulting enhancement in mechanical performance. The results showed a dramatically differential effect: the high-porosity BJT parts exhibited an increase in ultimate tensile strength, ranging from 411% to 568%. In contrast, the already highly dense PBF parts showed lower relative improvement (2% to 5%). Air gaps analysis confirmed that the combined effect of heat and pressure during the WIP process effectively eliminated the air gaps. This study suggests that WIP is an essential strategy for dramatically improving the performance of low-density AM processes, particularly for highly porous materials like BJT.

Keywords: Warm Isostatic Press(WIP); Binder Jetting; Powder Bed Fusion; Air Gaps; Ultimate Tensile Strength

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Development of a Lightweight Lattice Structure via Material Extrusion

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In the automotive and aerospace industries, structural weight reduction has become critical for improving fuel efficiency and reducing carbon emissions. However, achieving a lightweight design while maintaining structural strength remains challenging. This study develops a novel lattice structure and exhibits superior specific strength at equivalent relative density. A new lattice structure is designed based on structural mechanics principles to implement efficient load transfer paths. The structure is fabricated using material extrusion-based additive manufacturing, and the influence of process parameters on structural quality is analyzed. Compression tests are conducted on fabricated specimens to evaluate mechanical performance, and the structure is compared with conventional lattice structures. Results demonstrate that the developed lattice structure exhibits superior lightweight and high-strength characteristics compared to conventional lattice structures. This study suggests that the lattice structure developed can be effectively applied in structural components where the strength-to-weight ratio is critical across various engineering fields.

Keywords: Lattice Structure; Lightweight; Additive Manufacturing; Material Extrusion

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Characterization for Anisotropy of the Developed Polymers in Material Extrusion

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This study establishes the optimal processing conditions for a newly developed polymer material and investigates its anisotropic behavior in material extrusion (MEX)-based additive manufacturing. Chamber temperatures of 40–150 °C and nozzle temperatures of 230–300 °C are evaluated, focusing on warpage, surface roughness, and tensile properties in longitudinal and transverse directions. When the chamber temperature exceeded 100 °C, specimen warpage significantly decreased. The optimal nozzle temperature range of 260–270 °C resulted in minimal surface roughness (R_a: 2.65–2.78 μm), outperforming commercial polycarbonate (Ra: 9.57 μm) and ABS (9.07 μm), respectively, indicating superior surface quality and enhanced bonding. Mechanical testing showed that the developed material reached 56.24 MPa for longitudinal and 34.78 MPa for transverse at 270 °C, respectively, yielding a strength ratio of 61.84%, higher than PC (45.95%) and ABS (45.08%). Overall, we established the optimal MEX process for a new polymer. Furthermore, the developed polymer led to enhanced bonding between layers. This study provides important information that new materials can solve the issue regarding anisotropy if an optimal process is established in MEX.

Keywords: Additive Manufacturing; Material Extrusion; Anisotropy; Surface Roughness; Tensile Strength

Acknowledgement: This work was supported by the KITECH internal project (EH250006, Development of 3D printing commercialization technology for military parts and demonstration support technology) and the Industrial Technology Innovation Program funded By the Ministry of Trade, Industry & Energy (KM250130, Development of 3D printing digital transformation platform technology based on process metadata)

Evaluation for Environmental Reliability of Material-Extruded Parts in Additive Manufacturing

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To apply material-extruded (MEXed) parts in the aerospace and automotive industries, it is essential to evaluate their mechanical performance under harsh environmental conditions. This study evaluates the environmental reliability of MEXed specimens by focusing on their mechanical performance after exposure to thermal shock and high temperature/humidity conditions. Bio polycarbonate (PC), fossil PC, and acrylonitrile butadiene styrene are MEXed in both longitudinal and transverse directions and are carried out on environmental reliability tests. Tensile testing is performed before and after environmental reliability testing to evaluate mechanical property changes. All specimens exhibit improved tensile strength after environmental testing, which is attributed to polymer chain rearrangement and enhanced interlayer fusion caused by heat. Optical microscopy analysis revealed that the air gaps initially formed between layers before testing disappeared after environmental exposure, resulting in a denser and smoother internal structure. These findings indicate that specimens fabricated using polymer materials through material extrusion can maintain or even improve mechanical reliability under harsh environments.

Keywords: Material Extrusion; Environmental Reliability; Thermal Shock Test; High Temperature and Humidity Test

Acknowledgement: This work was supported by the KITECH internal project (EH250006, Development of 3D printing commercialization technology for military parts and demonstration support technology) and the Industrial Technology Innovation Program funded By the Ministry of Trade, Industry & Energy (KM250130, Development of 3D printing digital transformation platform technology based on process metadata).

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Thermoresponsive 4D Printing of Stretchable Wrist Guard with Re-Entrant Cellular Structures

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4D printing enables the design of structures that can change their shape and/or function in response to external stimuli. This study aims to develop a thermoresponsive 4D-printed wrist guard from a shape-memory polymer, featuring a programmable re-entrant cellular structure. A polyurethane-based shape-memory polymer was used for hot programming and 4D recovery to improve portability and repeatability. Both numerical and experimental investigations show that the re-entrant structure provides a greatly higher stretchability and recovery, due to its bending-dominated mode of deformation, than those of the square and circular-hole porous shells. In the initial configuration, the wrist guard was a planar sheet that was thermomechanically programmed into the custom 3D wrist shape by stretching and bending. When the wrist guard was heated to 60 °C for 10 s, it returned to its compact 2D shape, with a recovery ratio above 97% across multiple programming cycles. Infrared thermographic images show the ability to complete the hot-programming step at a low surface temperature that is not harmful to human contact within a 15-second time limit, demonstrating thermoresponsive 4D printing with a re-entrant cellular SMP structure as lightweight, portable, and reusable personal protective equipment with rapid, reversible changing capabilities.

Keywords: 4D Printing; Shape Memory Polymer; Re-entrant Structures; Auxetic Metamaterials; Wearable Wrist Guard

Acknowledgement: This research was financially supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (Grant no.: RS-2024-00333936 and RS-2025-00512549).

Fabrication and Heat-Transfer Characteristics of Cu–H13 Hybrid Cooling Channel Fabricated by Using DED Process

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Thermoplastic polymeric products are widely used in everyday life, and the quality of molded parts is largely governed by the cooling performance of the mold. In this study, a hybrid cooling channel was fabricated by embedding a high-thermal-conductivity Cu tube into an H13 mold block, followed by directed energy deposition (DED) of H13 powder on the surface. This method aims to combine the superior thermal conductivity of Cu with the high mechanical strength and wear resistance of H13 tool steel. However, the difference in thermal expansion coefficients between Cu and H13 often causes solidification cracking and interfacial delamination during deposition. To improve interfacial compatibility between Cu and H13, intermediate layers—P21 tool steel and stainless steel 316L—were introduced. Finite element analysis was performed to optimize the press-fit groove dimensions to prevent tube buckling during DED. Furthermore, Computational fluid dynamics analysis was performed to compare the cooling performance between the press-fitted and conventional channels. The effects of buffer layer type, preheating condition, and laser power on the interfacial bonding, dilution behavior, and microhardness distribution were systematically investigated. Experimental results revealed that the P21 buffer layer effectively mitigated interfacial stress and promoted metallurgical bonding, resulting in enhanced thermal conductivity. A cooling-water circulation test further demonstrated that the tube-embedded hybrid mold exhibited approximately 29.5% higher cooling rate than the conventional H13 mold. These findings provide a practical guideline for developing Cu–H13 hybrid channel molds with improved heat-transfer efficiency and interfacial integrity using DED-based additive manufacturing.

Keywords: Directed Energy Deposition; Cooling Channel; Thermal Conductivity; Press-fit

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Development of a Robotic-Arm-Based Additive Manufacturing System for Cooperative 3D Printing

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Robot-arm-based Cooperative 3D printing (C3DP) for large parts is limited by collisions between printers and workload imbalance across printers. Using Voronoi layer tessellation, we physically partition the workspace and, through print sequencing, generate collision-free toolpaths. Balanced cell partitioning further enables time-efficient printing. For hardware validation, we built manipulators for FDM with Dynamixel actuators, an OpenCR controller, and an Ender-3 extruder, and characterized their kinematic sensing accuracy to quantify achievable print resolution and assess hardware suitability. We built a Unity-based digital twin that mirrors UART commands to simulate and monitor a robotic arm. It currently supports process-level monitoring, and we next aim to enable dynamic planning of layer segmentation and equipment printing schedules. This study implements Voronoi cell-based layer segmentation for C3DP and validates it by executing the resulting toolpaths on a developed robotic arm, while a Unity-based digital twin monitors collision-free, balanced execution.

Keywords: Cooperative 3D Printing; Robot-based Additive Manufacturing; 3D Model Partitioning

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Study on a Wire Arc DED Hybrid Additive Manufacturing Technique Using Sand-Printed Supports for Freeform Fabrication

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Wire Arc Directed Energy Deposition (WA-DED) is a metal 3D-printing process that melts a metal wire with an arc heat source and deposits it layer by layer. Compared with powder-based methods, it offers higher deposition rates and the simplicity of wire feeding, making it particularly advantageous for fabricating large structures. Because WA-DED adds only the required volume rather than removing bulk material as in subtractive machining, it minimizes material loss and improves process efficiency, while toolpath design affords geometric freedom and design flexibility. However, in low-angle inclined regions and internal hollow sections, gravity-induced bead sagging and shape collapse can occur, complicating process control. To address these limitations, this study proposes a hybrid WA-DED process that integrates sand-printing-based supports. Sand is highly refractory and can be shaped arbitrarily, enabling customized supports and guides in regions prone to sagging. Baseline experiments without supports, using torch angle and build angle as variables, revealed pronounced bead sagging at angles of approximately 40° or less. Subsequently, sand supports with varying inclinations were fabricated and the same deposition conditions were applied; stable deposition without shape collapse was verified even for low-angle overhangs. Furthermore, along arched, curved paths the target geometry was successfully achieved, and by using the sand side face as a support, the bead side surface after deposition was evaluated for waviness using a Laser Vision Sensor (LVS) and machining allowance, quantitatively confirming improvements in bead quality. The proposed process thus demonstrates the feasibility of applying free-form metal deposition to inclined and hollow structures

Keywords: Wire Arc Directed Energy Deposition; Bead Sagging; Sand Printing Support; Low-angle Overhang; Waviness

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Friction Stir Process for Thermoplastic Polyurethane Parts Fabricated by Additive Manufacturing

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This research presents the design, installation, and implementation of an FSW machine equipped with integrated load-cell instrumentation for real-time force monitoring. Experimental investigations focus on material combinations: TPU-TPU similar butt joints, PLA-TPU dissimilar butt joints, ABS-TPU dissimilar butt joints, and Al-Al similar lap joints via the FSW process. Systematic parameter optimization, considering motor frequency, traverse speed, plunge depth, and applied force analysis, has been undertaken to establish frameworks for defect-free, strength joints. Mechanical characterization included tensile and strain testing, implemented by the tensile testing machine of the weld zones. For the Al–Al lap joints, thermal and microscopic analyses were also conducted to evaluate the heat distribution, microstructural evolution, and material bonding characteristics resulting from the applied process parameters. The study concludes with an analysis of machine structural stability, identification of optimal parameter ranges for high-quality welds, and demonstration of predictive modeling capabilities. Experimental results on both similar and dissimilar thermoplastics validated the effectiveness of joint configurations under varying conditions. Collectively, these findings provide new insights into the adaptability and performance of FSW for polymers and metals, contributing significantly to both academic research and industrial applications.

Keywords: Friction Stir Welding(FSW); Polylactic Acid(PLA); Thermoplastic Polyurethane(TPU); Acrylonitrile Butadiene Styrene(ABS)

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Fabrication of Hierarchical Microstructures via FPP–Imprint Integration and Wettability Characterization by Array Geometry

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Various micro- and nano-scale structures have been widely explored to achieve surface functionalities such as hydrophobicity, adhesion control, and precise fluid manipulation. However, conventional fabrication techniques for hierarchical or reentrant structures often rely on multi-step deposition processes and complex procedures, which require high cost, long processing time, and limited material compatibility. Moreover, these methods are typically constrained to flat substrates, making implementing hierarchical architectures on curved or flexible surfaces challenging.

In this study, a novel and simplified fabrication strategy is proposed by integrating Frontal Photo Polymerization (FPP) with imprint lithography. This method takes advantage of the self-propagating polymerization front of FPP, which enables gradient curing and controllable volumetric deformation within photocurable resins, eliminating the need for additional processing or complex post-treatment. By combining this with the pattern transfer capability of imprint lithography, complex hierarchical morphologies can be generated in a single-step, mask-free, and material-independent process.

To demonstrate the feasibility of this approach, reentrant structures with a diameter of 500 μm and a pitch of 600 μm were fabricated on the final exposure layer of a Digital Light Processing (DLP) process. Films with triangular, square, and hexagonal arrays were applied to form distinct hierarchical geometries. Contact angle analysis confirmed that the surface wettability can be tuned according to the array configuration. This method provides a scalable, cost-effective, and versatile route to engineer functional surfaces for applications in microfluidics, self-cleaning systems, and adaptive materials.

Keywords: Frontal Photo Polymerization; Imprint Lithography; Hierarchical Structure; Surface Wettability; Digital Light Processing

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Emission Reduction in Diesel Generators Using CuO-Coated Ceramic and Polymer Micro-Lattice Filters

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Diesel generators emit considerable amounts of particulate matter (PM) and carbon monoxide (CO), both of which are major contributors to air pollution. Conventional emission control systems—Diesel Particulate Filters and Diesel Oxidation Catalysts—are typically based on ceramic monoliths coated with precious metals such as Pt or Rh. However, these systems face challenges including high cost, limited regeneration capability, and clogging due to PM accumulation. In this study, we investigated two complementary approaches for emission reduction: catalytic oxidation using a low-cost copper oxide (CuO) catalyst and PM filtration using polymer-based micro-lattice structures. The CuO catalyst was fabricated by dip-coating a ceramic substrate with an aqueous Cu precursor solution, followed by thermal oxidation to form an active CuO layer. When applied to a 10 kW diesel generator, the CuO-coated ceramic substrate markedly decreased CO concentration from approximately 6000 ppm to near zero. Separately, polymer micro-lattice filters with varying unit-cell sizes and strut thicknesses were fabricated via Digital Light Processing 3D printing to examine PM reduction behavior. Tests under actual diesel exhaust conditions revealed that smaller unit-cell sizes considerably improved PM removal efficiency, whereas strut thickness had minimal influence. These results suggest that combining CuO catalysis with micro-lattice filtration provides a feasible approach toward developing a ceramic-based CuO-coated lattice filter capable of simultaneously reducing CO and PM emissions in diesel generators.

Keywords: Diesel Emission Reduction; Particulate; Copper Oxide; Micro-Lattice Filter; DLP 3D Printing

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Algorithmic Prediction of Contact Tip to Work Distance (CTWD) Considering Interlayer Temperature, Current, and Voltage in Wire Arc-DED (Directed Energy Deposition)

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The Wire Arc-DED (Directed Energy Deposition) process is a metal additive manufacturing method that uses an arc as a heat source and is highly sensitive to variations in heat accumulation and input energy. These factors directly affect the uniformity of interlayer spacing and surface morphology and can be optimized through the control of CTWD (Contact Tip To Work Distance). However, maintaining a consistent interlayer height to ensure the geometric stability of deposited structures is challenging under varying welding parameters. Therefore, an algorithm capable of predicting and maintaining interlayer height is required for the application of this process to multi-layer or large-scale additive manufacturing. In this study, a machine learning–based predictive algorithm was developed to recommend the optimal CTWD by considering major process parameters that influence bead geometry, specifically heat input and interlayer temperature, in the Wire Arc-DED process. The number of deposited layers and interlayer heights were measured under each condition to construct a training dataset. Multiple linear regression analysis was conducted to identify correlations between process parameters and contact distance, enabling the model to accurately predict the CTWD required to achieve the target build height. Surface roughness parameters Ra (arithmetic average roughness) and Rz (ten-point mean roughness) were also analyzed to evaluate the correlation between process variables and surface quality. The proposed algorithm accurately predicted the optimal contact distance and effectively identified process conditions that enhance surface quality and process stability in Wire Arc-DED.

Keywords: Wire Arc-DED(Directed Energy Deposition); Contact Tip To Work Distance; Interlayer Temperature; Multiple Linear Regression; Surface Roughness

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Light-Induced Slippery Interface for Rapid Resin Infiltration in Large-Area and High-Speed Continuous DLP 3D Printing

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In DLP-based 3D printing, resin infiltration at the narrow interface strongly affects printing speed and accuracy, especially for high-viscosity resins. To overcome this limitation and to improve resin mobility and reduce adhesion, we developed a light-induced slippery organogel interface on the vat window. The surface was fabricated by mixing photocurable PDMS with silicone oil, UV-curing at 365 nm, followed by oil coating and UV grafting to stabilize the lubricant layer. This simple and rapid process provides a durable, self-replenishing slippery surface that maintains stable resin flow, offering advantages over conventional SLIPS fabrication. The performance of the developed surface was then evaluated against organogel, PDMS, and FEP under simulated DLP printing conditions. In each test, the build plate was brought into full contact with the surface and lifted at a controlled rate of 0.14 mm/s while measuring resin infiltration over a 10 mm circular area. The slippery organogel achieved the fastest infiltration time of 1.7 s, about 1.7× faster than the others (average 2.9 s), confirming superior resin replenishment. Load-cell adhesion tests showed the lowest detachment force, indicating minimal interfacial adhesion. Finally, using this slippery interface in continuous DLP printing, complex and finely detailed 3D structures were successfully fabricated. The printed parts maintained high dimensional fidelity and mechanical strength while achieving a continuous printing speed of 500 mm/h. These results demonstrate that the slippery organogel interface enables rapid resin refilling and stable layer separation, thus improving the speed and stability of DLP 3D printing.

Keywords: Organogel; Slippery Surface; Light-induced Process; Digital Light Processing

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A Study on the Effects of Layer Height and Thickness of Unit Cell for TPMS on Manufacture Characteristics Using FDM Process

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Triply periodic minimal surface (TPMS) structures possess a high surface-to-volume ratio and highly complex internal curved surfaces. These characteristics can increase the current path and promote multiple reflections of electromagnetic waves. Hence, the structure can enhance electromagnetic interference (EMI) shielding effectiveness. Due to these advantages, TPMS structures have attracted attention in the EMI shielding field. However, they face limitations in manufacturing due to their geometric complexity. TPMS structures can only be fabricated using additive manufacturing (AM) technologies, where material is deposited layer-by-layer from the substrate to form a three-dimensional shape. Among various AM processes, this study employs the fused deposition modeling (FDM) process to investigate the effects of layer height and the thickness of unit cell for TPMS on manufacturing characteristics. A FDM 3D printer was used to fabricate of the unit cell. This method involves melting a thermoplastic material and then molding it after deposition. The fabrication error was assessed through a comparative analysis of the design model and the corresponding fabrication data. Additionally, a density and dimension were examined. Based on these results, the optimal design and manufacturing parameters for TPMS structures are proposed.

Keywords: Layer Height; Thickness; Triply Periodic Minimal Surface; Manufacture Characteristics; Fused Deposition Modeling

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Multi-Layered Esophageal Scaffold via 3D Dragging Printing Technique and Peristalsis-Mimicking Bioreactor Culture

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The esophagus plays a vital role in the digestive system by transporting food from the mouth to the stomach. It is composed of distinct hierarchical layers, including a muscular layer responsible for peristalsis and a mucosal layer that protects against gastric acid. Unlike other gastrointestinal organs, the esophagus lacks a protective serosal layer, making it particularly vulnerable to injury and poor postoperative healing. These features make esophageal damage a significant clinical concern, often resulting from congenital anomalies, trauma, or malignancy. Surgical resection with reconstruction using gastric pull-up or colonic interposition remains the standard treatment for esophageal damage, although it often fails to restore native peristaltic function. As a result, patients commonly experience complications including anastomotic leakage and long-term dysphagia, ultimately reducing their quality of life. To address these limitations, in this study, we fabricated a porous, multi-layered esophageal scaffold using a three-dimensional dragging printing technique to replicate the hierarchical architecture of esophageal tissue. Decellularized extracellular matrix-based bioinks were printed between scaffold layers to provide a biocompatible environment that supports cell viability. In addition, a custom-designed bioreactor system was developed to apply cyclic mechanical stimulation mimicking esophageal peristalsis. This dynamic culture condition enhanced cellular alignment, proliferation, and tissue-specific organization of seeded esophageal cells. These findings demonstrate that replicating the esophagus's hierarchical architecture through multilayered scaffold design, combined with peristalsis-mimicking mechanical stimulation, can effectively support in vitro esophageal tissue regeneration. This integrated approach provides a potential foundation for the development of functional tissue substitutes applicable to future clinical treatments.

Keywords: Esophageal Cancer; Additive Manufacturing; Tissue Engineering; Scaffold; Bioreactor

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Development of a Novel Hybrid Composite Structure and Bioreactor to Promote Bone Regeneration in Dental Implants

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The dental implant surgery is a long-term procedure. This surgery period usually lasts 6–9 months and requires a significant amount of treatment time. Due to this, implant patients spend a lot of time and money during the treatment process. To address this issue, a novel hybrid composite structure and a hydrostatic pressure bioreactor system were developed to help promote bone regeneration. In this study, the hybrid composite structure consists of the assembly-type implant, scaffold and bioink. The scaffold is positioned in the middle of the assembly-type implant, and bioink is loaded inside the scaffold. The scaffold was fabricated using a 3D printer with medical-grade polycaprolactone. It was designed in a cylindrical shape with a dimpled surface structure to enhance the medium contact area for cell culture. The circumferential regions of the scaffold were printed with a controlled feed rate to achieve uniform pores. The bioink was fabricated to promote bone regeneration by mimicking bone composition and ratios, mixing collagen type I and nano hydroxyapatite in a weight ratio of 1:2. The developed hydrostatic pressure bioreactor system was composed of an air compressor, an air filter, a controller, and a chamber. To stimulate cell into the scaffold, a hydrostatic pressure bioreactor system was fabricated to allow a scaffold to be placed inside the chamber and subjected to compression. In vitro experiments were conducted to compare static and dynamic conditions. The results evaluated cell viability under dynamic stimulation and demonstrated a difference in cellular biological functions compared to static stimulation.

Keywords: 3D Printing; Bioreactor; Scaffold; Dental Implant

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Bending Strength Evaluation of Powder Bed Fusion Based High Refractory and Stainless Steel Dissimilar Joint

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This study investigates the bending performance of a dissimilar metal joint fabricated by a Powder Bed Fusion (PBF) additive manufacturing process, combining a high refractory 90W–Ni–Fe alloy substrate with SUS316L stainless steel. The two materials were metallurgically bonded through layer-wise fusion, forming a dense interfacial region without visible defects or delamination. Mechanical integrity was evaluated using a three-point bending test according to ASTM E855 standards. The additively manufactured specimens exhibited a maximum bending strength of approximately 595 MPa, a bending strain of 3.07 %, and a calculated toughness of 1176.7 J/mm^3. These results demonstrate that PBF technology can successfully join refractory and stainless systems while maintaining stable interfacial bonding and sufficient flexural strength. The combination of high refractory 90W–Ni–Fe alloy and SUS316L stainless steel offers a promising route for hybrid components designed for high-temperature and high-stress environments requiring both mechanical robustness and thermal stability.

Keywords: Powder Bed Fusion; Additive Manufacturing; High Refractory Alloy; Bending Strength

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A Study on Deep Learning-Based Remaining Flight Time Prediction for Autonomous Flying Drones

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Autonomous drones are being applied across various fields such as military, agriculture, and security, and their applications are increasing This autonomous flight drone is powered by a battery. Since the battery has a limited capacity for power supply, the drone also has the limited flight time. Additionally, a drone's power consumption is influenced by the environment in which it operates, its flight patterns, and the chemical properties of the batteries used. Therefore, for autonomous drones to perform missions reliably, it is crucial not only to employ traditional autonomous navigation algorithms such as SLAM, localization, and path planning, but also to accurately predict remaining flight time. However, most prior studies related to this issue indirectly estimate remaining flight time by predicting power consumption and only predict remaining flight time under specific constraints. In this paper, we propose a methodology that can directly predict flight time using only the drone's internal sensor data. The proposed method utilizes internal sensor data such as voltage and current to reflect flight patterns and battery characteristics. By applying a sliding window to the acquired internal sensor time-series data, it directly predicts remaining flight time using this as input for a deep learning model. In this study, drone operation data was acquired under various routes, flight patterns, and operational environments to validate and evaluate the proposed algorithm. The drone was operated until it landed autonomously based on its internal safety functions. The experimental results confirmed that the proposed method can reliably predict the remaining flight time.

Keywords: Deep Learning; Drone; UAV; Battery

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A Study on Stacked-GRU Transformer Model Based Hydrogen Compressor Anomaly Detection Considering Multi-Sensor Correlation

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Hydrogen compressors are a core technology for safely and efficiently transporting and storing large quantities of hydrogen. However, due to hydrogen's high flammability, abnormalities during the compression process can lead to serious accidents such as explosions and fires. To prevent such accidents proactively, anomaly detection technology within PHM (Prognostics and Health Management) is gaining attention. Anomaly detection is a core element of PHM, as it enables early recognition of system state changes and provides advance warning of potential defects. While previous approaches utilized data from a single sensor in hydrogen compressors for anomaly detection, compressor sensors influence each other closely. Therefore, anomaly detection that accounts for the correlations between sensors is necessary. Furthermore, traditional machine learning methods struggle to adequately capture complex patterns, necessitating models capable of simultaneously learning both short-term variations and long-term dependencies in time-series data. Therefore, this study employs a Stacked-GRU and Transformer hybrid model for multivariate time-series anomaly detection. The Stacked GRU, with its structure of two nested GRU layers, effectively learns short-term and local anomaly signals. Conversely, the Transformer model, utilizing a Self-Attention mechanism, learns long-term dependencies across the entire time series data and global correlations between sensors. This parallel architecture can simultaneously reflect different time scales and sensor correlations, enabling effective learning of the complex characteristics of multivariate time series data. It is expected to contribute to reducing facility maintenance costs and improving operational stability when applied to hydrogen refueling stations and PHM system construction.

Keywords: Anomaly Detection; Stacked-GRU; Transformer; Hydrogen Compressor; Correlation

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Weighted-Loss-Based Segmentation for Detecting Damage in Fish Farm Nets

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Robust visual perception is essential for marine robots operating in adverse visual conditions such as underwater turbidity, haze, and low contrast. These environmental factors weaken the boundary information between fishnets and the background, which reduces the stability of deep learning based segmentation models and complicates damage inspection using ROVs (Remotely Operated Vehicles). To overcome this limitation, this study proposes an enhancement method for underwater net segmentation that incorporates a weighted loss function into a U-Net based model. The weighted loss assigns greater learning weight to object boundary regions so that the model can maintain stable structural recognition even when edges become blurred or visually degraded. The weight map is generated using contrast enhanced images obtained from the Dark Channel Prior based dehazing algorithm, which highlights structural transitions that should receive higher emphasis during training. After segmentation, the resulting mask is analyzed using a Mesh hole Grouping based damage detection algorithm that is robust to non frontal camera angles and perspective distortion frequently observed during ROV operations. Validation on real world ROV datasets acquired under dense haze conditions demonstrated that the proposed system significantly improved damage detection performance, increasing Recall from 18.51 percent to 77.77 percent and boosting overall Accuracy from 11.9 percent to 34.34 percent. These findings confirm that weighted loss based segmentation effectively enhances underwater net boundary recognition in visually challenging environments and supports its practical applicability for reliable aquaculture monitoring.

Keywords: ROV; Underwater Segmentation; Loss Function; Fishnet; Damage Detection

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Digital Transformation and AI-Driven Anomaly Detection for WA-DED

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Wire Arc Directed Energy Deposition (WA-DED) provides high productivity for metal additive manufacturing but faces limitations in maintaining consistent quality due to complex interactions among process parameters. Digital twin technology reproduces process conditions through real-time synchronization between physical and virtual environments, enabling advanced monitoring through integrated data analysis and visualization. However, existing digital twin research in WA-DED has been limited to conceptual frameworks or simulations, with insufficient research on heterogeneous robot communication architectures required in industrial settings. Therefore, this study develops an AI-based digital twin platform for monitoring and anomaly detection in WA-DED processes. A precise kinematic model of a 6-axis industrial robot and bead visualization function were implemented, with joint angles and process parameters reflected in the virtual model through TCP/IP-based communication for heterogeneous robots. An AI-based system was implemented to realize Cognitive Digital Twin with autonomous decision-making. LSTM-Autoencoder performs anomaly detection through reconstruction error by learning temporal patterns of current and voltage signals, while YOLOv12 detects and classifies bead geometry defects in real time. Both algorithms operate within the digital twin platform, providing anomaly information through a visual interface.

Keywords: WA-DED; Digital Twin; Anomaly Detection; Real-time Monitoring

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MM-Manipulator: A Mobile Heavy-Duty Robot for Autonomous Process Automation

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Robotic manipulators are widely used to automate repetitive and labor-intensive tasks. However, many existing mobile manipulators are built with lightweight arms for light-duty work, which inherently limits their performance. This study proposes a medium- to heavy-load mobile manipulator to overcome these limitations for applications in autonomous robot-based process automation. The system integrates a jib-crane structure with an upper-limb mechanism to achieve high payload capacity, an expanded workspace, and excellent manipulability. It is optimized to ensure structural robustness for heavy-duty tasks while maintaining weight compatibility with mobile platforms. As a result, the developed mobile manipulator provides a maximum reach of 2,900 mm, a payload of approximately 50 kg, and position repeatability within ±0.1479 mm. Its weight is reduced by 32.7 percent compared with conventional medium- to heavy-load manipulators. For concept validation, the system was mounted on a mobile platform model and successfully executed autonomous object recognition and pick-and-place tasks using hierarchical visual servoing and a collision-free path-planning algorithm. These results suggest that the proposed mobile manipulator is a practical and field-deployable solution for next-generation industrial automation.

Keywords: Manipulator; Mobile; High Payload; Robot-based Pick-and-place

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Robotic 3D Printing of Components on a Shape Mold

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Robotic arms are widely used in industry, especially in increasing the efficiency, accuracy and repeatability of production processes. One of the progressive areas of their use today is the integration of robots into additive manufacturing technology, which allows them to effectively replace large-volume 3D printers. In combination with specialized extruders, robotic arms can print from plastics, metals or cement mixtures, in practice primarily in the form of large-volume prints. Compared to conventional 3D printers, they offer greater flexibility, the possibility of experimental printing of non-planar layers of material and a larger working range. The paper deals with the design of the print head structure and the implementation of the production of components for a shaped mold using 3D printing technology using the ABB IRB140 robot arm. It describes the design of the print head with a detailed description of the individual parts of the hardware and software solution for the implementation of 3D printing. The result is the development of a control program for the robot in the RoboDK simulation software environment, as well as subsequent verification and implementation of 3D printing of the mold using an industrial robot.

Keywords: Robotic 3D Printing; Additive Manufacturing Technology; Industrial Robot; Print Head

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Development of an ISPH–MBD Coupled Solver for Hydrodynamic Analysis of Underwater Robots

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Accurate modeling of hydrodynamic forces is essential for analyzing underwater robot dynamics, where fluid–structure interactions play a dominant role. This study introduces a coupled framework that integrates an in-house Incompressible Smoothed Particle Hydrodynamics (ISPH) code with an Multi-Body Dynamics (MBD) code, aiming to verify its applicability for underwater motion analysis. The free-fall motion of cylindrical rigid bodies in water was selected as a representative case. The ISPH–MBD solver was applied to simulate the interaction between rigid-body motion and the surrounding fluid. For reference, additional simulations were carried out under identical conditions using RecurDyn for MBD and Particleworks, which implements the Moving Particle Simulation (MPS) method. Experimental data of cylinder free fall were also obtained for comparison. The results indicate that the ISPH–MBD coupled solver reproduces general trends in motion trajectories, velocity histories, and hydrodynamic responses, showing comparable behavior to both experimental observations and MPS-based simulations. While further refinement and validation are ongoing, these findings suggest that the developed solver can serve as a reliable computational tool for capturing nonlinear fluid–structure interactions in underwater environments. This approach provides a potential foundation for hydrodynamic analysis, design, and motion control of underwater robotic systems.

Keywords: Underwater Robot; Multi-body Dynamics(MBD); Moving Particle Simulation(MPS); Incompressible Smoothed Particle Hydrodynamics(ISPH)

Acknowledgement: This work was supported by the National Research Foundation(NRF), South Korea, under project BK21 FOUR (Smart Robot Convergence and Application Education Research Center).

Full Car Dynamics Simulation Based on KIMM-Motion

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Commercial MBD simulation programs are often inaccessible to small and medium-sized enterprises and researchers due to cost constraints. As a result, the need for freeware MBD simulation programs is growing. The Korea Institute of Machinery and Materials has developed freeware simulation programs to support the adoption of digital twin technology by small and medium-sized enterprises. In this study, KIMM-Motion, under development at the Korea Institute of Machinery and Materials, was used to establish a full car computer model, and several simulations were carried out. RecurDyn, which is a kind of commercial multibody dynamics software, is employed to evaluate the accuracy of the KIMM-Motion simulations. A bump simulation and a steering input simulation are compared with each other. It is noted that the simulation results provided by KIMM-Motion are similar to those of the commercial program, RecurDyn. This demonstrates that KIMM-Motion can address the cost issues associated with commercial programs, positioning itself as a valuable tool for various vehicle simulations.

Keywords: Vehicle Dynamics; Computer Simulation; Multibody Dynamics; Driving Performance

Acknowledgement: This research was financially supported by the Ministry of Trade, Industry, and Energy (MOTIE), Korea, under the "Virtual Engineering Platform Construction Project"(No. P0022333) supervised by the Korea Institute for Advancement of Technology (KIAT).

Speed Control for a Rotary Loaded Shaft Driven by Electric Motors via a Magneto-Rheological Clutch and Feedfoward-Feedback Controller

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This research proposes and realizes a new method to control the speed of a rotary loaded shaft driven by electric motors using a magneto-rheological clutch (MR clutch). First, the configuration of a motor speed control system using an MR clutch is proposed. The MR clutch configuration is then proposed and mathematically modeled based on the Bingham-plastic rheological model of MR fluid. An optimal design of the MR clutch is conducted to find the optimal geometric dimensions that can transmit a required torque with minimum mass. Based on the optimization results, a prototype of the MR clutch is manufactured, and its performance characteristics are experimentally investigated. A feedfoward-feedback controller is then designed to control the output speed of the system. To evaluate the effectiveness of the proposed motor speed control system, experimental results are obtained and presented with discussions.

Keywords: Magnetorheological Clutch(MRC); Speed Control; Rotary Loaded Shaft; Feedfoward-feedback Controller

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Microfabricated MOF-Integrated Hybrid Preconcentration–Separation Chip for Low-Cost Portable Gas Analysis Systems with Manufacturing Advantages

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The demand for compact and efficient volatile organic compound (VOC) analysis platforms has accelerated the development of miniaturized micro gas chromatography (μ-GC) systems. Conventional platforms typically integrate a micro gas preconcentrator (μ-PC), a μ-GC column, and a detector, where the μ-PC preconcentrates low-concentration analytes to improve sensitivity and the μ-GC separates multiple VOCs to enhance selectivity. However, using multiple discrete chips increases system size, weight, and manufacturing cost, limiting portability and broader deployment. Integrating these functions into a single microfabricated device offers a promising approach for reducing manufacturing complexity and overall production cost. In this study, we developed a MEMS-based hybrid GC chip that replaces separate μ-PC and μ-GC components. Metal–organic frameworks (MOFs), an advanced class of high-surface-area and tunable porous materials, were coated along the inner walls of a serpentine microchannel to serve simultaneously as an adsorbent for preconcentration and a stationary phase for chromatographic separation. The hybrid GC chip was fabricated using established microfabrication processes, and integrated microheaters and a resistive temperature detector enable controlled thermal desorption and stable operation. Experimental evaluation with benzene, toluene, ethylbenzene, and xylene (BTEX) demonstrated strong preconcentration capability and clear component separation. These results confirm the feasibility of unifying μ-PC and μ-GC functions within a single MEMS chip. The developed hybrid GC chip can effectively reduce system size, weight, and manufacturing cost, providing a promising core technology for portable gas-analysis applications in indoor air-quality monitoring, industrial safety, and field-deployable sensing.

Keywords: Hybrid GC Chip; Volatile Organic Compound; Metal-Organic Frameworks; Low Cost Manufacturing

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Application of Vision-Based Joint Motion Analysis Using Public Fall Data for Industrial Safety Monitoring: A Pilot Study

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This study presents a preliminary investigation aimed at preventing worker falls, one of the most frequent accidents in manufacturing environments. Utilizing publicly available fall video datasets, we quantitatively analyzed the kinematic changes of lower-limb joints during fall events. Although the demand for intelligent safety systems capable of real-time worker state monitoring is increasing in smart manufacturing environments, collecting fall data directly from actual industrial sites poses significant risks and cost-related challenges. To address this issue, this study applied an open-source, AI-based pose estimation model to extract the hip, knee, and ankle joint angles and angular velocities throughout the fall progression. Using the AI-Hub fall video dataset, frame-level joint coordinates were extracted, and characteristic patterns in pre-fall phases were identified, including abrupt changes in joint angles, collapse of knee and ankle flexion patterns, and disruption of horizontal gait rhythm. The analysis revealed recurring patterns of sudden joint acceleration and loss of balance, suggesting that these features may serve as key indicators for hazardous worker movements in industrial settings. The findings of this study provide foundational insights for developing real-time fall-prevention algorithms and can be extended to embedded monitoring systems and industrial vision sensors. By presenting joint-level motion features that objectively evaluate worker movement states, this work offers baseline data for designing digital-twin–based safety monitoring platforms in manufacturing environments.

Keywords: Fall Detection; Pose Estimation; Industrial Safety

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Experimental Investigation of Continuously Variable Transmission (CVT) Based on Differential Gear System

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This study presents the experimental validation of a novel continuously variable transmission (CVT) that utilizes a differential gear system as its core mechanism. Conventional CVTs often face limitations related to torque capacity and efficiency. The proposed design aims to overcome these by employing a controlled differential, where the speed of one input is regulated to achieve a continuous range of output speed ratios. A functional prototype was designed and fabricated to assess its practical performance. The transmission was tested under various load and speed conditions to measure key parameters such as transmission efficiency, speed ratio range, and torque response. Experimental results confirm the system's ability to provide seamless, continuous speed variation. The data demonstrates a direct correlation between the control input and the output ratio, validating the operational principle.

Keywords: Continuously Variable Transmission(CVT); Differential Gear; Transmission Efficiency; Stepless Speed Control

Flexible and Cost-Effective Maskless Fabrication of PEDOT:PSS-Based Bioelectronics and Its Application

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PEDOT:PSS, which attains wet stability through treatments such as organic solvent washing or acid processing, has emerged as a promising conductive hydrogel for bioelectronics. However, achieving high-resolution patterning while maintaining high electrical conductivity remains challenging. Existing high-resolution (<50 μm) fabrication methods typically rely on mask-based processes, which limit design flexibility and increase cost of fabrication of bioelectronics. In this work, we present a mask-free, design-flexible, and cost-effective fabrication process for PEDOT:PSS-based bioelectronics. When exposed to a 355 nm UV pulsed laser, PEDOT:PSS undergoes phase separation accompanied by PSS ablation, enabling its conversion into a wet-stable hydrogel. This approach also allows encapsulation using UV-curable polymers, while CAD-based pattern modification provides rapid and precise control over device geometry. Leveraging this rapid design-iteration capability, we successfully fabricated sensors tailored to various organ sizes and geometries, enabling stable in-vivo physiological signal acquisition. Overall, this study demonstrates a high-resolution, low-cost, and maskless laser-patterning platform for PEDOT:PSS, significantly expanding its potential as a customizable bioelectronic interface. Successful in-vivo signal acquisition further validates the practical applicability and scalability of this fabrication strategy for next-generation biointegrated electronics.

Keywords: PEDOT:PSS; Maskless; Bioelectronics; Laser Fabrication

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Modeling and Analysis of Powder Rolling Dynamics in Dry Electrode Manufacturing Using DEM

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The dry electrode manufacturing process utilizes fibrillated polytetrafluoroethylene (PTFE) as a binder to continuously calender dry mixtures of active material and conductive additive powders under high temperatures using a roll-to-roll (R2R) process, without the use of solvents. Compared to conventional wet processes, this technique simplifies the manufacturing steps, eliminates the need for costly solvent recovery systems, and offers environmental advantages by minimizing the use of hazardous solvents. However, large-scale production of dry electrodes, particularly for cathode materials, remains at an early developmental stage, and a comprehensive understanding of powder behavior during high-temperature R2R calendering is required.

In this study, numerical simulations were performed for the R2R calendering process—an essential step in dry cathode electrode fabrication—using the Discrete Element Method (DEM). The simulations incorporated the deformation characteristics of PTFE and interparticle interactions to quantitatively analyze phenomena such as non-uniformity in film formation, poor particle connectivity, uneven fiber orientation, and increased tortuosity. From these analyses, key process parameters influencing the mechanical stability and electrochemical performance of electrodes were identified, providing foundational data for optimizing the dry electrode manufacturing process.

Keywords: Cathode; Dry Electrode; Polytetrafluoroethylene(PTFE); Discrete Element Method

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Integrating Quality Control Circles with the Cheaper-Better-Faster Framework in an Automotive Manufacturing Industry

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This study examines the integration of the Cheaper-Better-Faster (CBF) operational framework with Quality Control Circle (QCC) activities to reduce product rejection rates in an automotive manufacturing sector of a developing country. The primary objective was to assess the efficacy of the combined QCC-CBF model in mitigating defects. The model was applied at a crankshaft manufacturing facility. The methodology employed a mixed-methods approach. Quantitative product rejection data were collected and compared from pre- and post-implementation phases. Concurrently, a survey was distributed to 75 manufacturing practitioners to gather qualitative insights on the intervention's impact. The results demonstrated a statistically significant positive correlation between the QCC-CBF implementation and the reduction in rejected products. In this study, the dimensional defects based on diameter of a crankshaft's component was used as the rejection criteria. This tangible quality enhancement directly translated into superior cost performance, more reliable shipping schedules, and a significant boost in employee morale. The study concludes that the synergistic integration of QCC and CBF provides a potent and replicable model for synchronizing shop-floor quality initiatives with strategic operational goals. It offers a viable pathway for manufacturing units in resource-constrained environments to achieve significant and sustainable performance enhancements.

Keywords: Quality Control Circle; Cheaper-Better-Faster; Rejection Rate; Automotive Manufacturing

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Monolithic Liquid Metal Multilayer Routing without VIAs for Ultra-Stretchable Electronics

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Stretchable electronics for wearables, soft robots, and human–machine interfaces demand interconnects that survive extreme elongation while supporting multilayer circuit layouts. When such circuits are vertically stacked, however, conventional vertical interconnection access (VIA) structures act as severe stress concentrators, so that mechanically stable conductors often fail prematurely once they are assembled into stacked architectures.

In this work, we realize a stretchable liquid-metal circuit that achieves electrical multilayer routing without relying on any vertical posts. The circuit adopts a monolithically stacked, VIA-free architecture in which all conductive paths are embedded in a single compliant body but are functionally separated along the thickness direction. This configuration is enabled by combining an eutectic liquid metal with spatially programmed surface modification, which selectively defines wetting and non-wetting regions to form overlapping conductive layers.

The resulting circuit tolerates tensile strains exceeding 1100 % with virtually no loss in stretchability compared with a single-layer liquid-metal trace, highlighting its outstanding electromechanical robustness. Furthermore, multilayer routing allows unique functionalities that exploit hidden or reconfigurable current pathways. We demonstrate encrypted signal transfer, user-selectable routing, and extendable interconnects as representative examples. The proposed VIA-free stacked liquid-metal platform provides a general route toward highly integrated, mechanically reliable soft electronic systems.

Keywords: Stretchable Electronics; Liquid Metal Interconnects; VIA-free Multilayer Circuits; Monolithic Integration; Soft Wearable Systems

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Development of Flatfoot Diagnostic Equipment through Image Processing

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The importance of body monitoring technologies to prevent musculoskeletal disorders in the active senior population is steadily increasing. Early diagnosis of flatfoot is important for preventing secondary complications. This study aimed to develop an automated image-based system to assess flatfoot progression by quantifying the resting calcaneal stance position (RCSP) angle, a clinically validated indicator strongly correlated with radiographic parameters.

Hindfoot images were acquired under standardized conditions, including fixed foot alignment, constant camera distance, and controlled lighting to ensure reproducibility. Anatomical contours necessary for RCSP calculation were extracted using the Canny edge detection algorithm. The RCSP angle was then computed as the angle between the vertical reference line and the line connecting the midpoint of the malleolar axis to the midpoint of the posterior heel.

Manually segmented images were analyzed using image-editing software and a goniometer to generate reference values for validating the automated method. In the flatfoot group, RCSP angles of −4.0° and −7.0° were observed, whereas the control group exhibited +5.9° and +7.2°, confirming the method's ability to distinguish normal and pronated hindfoot alignment. The automated system produced angle values aligned with manual measurements, demonstrating reliability and consistency.

These results support the feasibility of an automated RCSP-based diagnostic approach. Expanding the dataset to include larger and more diverse subject groups would enhance algorithm robustness and generalizability. Ultimately, this system is expected to lead to the development of a diagnostic device for preliminary patient classification.

.**Keywords:** Flatfoot Diagnosis; Resting Calcaneal Stance Position(RCSP); Image-Based Assessment; Canny Edge Detection; Automated Diagnostic System

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Finite Element Analysis and Reduced Order Model of Residual Stress Behavior in Thermal Barrier Coatings

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The Thermal Barrier Coating (TBC) process, based on thermal spraying, involves non-uniform heat source distribution, differences in cooling rate, interfacial bonding characteristics, and free-form curvature geometry. These factors cause localized stress concentration and temperature gradient variations, leading to the accumulation of thermal and residual stresses within the coating layer. Such stresses are the primary causes of delamination, cracking, and lifetime degradation of TBC systems. In this study, a thermo-mechanical coupled analysis model based on the Finite Element Method (FEM) was developed to analyze these issues, using ANSYS as the simulation platform. The proposed model evaluates the stress distribution under varying preheating temperatures, heat source conditions, cooling environments, and coating thicknesses. Furthermore, data obtained from FEM simulations were utilized to train a machine-learning-based non-intrusive reduced order model (ROM), aiming to reduce the computational cost of numerical simulations and enhance the efficiency and reliability of stress prediction in the coating process.

Keywords: Thermal Barrier Coating(TBC); Thermal Spray Coating; Finite Element Method(FEM); Reduced Order Model(ROM)

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Metamodel Based Simulation of Immersion Phased Array Ultrasonic Testing (PAUT) Data for Premium Quality Inconel 718 (PQ IN718) Alloy

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The PQ IN718 alloy, widely used in the aerospace industry, requires high durability to withstand high-temperature and high-pressure environments. Securing the integrity of such materials necessitates quality evaluation through non-destructive testing (NDT) during the manufacturing process, among which immersion ultrasonic testing is commonly used. In particular, Phased Array Ultrasonic Testing (PAUT) has gained attention as a highly effective technique for inspecting aerospace materials due to its superior capability to detect various types of defects in complex geometries. However, the coarse microstructure of PQ IN718 causes significant attenuation, making it difficult to establish a systematic and reliable NDT system. To construct a high-reliability inspection system, it is essential to identify the key factors that significantly influence defect detection. A simulation-based approach using a Meta-Model was adopted to achieve this goal. By constructing a the Immersion PAUT Meta-Model simulations, this study enabled sensitivity analysis across multiple inspection parameters such as water path, focal depth, defect size, and defect depth. This approach not only reduced computational time but also provided a quantitative framework for reliability optimization in PQ IN718 inspections.

Keywords: Metamodel Simulation(Latin Hypercube Sampling(LHS); Kriging Model; Nondestructive Testing(NDT); Phased Array Ultrasonic Testing(PAUT); Defect Detection; Premium Quality Inconel 718 Alloy

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Analysis of Deformation Characteristics According to the Back Heating Condition of Steel for Hull Flat Blocks

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In the shipbuilding industry, hull assembly is carried out by fabricating relatively simple flat blocks and various types of curved blocks. Flat blocks, which account for approximately 70% of the hull assembly process, are relatively easy to fabricate due to their simple shape. However, they are prone to deformation or warping caused by welding heat or constraints during block transport and erection. Such deformation leads to a decrease in dimensional accuracy and causes discrepancies between blocks. To correct this, various types of straightening work, such as line heating or spot heating, are essential. Due to the wide variety of factors in the shipbuilding industry, such as the degree of block constraint, material properties, and environmental conditions, straightening work is still heavily reliant on manual labor. This results in significant variations in the corrected outcome depending on the worker's skill level, and the number of skilled professionals is steadily decreasing. In this experiment, to automate the traditionally manual straightening process, we aimed to secure fundamental data by performing straightening work on flat plates of different thicknesses using a combination of oxygen and acetylene gases, and subsequently measuring the amount of deformation.

Keywords: Back Heating; Deformation; Flat Block; Shipbuilding

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Data-Driven AI Model for ISO Workpiece Grade Classification and Mechanical Property Prediction in Metal Cutting Processes

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This study proposes a data-driven approach for predicting workpiece machinability and ISO classification using machine learning. A material property database was constructed by applying ISO workpiece and tool grade standards to metallic cutting materials collected from catalogs and material datasheets. The final dataset consists of 728 alloys with 30 input variables, including detailed chemical composition and basic mechanical properties. After data cleaning (missing-value treatment, outlier removal, scaling, and normalization), XGBoost-based models were developed for both classification and regression tasks. The classification model predicts the ISO workpiece group, while two regression models estimate tensile strength and hardness, respectively. Model performance was evaluated using F1-score, R^2, RMSE, MAE, and MAPE on separate training and test sets. The ISO group classifier achieved an F1-score of 0.99 on the test set, indicating highly reliable discrimination among the P, M, N, S, H, and K groups. The mechanical property prediction models yielded a coefficient of determination of R^2 = 0.98 for both tensile strength and hardness, with low prediction errors across the entire range of the data. These results demonstrate that the constructed dataset, combined with XGBoost, enables highly accurate prediction of ISO workpiece grades and key mechanical properties from readily available material information. The proposed framework is expected to support intelligent tool selection, cutting condition design, and future digital twin applications in metal cutting processes.

Keywords: ISO Workpiece Classification; Mechanical Property Prediction; Data-driven AI Model; Metal Cutting Processes; Material Database

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A Study on Chattering Detection in Vertical Turning Center through Accelerometer and Current Sensor Signals Based on Transfer Learning

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In turning, tool wear caused by tool overload and chattering reduce machining quality. In particular, chattering refers to irregular vibrations between the tool and the workpiece, which affects machining quality. Monitoring and preventing chattering is an important factor for improving machining quality and increasing productivity. However, predicting chattering in a turning center is not easy. In actual field operations, operators detect chattering based on intuition and experience, and once chatter occurs, a decrease in machining quality is inevitable.

Recently, there has been active research on using artificial intelligence algorithms to learn the correlation between machining signals generated during processing and the tool wear state for indirect process monitoring through sensors. AI models trained through machine learning and deep learning are being used to monitor machining conditions. In addition, research is being conducted on developing AI models that classify chattering based on accelerometer signals and on real-time monitoring methods by utilizing the relationship between accelerometer signals and chattering in turning processes.

In this study, accelerometer and current sensors were installed on a vertical turning center to measure the vibrations and cutting loads generated during machining. To detect chattering occurring during turning, machining was carried out under three different conditions, and signals from the accelerometer and current sensor were obtained according to cutting depth, cutting speed, and RAM length. Transfer learning was performed based on an AI model developed in previous research, and the relationship between the actual measured machining signals and chatter was examined using the developed transfer learning model.

Keywords: Turning; Accelerometer; Current sensor; Chattering Detection; Transfer Learning

Acknowledgement: This research was funded by "(Details2) AI-based high-reliability large vertical turning center" of the Ministry of Trade Industry and Energy (MOTIE), Korea (Grant No. 20021890).

Improved Milling Force Prediction of Inconel 718 via Dynamic Recrystallization-Coupled Modeling

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The machining of Inconel 718 generates severe thermo-mechanical loads that trigger dynamic recrystallization (DRX), which significantly alters subsurface microstructures and affects cutting forces and thermal evolution. Conventional constitutive models, such as the Johnson–Cook (JC) model, cannot accurately capture these microstructure-dependent phenomena. This study develops an integrated thermo-mechanical milling force model that incorporates DRX behavior. A DRX-based constitutive formulation is established by introducing the DRX volume fraction as an internal variable within the JC framework to describe flow softening during high strain and temperature conditions. To accurately quantify temperature effects, a temperature prediction model is formulated based on Jaeger's moving heat source theory, including shear deformation, tool–workpiece friction, and chip–tool friction. The two models are sequentially coupled to account for thermal feedback on DRX evolution. Experimental validation using cutting force measurements and infrared thermography shows that the proposed model achieves an average temperature prediction error of 6.30% and force prediction errors of 8.51% in the Fy direction, which is significantly lower than the JC model. The results demonstrate that incorporating DRX effects improves predictive accuracy and provides a robust theoretical basis for optimizing the milling of difficult-to-machine alloys such as Inconel 718.

Keywords: Dynamic Recrystallization(DRX); Thermo-mechanical Coupling; Inconel 718; Milling Force Modeling; Constitutive Model

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Dimensional Accuracy Improvement of Combustion Chamber Throat Fabricated by Metal PBF through Dimensional Deformation Compensation Design Based on Inconel 718 Inherent Strain

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Additive Manufacturing (AM) of aerospace propulsion system components has gained significant attention due to its ability to fabricate complex geometries in a short period. However, when nickel-based superalloys such as Inconel 718 are fabricated using the Powder Bed Fusion-Laser Beam (PBF-LB/M) process, high residual stresses and deformations occur due to steep thermal gradients and repeated melting-solidification phenomena, inevitably resulting in dimensional deviations from the target geometry. In this study, a combustion chamber throat structure was fabricated using the PBF-LB/M process, and deformation was predicted using inherent strain-based analysis in Simufact Additive. Based on this prediction, a dimensional compensation design model was generated and printed under identical conditions, and specimens before and after applying the compensation design were compared and analyzed. The results confirmed that dimensional errors were significantly reduced in the model with dimensional compensation design applied. This study demonstrates that the inherent strain-based dimensional compensation design technique is effective in improving dimensional accuracy for the combustion chamber throat.

Keywords: Additive Manufacturing; Deformation Compensation; Inherent Strain; Dimensional Accuracy

Experimental Investigation of Polishing a Steel Shaft Using Magnetorheological Grease

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This paper presents an experimental study on the finishing of a steel shaft using a magnetorheological grease (MRG) polishing process. The objective is to evaluate the effectiveness of MRG, which stiffens controllably under a magnetic field, in improving the surface quality of cylindrical workpieces. The experimental setup involves rotating a steel shaft while an electromagnet activates the MRG abrasive medium in the polishing zone. Key parameters, including magnetic field strength, rotational speed, and polishing duration, are varied to assess their influence on surface finish, which is quantified by the reduction in average surface roughness (Ra). Results indicate that the MRG-based process consistently achieves a significant improvement in surface smoothness. The controlled rheological property of the grease allows for conformal contact and uniform material removal, effectively minimizing surface defects. This investigation confirms the viability of MRG as a versatile and efficient medium for precision polishing of rotational components.

Keywords: Magnetorheological Grease(MRG); Surface Finishing; Precision Polishing; Magnetorheological Materials

In-situ Observation of Brittle Behavior in Machining of Ti-6Al-4V

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Ti-6Al-4V, widely employed across industrial sectors, is a typical difficult-to-machine alloy due to its low thermal conductivity and high strength and hardness. These characteristics lead to rapid temperature rise and accelerated tool wear during cutting, which deteriorate surface quality and markedly reduce tool life. Moreover, the alloy's brittle behavior promotes the formation of serrated, unstable chips and induces cracking in the primary shear zone, causing irregular fluctuations in cutting forces. A comprehensive understanding of material deformation and chip-formation mechanisms is therefore crucial for stabilizing cutting forces, extending tool life, and achieving high-quality machining. However, conventional post-process observation techniques offer limited insight into chip formation and localized deformation. To systematically elucidate cutting mechanisms, real-time, in-situ observation of material deformation during machining is required. In this study, an in-situ observation system combining a high-speed camera with a dynamometer was developed to measure deformation, chip formation, and cutting-force variations of Ti-6Al-4V during orthogonal cutting. Experiments were performed under various depths of cut and cutting speeds. The captured image sequences were analyzed using Digital Image Correlation (DIC) to quantitatively obtain the strain-rate distribution in the primary shear zone, enabling detailed characterization of chip-formation processes and localized deformation at the tool–workpiece interface. Furthermore, by synchronizing deformation data with cutting-force measurements, the force-response characteristics associated with changes in shear behavior were systematically investigated.

Keywords: Orthogonal Cutting; In-situ Observation; Brittle Behavior; Digital Image Correlation; High-speed Camera

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Microstructural Origins of Machinability in Refractory Metal Alloy: The Role of Strain Rate-Dependent Crystallographic Heterogeneity

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This study investigates the microstructural origins of the poor machinability inherently observed in refractory metal alloys, utilizing Tantalum-Tungsten alloy (Ta-10W) as a representative material to examine the role of crystallographic orientation during orthogonal cutting. To elucidate the underlying deformation mechanisms, an integrated approach was employed, combining experimental cutting tests across a wide speed range with Electron Backscatter Diffraction (EBSD) analysis and Crystal Plasticity Finite Element Method (CPFEM) simulations. The results unequivocally identify a critical transition threshold at high cutting speeds. In low-speed regimes, the machining process is characterized by severe instability, including excessive cutting forces, pronounced built-up edge (BUE) formation, and extreme chip thickness ratios. Detailed microstructural analysis attributes these phenomena to strain rate-dependent crystallographic heterogeneity. Under conditions of prolonged tool-chip contact, the mechanical mismatch between ductile α-fiber and strain-sensitive γ-fiber grains is amplified, causing intense strain localization and significantly expanding the secondary shear zone. Conversely, increasing the cutting speed above the critical threshold effectively suppresses this heterogeneity by elevating strain rates and drastically reducing contact duration. This transition results in a substantial reduction in cutting forces, a marked decrease in chip thickness, and the formation of a thin, stable secondary shear zone. Consequently, the study demonstrates that the poor machinability of refractory alloys stems fundamentally from texture-induced strain localization, suggesting that optimizing cutting speeds to achieve flow stress homogenization is critical for enhancing process stability.

Keywords: Refractory Metal Alloys; Tantalum; CPFEM; Machinability; Strain Localization

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Experimental and Simulation-Based Optimization of Planarity in Rectangular Substrate CMP

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In the display and semiconductor packaging industries, achieving high-level planarity in large-area substrates has emerged as a critical challenge to prevent thickness non-uniformity and electrical shorts caused by surface irregularities. Consequently, research on applying chemical mechanical polishing (CMP) process is actively underway. CMP plays a crucial role in achieving ultra-precision flatness at the nanometer (nm) or angstrom (Å) level when applied to existing semiconductor device and substrate manufacturing processes, and controlling the material removal rate (MRR) is extremely important for achieving the final flatness. Therefore, this study aims to analyze the effects of key variables on material removal characteristics in rectangular substrate CMP processes and derive optimal CMP conditions capable of achieving high-level planarity by comparing them with simulation models.

The experiment utilized POLI-400 equipment from GnP Technology. The backing layer and copper-clad laminate (CCL) panel were attached on the polishing table, and a polishing pad was attached to the carrier head to perform polishing. The Cu thickness of the CCL panel before and after polishing was measured using a coating thickness measurement instrument, and MRR was calculated based on these measurements. Additionally, the flatness of the panel was evaluated based on non-uniformity (NU) of MRR.

The simulation model was developed using Python, integrating the trajectory generated by an arbitrary point on the carrier head from the panel with the pressure distribution derived from finite element analysis (FEA).

Keywords: Rectangular Substrate; Chemical Mechanical Polishing; Material Removal Characteristics; Non-uniformity; Simulation

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Correlation between Cutting Force and Surface Roughness in Ultra-Precision Machining of STAVAX Using a Micro CBN Ball End Mill

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The surface roughness of injection mold cavities is a critical factor influencing the dimensional accuracy, appearance, demolding behavior, and lifetime of molded products. For precision and optical molds made of STAVAX stainless steel, achieving nanometer-level surface quality requires ultra-precision machining. However, frequent direct measurements of surface roughness interrupt the machining process and increase production costs. This study investigates the correlation between cutting force signals and surface roughness during ultra-precision machining of STAVAX using a φ0.2 mm CBN ball end mill, aiming to enable indirect and non-contact monitoring of surface quality. Machining experiments were conducted on a 45° inclined surface under cutting conditions of a spindle speed of 40,000 rpm, feed rate of 1,200 mm/min, axial depth of cut 0.007 mm, and radial depth of cut 0.02 mm. Cutting forces were measured using a piezoelectric dynamometer, and surface roughness parameters (Sa) were evaluated with a confocal microscope after each machining stage. The analysis revealed that as machining progressed, both the overall magnitude of cutting forces and the measured surface roughness increased consistently. A clear positive correlation was observed between the force features and roughness indices, confirming that cutting force signals can serve as reliable indicators of surface integrity in ultra precision machining. These findings suggest the potential of cutting force-based real-time surface quality monitoring and adaptive control for high precision injection mold manufacturing

Keywords: Ball end Mill; Cutting Force; Surface Roughness; Ultra-precision Machining

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Ultra-Precision Flexible Polishing Method

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To meet the demand for high-performance and high-efficiency fabrication of optical components, this study proposes a novel ultra-precision flexible polishing method that integrates a chemical reaction process with a shear-thickening removal mechanism in a fluid medium, enabling low-damage and high-accuracy machining. By synergistically combining chemo-mechanical friction with thickening-induced micro-cutting, the method efficiently removes the oxide layer formed on the workpiece surface, and the material removal process exhibits a dynamic equilibrium in which surface atoms continuously participate in the formation of a new oxide layer while being simultaneously removed through flexible shear. On the basis of this mechanism, a mathematical control model for the material removal rate (MRR) was established, and polishing experiments were conducted to identify key process parameters and to validate the model. The results show that, after 60 minutes of polishing, the surface roughness (Sa) of the optical component decreased to below 3.688 nm and the average infrared transmittance increased by approximately 18.5%, confirming that the proposed method significantly enhances optical performance and has broad application prospects in optical material finishing.

Keywords: Flexible Polishing; Optical Components; Shear-thickening; Chemical Reaction

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Surface Damage in Glass Fiber-Reinforced Plastic/Copper Laminates: An Investigation Using a 3D Micro-Scale Oblique Cutting Model

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With the rapid development of artificial intelligence and communication technologies, printed circuit boards (PCBs) have attracted increasing attention from researchers. During the PCB drilling process, the drill-in at heterogeneous interfaces - such as those between copper, glass fiber, and resin - is a critical factor affecting machining quality. A microscale finite element model of PCB drilling was established to investigate the material removal process and the formation mechanism of interface damage at the microscale, by simplifying the drilling process into an oblique cutting process. The model enabled clear observation of the removal processes for both the glass fiber-reinforced plastic (GFRP) and the copper foil, as well as the resulting damage at their interfaces. The mechanisms of material removal and damage at heterogeneous interfaces were examined for a microscale cutting process applied to a laminated structure of copper foil and resin-based glass fiber composites with varying fiber orientations. To validate the accuracy of the established microscale damage model, a comparative analysis between the simulation and experimental results was conducted. It is demonstrated that the morphology and distribution patterns of the interface damage predicted by the simulation model are in good agreement with the experimental findings, thereby effectively verifying the feasibility and reliability of the proposed model. This study provides a theoretical basis for optimizing machining processes to suppress interface damage.

Keywords: Heterogeneous Interface; Surface Damage; Finite Element Analysis

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Experimental, Modeling, and Simulation Study on Ultrasonic-Assisted Micro-Drilling of Printed Circuit Boards

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Micromoles fabricated for high-density interconnections in printed circuit boards (PCBs) are key factors affecting the reliability and signal integrity of electronic devices. Traditional mechanical micro-drilling processes tend to generate defects such as burrs and copper foil tearing during machining, severely limiting their application in precision electronics manufacturing. This study proposes the use of ultrasonic-assisted micro-drilling technology (UAMD) by constructing a high-frequency ultrasonic vibration system and combining finite element simulations with experimental validation to systematically explore the machining characteristics of the UAMD process. The study focuses on the influence of key parameters, such as cutting parameters and vibration parameters, on drilling force, hole quality, hole wall morphology, chip formation, and tool wear. The results indicate that the high-frequency impact effect of ultrasonic vibration effectively improves energy distribution in the cutting zone, promotes chip breaking and removal processes, and significantly enhances machining stability and hole wall quality. Thanks to effective control of cutting heat, tool durability is significantly improved. This study not only provides an innovative process solution for high-precision micro hole fabrication but also lays the necessary theoretical foundation for its industrial application.

Keywords: Printed Circuit Boards(PCBs); Ultrasonic-assisted Micro-drilling; Numerical Analysis

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Robust Volumetric Error Compensation for 5-Axis Machine Tool Using Sensitivity-Based Weight Assignment Method

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With the increasing demand for high geometric accuracy of machine parts in advanced industries, 5-axis machine tools are widely adopted for their flexibility in controlling tool-workpiece orientation through rotational axes. However, the machining accuracy of these complex machines can be significantly degraded by volumetric error, defined as the discrepancy between the tool and workpiece. The primary contributors to this volumetric error are position-independent geometric errors (PIGEs), also known as kinematic errors, which arise from imperfections in the assembly of the machine tool. Since the influence of each kinematic error is not identical, quantifying their effects through sensitivity analysis is crucial for effective compensation. This study presents a robust volumetric error compensation method integrating global variance-based sensitivity analysis with a weighted error extraction algorithm. A volumetric error model is formulated using homogeneous transformation matrices (HTMs) to conduct sensitivity analysis, quantifying the contributions of individual kinematic errors. The resulting sensitivity indices are used to construct a weighting matrix for the least-squares fitting (LSF) procedure. This enhances reliability by prioritizing critical error parameters while suppressing less influential ones. The extracted parameters are used to calculate the predicted volumetric error for compensation, reducing the residual error. The performance of the proposed method was validated through a numerical simulation using tool center point error measurement data obtained by a touch probe test. The results demonstrated superior compensation performance compared to conventional LSF, reducing the maximum volumetric error from approximately 21.8 mm to 3.7 mm and the mean error from 12.0 mm to 1.6 mm.

Keywords: 5-axis Machine Tool; Sensitivity Analysis; Volumetric Error; Weighted Least-squares Fitting

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Evaluation of Cold Forging Formability for High-Strength Micro-Alloyed Steel of Battery-Body Fastening Components

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The rapid expansion of the electric vehicle market and the reinforcement of vehicle safety regulations have increased the necessity for high-strength and high-reliability fastening parts that connect the battery pack to the vehicle body. As this joint structure directly dictates driving and crash safety performance, the application of fasteners with 1.2Gpa steel grade has become increasingly prevalent. However, the conventional forging material, SCM435, faces inherent limitations such as restricted formability at high strength levels, reduced die life, and increased manufacturing costs due to the mandatory heat-treatment process. To overcome these constraints, this study investigates the feasibility of applying high-strength micro-alloyed steel whose yield and tensile strength can be controlled through plastic deformation without heat treatment to the forging process of battery-body fastening parts. First, pull-out strength CAE analyses were performed on bolts and nuts for battery-body fastening to evaluate structural stiffness and durability when using micro-alloyed steel. Next, multistage cold-forging simulations were conducted to assess the formability, material flow behavior, and die load characteristics of the micro-alloyed steel, and the results were compared with those of SCM435. Based on these structural and forming analyses, the applicability and effectiveness of high-strength micro-alloyed steel for battery-body parts were validated.

Keywords: Micro-alloyed Steel; High Strength; Formability; Cold-Foring; Battery-body Fastening Parts

Acknowledgement: This work was supported by the Technology Innovation Program (RS-2024-00410657, Development of 1.2GPa-class high-strength fastening mount parts for future vehicle conversion parts and high-efficiency battery forging technology) funded By the Ministry of Trade, Industry & Resources(MOTIR, Korea).

DIC Based Determination of Stress-Strain Curves of Metal Sheets Considering Large Deformation

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This study deals with determination of stress-strain curves of metal sheets for large deformation by utilizing the DIC (Digital image correlation) method. For forming simulations, the stress-strain curves of general metal sheets are obtained up to the uniform elongation which is the strain corresponding to the UTS (Ultimate tensile strength) because the uniaxial tension path remains until the strain reaches the uniform elongation. However, the stress-strain data for the uniform elongation are not enough to cover the material behavior in FE simulations when the strain levels are much higher than the uniform elongation during the forming. To address this issue, a determination method with the DIC system was proposed to obtain the stress-strain curves for large deformation. Tensile tests were, firstly, conducted at a quasi-static state following the ASTM E8M standard. The DIC analysis was then carried out to identify the strain distribution in the gauge section of the tensile samples. Stress-strain curves were calculated using the point strain data distributed along the center-line of the gauge section. The stress-strain curves for large strains which are much higher than the uniform elongation were successfully obtained from the DIC based analysis. The proposed method would be useful to apply reliable material properties to the simulations when the usage of various testing machine is limited except simple tension testing machine.

Keywords: Digital Image Correlation; Stress-strain Curve; Metal Sheet; Large Deformation; Tensile Test

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A Study on High-Accuracy Springback Analysis for Ultra-High-Strength Steel in Chassis Components

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High-strength steel is increasingly applied to automotive chassis components to meet both lightweighting requirements and high structural rigidity. However, its high yield strength and low ductility often lead to forming defects such as springback and cracking. Therefore, optimizing product geometry and forming processes is essential to ensure stable manufacturability.

This study aims to enhance the reliability of springback prediction in the forming process of ultra-high-strength steel sheets by developing an analysis-based forming process optimization methodology. Mechanical properties of a 980 MPa hot-rolled steel sheet were characterized, and a corresponding material model for forming simulations was established. Various hardening models and yield functions were compared and applied to improve the accuracy of springback analysis. Using AutoForm software, the refined material model was applied to an S-Rail component involving complex forming modes, and forming simulations were conducted. Prototype samples were manufactured, and the actual springback deformation (angle) was measured through 3D scanning. The trends of the simulation results were compared with the experimental measurements to validate the reliability of the springback prediction.

Overall, this study demonstrates that accurate forming analysis and process optimization under complex forming conditions for ultra-high-strength steel can significantly improve the reliability of springback prediction.

Keywords: Ultra-High-Strength Steel; Material Modelling; Springback; Forming Simulation; AutoForm

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Study on Tensile Test and FLD Evaluation of Ultra-Thin SUS 0.05 mm Stainless Steel Plates

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In this study, uniaxial tensile tests and Forming Limit Diagram (FLD) experiments were conducted on a 0.05 mm ultra-thin SUS stainless steel sheet to obtain the forming properties required for miniaturized electronic devices and plate heat exchangers, where high thermal efficiency and compact design are essential. The tensile tests were performed under quasi-static conditions using ASTM E8 subsize specimens to ensure consistent mechanical property acquisition. For FLD construction, ISO 12004 standards were applied. Considering that the viscosity of the spray pattern used for strain measurement increased friction with the tooling and adversely affected formability, the pattern was applied only to the central region of the specimen to minimize frictional influence. In addition, several specimen geometries exhibited fracture initiation at the lower region, preventing the acquisition of upper-surface fracture data. To address this, Nakazima-type specimens were employed to supplement deformation paths and secure the required fracture strains. Through these stabilization and compensation measures, the mechanical properties and forming limits of the ultra-thin sheet were successfully determined. The resulting dataset provides essential foundational information for future evaluations of ultra-thin sheet formability and for the design of high-precision forming processes..

Keywords: Ultra-thin Stainless Steel; Tensile Testing; Forming Limit Diagram(FLD); Wrinkling Suppression

Acknowledgement: This work was supported by LG Electronics under the project (Project No.IR250025, "Development of technology to predict the formability of ultra-thin plate materials").

A Study on Galling Behavior of Stainless Steel Sheet Metal Forming

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Stainless steel sheets are widely used in industries where surface appearance is crucial; however, they are highly susceptible to galling when processed without surface protection. Protective films are commonly applied to prevent such damage during forming, but they increase production costs and generate waste, motivating the development of film-free and environmentally sustainable forming technologies. When the film is removed, direct contact between the tool and the sheet accelerates material transfer and galling, leading to premature surface failure in forming processes.

To investigate the mechanism responsible for galling in stainless steel sheet forming, we conducted single-sided friction tests that replicate industrial forming conditions. A line-contact indenter was designed according to Hertzian contact theory, and the maximum forming pressure was evaluated through AutoForm simulations to determine realistic test parameters. Friction tests were then performed under varying normal pressures, sliding speeds, tool coatings, and tool materials to examine the evolution of wear behavior. The results revealed that galling progressed more rapidly under higher pressure and speed, and that the generated debris accumulated at the tool–sheet interface, intensifying adhesive wear. Furthermore, the dominant wear mode was strongly influenced by the hardness difference between the tool and sheet; a larger hardness gap promoted galling, whereas a smaller gap favored abrasive wear.

This study provides a mechanistic understanding of galling in stainless steel sheet forming and highlights the critical process parameters governing wear behavior. The findings offer valuable insight for designing film-free forming processes that are both cost-effective and environmentally sustainable

Keywords: Stainless Steel; Sheet Forming; Galling; Friction Test

Acknowledgement: This work was supported by LG Electronics under the project (Project No. IR250020, "Analysis of the Causes and Mechanism of Sticking During Protection Film-Free Forming")

Characterization of Springback in the Forming of Lightweight Aluminum Extruded Tubes

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The rapid growth of electric vehicles (EVs) has led to a significant increase in vehicle weight due to the integration of high-capacity battery systems. To compensate for this weight penalty, the automotive industry has actively pursued the application of lightweight non-ferrous materials. Among them, aluminum extruded profiles have gained attention because their closed-section geometry provides high bending and torsional stiffness, making them suitable for crash-critical body structures. However, since extrusions are manufactured in straight prismatic forms, the limited shape flexibility restricts their use in certain structural components requiring complex geometries. In this study, the formability of high-strength 7xxx-series aluminum extruded tubes was investigated using a specially designed forming-roll unit. A detailed finite element analysis (FEA) model was developed to evaluate deformation behavior during the roll-forming process and to predict potential defects such as local buckling or excessive thinning. The simulation results confirmed the feasibility of forming curved profiles from straight extrusions and provided quantitative insight into springback behavior, which is a critical issue for high-strength aluminum alloys due to their low elastic modulus-to-strength ratio. The findings indicate that with appropriate bending-forming strategies and process optimization, 7xxx-series aluminum extrusions can be effectively shaped into complex geometries while maintaining structural integrity. This study demonstrates the potential for expanding the application of high-strength aluminum extruded components in future EV body structures, contributing to improved lightweight design and overall crash safety.

Keywords: Aluminum; Extrusion; Bending; Springback; Car Body Parts

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Coating Damage Tolerance Requirements for Insulation Performance in EV Motor Continuous Winding

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Polyamide-imide (PAI) coated copper wires are widely used in motor windings due to their excellent thermal and electrical insulation properties. During manufacturing and operation, the coating experiences two primary mechanical damage mechanisms: friction-induced wear from repeated contact with guides and adjacent wires, and compressive deformation from winding tension and coil packing forces. Both mechanisms reduce coating thickness and may compromise insulation integrity. This study evaluates insulation performance under both damage modes to suggest minimum coating thickness requirements. Two wire types with different initial coating thicknesses (80 μm and 110 μm) were tested. Friction-wear behavior was characterized using reciprocating linear motion tests, while compressive damage was tested using punch. After each damage test, residual coating thickness was measured and brush tests were conducted to assess insulation integrity. By testing specimens with various degrees of coating reduction, threshold thickness values for insulation failure were identified for each damage mode. The friction-wear data provides tribological parameters for process simulation, while compression results offer guidance for quality control. These findings provide quantitative design guidelines for PAI-coated wire applications.

Keywords: Continuous Winding; Insulation Integrity; Mechanical Damage

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Process Design Criteria for Insulation Integrity in Wire Forming of EV Motor Continuous Winding

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With increasing electric vehicle demand, traction motor efficiency improvement has become increasingly important. Conventional hairpin wires require individual insertion into slots and welding, resulting in numerous weld points, which can cause porosity and spatter issues. Continuous winding wires address this limitation through insertion of connected wire bundles, thereby minimizing weld points. However, due to the limited thickness of the insulating coating layer, the coating is insufficient to withstand the tensile and compressive stresses during bending, leading to deformation-induced insulation rupture. This study aims to analyze the characteristics of the continuous winding process and suggests process design criteria to minimize insulation rupture through evaluation of forming limits based on finite element analysis. FE-SEM analysis identified insulation layer thickness distribution and regions susceptible to rupture in wire cross-sections. Interfacial fracture mechanisms were analyzed through DIC-based tensile testing and validated against ultimate tensile strength estimated from micro-Vickers hardness tests. Finite element analysis, utilizing experimentally derived material properties, was performed to evaluate fracture behavior across varying minimum bending radii, punch-die corner radii, and bending angles, and assessed formability for different wire aspect ratios. The analysis identified bending conditions inducing wire rupture and observed correlations between punch-die geometry parameters and wire aspect ratios. Process windows for maintaining insulation integrity were identified, and rupture model-based quantitative design criteria are suggested. Threshold values for predicting insulation cracking and fracture were obtained. These results provide a basis for forming defect prediction and optimal condition selection during die design, contributing to improved productivity and quality stability in EV motor manufacturing.

Keywords: Continuous Winding; Insulation Rupture; Finite Element Analysis(FEA); Digital Image Correlation(DIC); Fracture Mechanism

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A Study on the Strain Localization Mechanism under High Strain Rates

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After severe plastic deformation, strain localization occurs, and this localized strain eventually leads to fracture. Strain localization under high strain rate deformation, has a greater influence on fracture behavior because temperature rise and thermal softening occur in the severely deformed region. In this study, the mechanism of strain localization is examined by considering inhomogeneous material properties. Figure 1 shows the region with inhomogeneous properties and the corresponding analysis results. A 40% reduction in flow stress is applied to the red region compared with the surrounding material. It is shown that localized deformation takes place and temperature rises more on the region.

Keywords: Strain Localization; Shear Band; Temperature Rise, Thermal Softening

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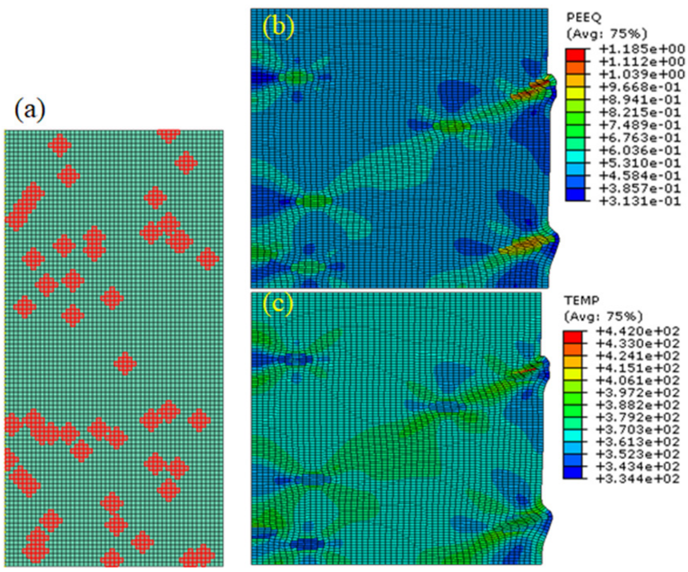

Fig. 1. (a) Property Inhonodeneous region, (b) strain localization and (c) temperature distribution

Predicting Fracture Strength of Dissimilar FDS Connections under Combined Loading through Artificial Neural Network

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The fracture strength of dissimilar-material Flow-Drill Screw (FDS) connections is typically evaluated through lap-shear and cross-tension tests. However, replicating the complex loading conditions present in actual structures requires numerous experiments for each material combination, resulting in significant time and cost inefficiencies. To address this issue, this study employs an artificial neural network (ANN) approach to reduce experimental dependence and predict fracture strength more efficiently. The LeakyReLU activation function was used, and the network architecture was varied by adjusting the number of hidden layers (3, 5, and 10) and nodes per layer (64 and 128) to identify the configuration with the highest accuracy. Experimental data were obtained from seven material combinations and up to six loading angles, resulting in a total of 37 training samples. The input variables consisted of five parameters: upper, lower-plate thickness and initial yield strength and loading angle. The network was designed to predict a single output, namely the fracture load. The dataset was divided into training and validation sets at an 8:2 ratio, and the model was trained for up to 2000 epochs. Model performance was evaluated by predicting the lap-shear load of the 980 (2.0t) + A6N01 (5.0t) connection configuration. Model comparison showed that the network with 10 hidden layers and 128 nodes per layer achieved the highest prediction accuracy. For the validation case, the ground-truth was 10.45 kN, corresponding to an accuracy of approximately 98.85%. These results demonstrate that the proposed approach offers an effective non-experimental alternative for estimating the fracture strength.

Keywords: Flow-Drill Screw(FDS); Artificial Neural Network(ANN); Multi-Layer Perceptron(MLP); Lap Shear Test; Cross Tension Test

Acknowledgement: This work was supported by the Ministry of Trade, Industry and Energy (MOTIE) and the Korea Evaluation Institute of Industrial Technology (KEIT) under the 2025 Research Funding Program (Project No. RS-2024-00425266, "Development of high-strength welding wire and ultra-high-strength chassis components for 1.5 GPa-class steels").

Effect of Robotic Extrusion Welding Parameters on the Mechanical Performance of HDPE Butt Joints

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High-density polyethylene (HDPE) butt joints were fabricated by robotic extrusion welding using a six-axis industrial robot and a commercial HDPE welding unit, and their mechanical performance was evaluated by tensile and flexural tests in accordance with EN 12814-1/2 and ASTM D790 standards. The study examined the combined effects of plastification temperature, preheating of the joint region, contact pressure, and the ratio between travel speed and material discharge rate on weld quality. Weld strength was mainly governed by the coupled control of plastification temperature and preheating: insufficient heating caused lack of fusion and low joint efficiency, whereas excessive heating led to bead collapse and internal defects. An intermediate process window produced stable bead formation and the highest weld strength, with the maximum average tensile strength of about 24.6 MPa obtained at a melt temperature of 280 °C, while bending strength remained roughly constant at 30–31 MPa. Contact pressure showed a threshold behavior, where overly low or high pressure increased porosity and interfacial defects, while a moderate range ensured intimate contact and reproducible performance. Welding speed also exhibited an optimum region around 15–20 cm/min, in which both tensile and bending strengths were maximized with relatively small scatter. These results clarify the key parameter interactions that control the structural integrity of HDPE robotic welds and provide practical guidance for defining robust process windows in automated welding of large-scale HDPE structures.

Keywords: High Density Polyethylene; Robotic Extrusion Welding; HDPE Butt Joint; Process Parameters; Weld Strength; Flexural Properties; Bead Geometry

Acknowledgement: This study was supported by the Korea Institute of Industrial Technology (KITECH) through the project "Autonomous Manufacturing Technology based on DNA Platform (EH250003)" and by the Technology Innovation Program (RS-2025-25402653, "Development and verification of technology process utilizing teaching-less AI autonomous manufacturing robots in charge of three-dimensional welding and party work"), funded by the Ministry of SMEs and Startups (MSS, Korea).

Effects of Cooling Techniques on Microstructure, Mechanical Properties and Thermal Distortion in Keyhole-Mode GTAW of 3mm SS316L Plates

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This study investigates the influence of five post-weld cooling techniques which is CO_2 spray cooling, water cooling, forced air cooling, room temperature cooling, and ice cooling on the mechanical properties, microstructure, hardness distribution, and angular distortion of 3 mm thick SS316L stainless steel joints welded using the keyhole-mode Gas Tungsten Arc Welding (GTAW) process. The welding process include back-purging gas on the back side (root) of the weldment. Weld quality was evaluated through radiographic inspection, macro- and microstructural analysis, Vickers microhardness profiling, tensile testing, and distortion measurement. Water cooling achieved the highest yield strength (942.64 MPa), while forced air cooling produced the highest ultimate tensile strength (963.37 MPa). In contrast, room temperature cooling (29.01%) and CO_2 cooling (26.79%) exhibited the greatest ductility. CO_2 cooling also recorded the highest fusion zone (FZ) hardness (~302 HV) and the lowest angular distortion (0.47°). Microstructural observations revealed that rapid cooling methods, such as CO_2 and ice cooling, produced refined dendritic structures, whereas slower cooling methods promoted grain coarsening. Fracture location analysis indicated that only forced air–cooled specimens failed in the base metal (BM), suggesting weld strength exceeded that of the parent material. Overall, the findings highlight the trade-off between strength, ductility, and dimensional stability, demonstrating that no single cooling method is universally optimal. The choice of cooling strategy should be application-specific: forced air and water cooling are suitable for strength-critical components, CO_2 cooling for distortion-sensitive applications, and ice cooling for balanced performance. These results provide practical guidance for welding engineers in optimizing post-weld cooling to achieve desired mechanical and dimensional properties in stainless steel GTAW applications.

Keywords: Post Weld Cooling; Keyhole-mode GTAW; 3mm SS316L; Back Purging in GTAW; Thin Metal Weld Distortion

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Derivative-Based Bead Profile Analysis Method for Multi-Pass Welding of V-Groove Joints

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Multi-pass welding of V-groove joints requires high precision and weld quality. However, automation remains challenging because the starting positions of the root and subsequent passes still depend on the operator's experience. Such positional errors lead to uneven bead deposition and welding defects, highlighting the need for quantitative criteria to achieve process automation. In this study, a method for determining welding start positions in Gas Tungsten Arc Welding (GTAW) was proposed based on derivative analysis of weld bead profiles. Bead-on-Plate experiments were conducted under various welding conditions including current, voltage, torch travel speed, and wire feed speed to derive optimal process parameters, which were then applied to multi-pass welding of V-groove specimens. After each pass, the cross-sectional profiles were precisely measured using a Laser Vision Sensor (LVS). The acquired profile data were denoised using a Savitzky–Golay filter, and the first derivative was analyzed to automatically detect contact points between the groove and bead as well as the lowest points on the upper surface. From these analyses, the welding start positions of each pass were quantitatively extracted. This study demonstrates that geometric analysis of weld bead profiles enables automatic recognition of multi-layer welding positions and provides a foundation for robotic path planning, deposition sequence optimization, and intelligent welding process control.

Keywords: V-groove Welding; Gas Tungsten Arc Welding(GTAW); Laser Vision Sensor(LVS); Welding Automation; Derivative Analysis

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Development of a Machine Learning-Based Prediction Algorithm for GMAW Bead Cross-Section Profiles Using a Laser Vision Sensor

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In arc welding, bead geometry changes nonlinearly with heat input conditions, directly affecting the mechanical strength and surface quality of the weld. This behavior is a key factor for ensuring quality stability in multi-pass welding and additive manufacturing processes, requiring precise prediction. Previous studies mainly focused on predicting single dimensional parameters such as bead width or height, making it difficult to quantitatively represent the actual cross-sectional curvature. In this study, a machine learning algorithm was developed to predict bead surface geometry based on GMAW cross-sectional data collected under various current and speed conditions using a laser vision sensor (LVS). The data were aligned to a reference plane and corrected in the toe region, then compressed into principal shape modes through principal component analysis (PCA). Gaussian process regression (GPR), random forest (RF), and multilayer perceptron (MLP) models were employed to learn the nonlinear relationships between process parameters and shape modes. The trained models can reconstruct bead cross-sections under new conditions and quantitatively analyze geometric variations by calculating curvature (κ), toe and crown characteristics, and effective width. Validation against LVS experimental data confirmed high prediction reliability based on RMSE and K-fold cross-validation.

Keywords: Gas Metal Arc Welding; Bead Geometry Prediction; Laser Vision Sensor; Machine Learning; Prediction Algorithms

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Theoretical and Experimental Analysis of the Area Increasing Rate of Stretchable Substrate Materials

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The development of next-generation wearable devices requires stretchable substrate materials that provide both flexibility and stretchability for stable attachment to the human body. Because human skin can exhibit area expansions of up to about 100% depending on movement, stretchable substrates must accommodate similarly large area changes, which can be evaluated using the area increasing rate during tensile deformation. Conventional approaches, however, consider only axial deformation, although all materials inevitably undergo transverse contraction under tensile strain. Therefore, an area-increasing-rate formulation that includes Poisson's ratio, which couples axial extension and transverse contraction, is needed. In this framework, the area increasing rate follows a quadratic form with a negative coefficient. Although Poisson's ratio is generally regarded as constant, several stretchable substrate materials have shown strain-dependent reductions in Poisson's ratio. In this study, thermoplastic polyurethane (TPU), a material known to exhibit such non-classical behavior, was investigated using dog-bone specimens subjected to uniaxial tension. Grid-point displacement measurements enabled precise determination of Poisson's ratio and the area increasing rate as functions of strain. The results showed a gradual decrease in Poisson's ratio at high strains, indicating that assuming a constant initial Poisson's ratio leads to significant underestimation of the actual area increasing rate in the large-strain region. To overcome this limitation, a regression-based strain–Poisson's ratio relationship was established, and an improved theoretical expression for the area increasing rate was derived and validated. Additionally, geometric analysis of the area-increasing-rate formulation provided insights for designing stretchable substrate materials suitable for future wearable devices.

Keywords: Stretchable Substrate Materials; Area Increasing Rate; Poison's Ratio; Strain-Dependent Behavior; Thermoplastic Polyurethane(TPU)

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Low Vapor Pressure Liquid-Based High Temperature-Stable Triboelectric Nanogenerators for Tactile Sensing

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Liquid electrode triboelectric nanogenerators (TENGs) based on aqueous solutions have attracted a lot of attention lately because of their remarkable stretchability, deformability, and innate shape-adaptability. Nevertheless, drying issues with earlier aqueous solution-based TENGs might result in malfunctions. In this study, we introduce a low vapor pressure liquid (LVPL) electrode TENG (LVPL-TENG) that improves the stability of TENGs at high temperatures by using branched polyethyleneimine (bPEI) or the deep eutectic solvent choline chloride/glycerol (ChCl:Gly). The stability of the aqueous-based liquid TENG was further compared using a 10 wt% NaCl solution. At the beginning, the NaCl liquid TENG's peak-to-peak voltage(V_{pp}) and peak-to-peak current (I_{pp}) were roughly 193 V and 31 μA, respectively. However, the V_{pp} and I_{pp} drastically dropped to around 11 V and 3 μA after being held for 24 hours at 100 °C in an oven, keeping only roughly 6% and 10% of the initial V_{pp} and I_{pp}, respectively. The improved thermal stability of bPEI and ChCl:Gly, on the other hand, is responsible for the LVPL-TENGs' V_{pp} and I_{pp} remaining stable after being exposed to an oven set at 100 °C for 24 hours.

Keywords: Liquid Electrolyte; Triboelectric Nanogenerator; Low Vapor Pressure; Thermally Stable

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Poster Session 3 | Polymer Processing | PP3-30

A Photo-Crosslinked GelMA Hydrogel System for Local Dexamethasone Delivery to Suppress Inflammation and Adhesion in Peripheral Nerve Injury

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Postoperative adhesion of peripheral nerves to adjacent tissues severely hinders functional recovery after surgery, causing neuropathic pain, nerve deformation, and reduced regenerative ability. Conventional anti-adhesion materials show limited success due to fast degradation, immune rejection, and formation of secondary adhesions. In this study, we developed a photocrosslinkable methacrylated gelatin (GelMA)-based hydrogel membrane capable of localized dexamethasone release to prevent adhesion and suppress inflammation simultaneously. GelMA was prepared by reacting gelatin with methacrylic anhydride and characterized using FT-IR spectroscopy and rheological analysis. Dexamethasone was incorporated into the GelMA hydrogel. Cytocompatibility was assessed through cell proliferation and adhesion tests. The anti-inflammatory and anti-adhesion effects were evaluated in a rat sciatic nerve injury model by implanting the Dexa-GelMA hydrogel at the surgical site.. FT-IR spectra confirmed successful methacrylation, and both GelMA and Dexa-GelMA hydrogels exhibited excellent cytocompatibility. Gross observation showed a marked decrease in perineural adhesion in the Dexa-GelMA-treated group compared with controls one week post-implantation. Western blot analysis indicated approximately 80% reduction in inflammation-related markers. The Dexa-GelMA hydrogel effectively mitigates postoperative adhesion and neuroinflammation, offering a promising strategy for enhancing peripheral nerve regeneration and functional recovery following surgical injury.

Keywords: Methacrylated gelatin hydroge, Anti-Adhesion, Dexamethasone, Photo-crosslinking

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A Novel Method for Measuring Areal Expansion in Highly Flexible Materials

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For stretchable electronic systems whose performance is strongly coupled to the achievable areal deformation under service conditions, flexibility can be defined as the achievable areal expansion. In many prior works, areal strain has been approximated solely from uniaxial tensile strain, under the assumption of zero lateral shrinkage, effectively treating materials as incompressible in the lateral direction. This simplification inevitably leads to an overestimation of areal expansion because the transverse tensile loading induces measurable lateral shrinkage. The resulting error becomes increasingly pronounced at high strain levels, commonly encountered in elastomeric or hyperelastic materials. Therefore, an accurate quantification methodology for areal changes in highly flexible materials is required. In this work, we derived a theoretical expression for the areal expansion ratio using Poisson's ratio to quantitatively account for lateral shrinkage. Since the shrinkage near the gripped region is restricted in practical tests, an additional parameter was introduced to reflect spatial variation in lateral strain. Furthermore, because Poisson's ratio in highly flexible materials may vary depending on the applied transverse strain, we separately derived analytical models assuming a constant Poisson's ratio and a strain-dependent Poisson's ratio. The calculated areal expansion values based on these formulations were compared with experimental measurements, demonstrating a substantial improvement in accuracy over conventional methods.

Keywords: Areal Expansion; Flexible Materials; Poisson's Ratio; Flexibility

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Defect Passivation of PVD-Based Hard Coatings via ALD for Improved Corrosion and Mechanical Properties

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Hard coatings have been extensively applied in various industrial applications such as cutting, forming and casting tools in order to increase the life time of such components and enhance the tools performance due to their high hardness, good chemical and thermal stability, and significant wear resistance. So far, hard coatings have been synthesized by a number of PVD techniques, such as magnetron sputtering (MS), arc ion plating (AIP), and their advanced or hybrid deposition techniques such as high power impulse magnetron sputtering (HIPIMS). Unfortunately, these hard coatings present intrinsic defects which can affect the corrosion behavior, especially when substrates are active alloys like steel or in a wear-corrosion process. Meanwhile, atomic layer deposition (ALD) has shown great potential for corrosion protection of high-precision metallic parts or systems due to the self-limiting surface reactions, which leads to the thin films possess high quality, low defect density, uniformity, low-temperature processing and exquisite thickness control. These merits make ALD an ideal candidate for the fabrication of excellent oxide barrier layer which can block the pinhole and other defects left in the coating structure to improve the corrosion protection of hard coatings. In this study, ALD interfacial layers such as Al2O3, TiO2, and their nanolaminated films were inserted in CrN-based hard coatings to improve the mechanical properties as well as corrosion properties of CrN-based hard coatings. The influence of the ALD interlayer addition on the microstructure, surface roughness, mechanical properties and corrosion behaviors were systemically investigated.

Keywords: Hard Coatings; ALD Interlayer; Corrosion; Mechanical Properties; CrN Hard Coatings

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Micro/Nano Structure Replicated CNT/PDMS Composite Surface with Solar-Driven Photothermal Effect for Zero-Energy Anti-Icing

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Icing on surfaces can significantly degrade the performance and reliability of industrial systems, and many existing de-icing technologies depend on external energy sources, leading to high operational costs and implementation challenges. To address these issues, this study presents a CNT/PDMS composite surface that achieves zero-energy anti-icing functionality by combining superhydrophobicity from replicated micro/nano structures with CNT-enabled photothermal heating. Copper foils were chemically oxidized to generate CuO micro/nano structures, which served as molds for PDMS replication. The replicated PDMS surfaces were then spray-coated with CNT modified with low-surface-energy materials, providing broadband light absorption, efficient photothermal conversion, and long-term superhydrophobicity. The fabricated surface exhibited a contact angle above 150° and rapid photothermal responsiveness, reaching approximately 60 °C within minutes under solar irradiation. Under identical coating conditions, PDMS surfaces with replicated micro/nano structures showed a 29% increase in icing-delay time and a 20.7% reduction in de-icing time compared with flat PDMS, confirming the effectiveness of structural replication. Durability tests conducted over 45 days further verified the stability of both the replicated structures and the CNT coating. Overall, the synergistic integration of micro/nano structuring and photothermal materials offers an effective and durable zero-energy anti-icing solution. The simple replication-based fabrication and spray-coating processes also highlight its potential for cost-effective, large-scale implementation in low-temperature industrial environments.

Keywords: Micro/Nano Structures; CNT/PDMS Composite Surface; Superhydrophobicity; Photothermal Effect; Anti-Icing

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Extending Silicone Mold Durability through Resin Wetting Prevention

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Silicone molds are widely utilized for the replication of micro/nano-structured surfaces due to their excellent flexibility, chemical stability, and processability. However, their durability often rapidly degrades during repeated molding cycles, primarily driven by the wetting, infiltration, and penetration of uncured resin into the surface. Such wetting induces interfacial swelling and irreversible surface damage, ultimately shortening mold lifetime and impairing dimensional and morphological fidelity. In this study, a strategy to extend silicone mold durability by suppressing resin wetting at the mold–resin interface is proposed. Comparative molding experiments using micropatterned silicone molds were conducted by tuning resin formulations, and additional manufacturing parameters affecting mold degradation during curing were also systematically evaluated. The results demonstrate that preventing resin wetting significantly extends mold lifetime while maintaining consistent pattern transfer fidelity over hundreds of molding iterations. Furthermore, the results highlight that manufacturing conditions must be carefully chosen to extend the durability of patterned silicone molds, regardless of resin formulation. This methodology provides a practical route to enhance mold robustness for soft lithography, precision replication manufacturing, and micro/nano-structured patterning, and also offers fundamental insight into wetting–adhesion–damage coupling mechanisms at flexible mold interfaces, suggesting new pathways for mass production of functional patterned surfaces.

Keywords: Silicone Molds; Wetting; Mass Production; Micro/nano-structures

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Influence of Prepolymer Structure and Crosslink Density on the Mechanical Properties and CMP Behavior of Polyurethane Pads

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This study investigates the influence of prepolymer structure and curing ratio on the mechanical and chemical mechanical polishing (CMP) performances of polyurethane-based micro-patterned (MP) pads. Two polyurethane prepolymers were formulated with an aromatic diamine curative, and the curing ratio was adjusted to 80%, 95%, and 110% of the stoichiometric level to control crosslink density. The cured pads were evaluated using Dynamic Mechanical Analysis (DMA), tensile and hardness testing, followed by CMP evaluation on SiO2 wafers. DMA results indicated that both prepolymers exhibited higher storage modulus and glass transition temperature with increasing curing ratio, reflecting enhanced crosslinking. Tensile and hardness results showed that pads cured at 95% displayed the best balance between stiffness and toughness. CMP tests confirmed that the pad cured at 95% achieved the highest material removal rate approximately 3900 Å/min with uniform removal, while pads cured beyond the stoichiometric ratio (110%) showed reduced flexibility and decreased polishing efficiency. These findings demonstrate that controlling crosslink density through the curing ratio is critical for optimizing mechanical strength and CMP performance. The 95% curing ratio provides the optimal balance between durability and removal efficiency, highlighting the importance of curing control in the design of advanced polyurethane-based CMP pads for next-generation semiconductor applications.

Keywords: Polyurethane; Micro-patterned Pad; Crosslink Density; Mechanical Property; CMP Performance

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Effect of Micropatterned Pad Design on Particle Removal Efficiency during Buffing

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The post-CMP cleaning process is essential for removing residual particles that may cause defects in subsequent semiconductor fabrication steps. However, the polyvinyl acetal (PVA) brush tends to accumulate contaminants during repeated use due to its porous structure, which can lead to re-deposition of particles onto the wafer surface. This study proposes a micropatterned (MP) pad buffing process as a pre-cleaning step to reduce particle accumulation on the PVA brush. The objective was to clarify how pad design parameters—Designed Contact Area (DCA) and Designed Contact Length (DCL)—influence particle removal efficiency (PRE). Nine MP pads with various pattern sizes and contact ratios were tested using deionized-water buffing. Experimental results showed that a DCA of 15% consistently provided the highest PRE, while excessive contact area (25%) caused particle trapping and lower cleaning performance. Pads with Basic Figure (BF) patterns exhibited 68% higher PRE than Repetitive Pattern Figure (RPF) designs, confirming that sufficient pattern spacing facilitates particle displacement. Moreover, introducing surface grooves promoted particle sliding, enhancing PRE more than sixfold within 10 s. These findings demonstrate that both detachment and displacement of particles are vital for efficient cleaning. The MP pad buffing process effectively mitigates PVA brush contamination while maintaining high particle removal performance, showing strong potential for advanced post-CMP cleaning applications.

Keywords: Post-CMP Cleaning; Micropatterned Pad; Pad Design; Particle Removal Efficiency; Contamination

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Influence of Micro-Patterned Pad Design on CMP Material Removal Rate

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This study investigates the relationship between micro-patterned (MP) pad design and material removal rate (MRR) in chemical mechanical polishing (CMP). MP pads with systematically varied unit figure (UF) size, density, and shape were fabricated to evaluate how pad geometry influences polishing behavior. Among the design parameters, UF size was found to have the greatest effect on MRR, followed by density and shape. The surface topography of each pad was precisely measured using optical profilometry, and the real contact area was calculated from the measured surface geometry data based on an elastic contact model. The calculated real contact area was then combined with a geometrical design factor defined as the ratio of UF perimeter length to apparent contact area. A linear correlation was observed between MRR and the product of this combined factor and the calculated real contact area, indicating that both the real contact mechanics and designed surface geometry collectively determine the polishing performance. These findings highlight that MRR can be effectively predicted through parameters derived from both measured surface profiles and geometric design characteristics. This approach provides a quantitative framework for optimizing micro-patterned pad structures, enabling more controllable and predictable CMP processes through the rational design of pad surface geometry.

Keywords: Chemical Mechanical Polishing; Structured Surface; Material Removal; Polishing

Acknowledgement: This study was conducted with the support of Key-Tech project of KITECH(EH250008)

Robust Microdroplet Dispensing Enabled by a Droplet Pusher Mechanism on Superhydrophobic Substrates

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Microdroplet injection technology is vital in many scientific and industrial applications, yet achieving precise control of microliter-sized droplets remains challenging due to reliance on expensive, complex systems. This study introduces a novel, simple, and cost-effective dispensing pusher (DP) made from a perforated aluminum plate treated to be superhydrophobic, enabling highly reliable separation of microliter droplets. The DP's surface, modified with heptadecafluoro trichlorosilane coating, exhibits an average contact angle of 161.5°, ensuring minimal wetting and outstanding corrosion resistance. Experimental methods included mechanical drilling of circular aluminum specimens with various hole diameters, followed by chemical surface treatments and 3D printing for consistent holder positioning. Droplets were dispensed using a stainless steel nozzle, with separation performed as the droplet contacted and was physically pushed by the DP. Quantitative experiments evaluated droplet separation across five hole diameters (0.85–2.50 mm, measured slightly higher post-etching), yielding droplets from 2.97 ± 0.41 μL up to 11.9 ± 0.52 μL. The average error rate between experimental values and calculated trend lines was only 4.33%, confirming high reproducibility. Mathematical analysis showed that surface tension and push force dominate over frictional effects, providing predictable droplet control. The DP's superhydrophobic properties supported durable, repeated use and scalability. In conclusion, this microdroplet dispenser provides robust, low-cost, and reusable control of microliter-sized droplets, overcoming conventional system limitations. Its reliability suggests strong potential for mass production and broad application in fields demanding precision liquid handling, such as biotesting and microfluidics.

Keywords: Droplet Pusher; Superhydrophobic; Superhydrophilic; Microdroplet; Microfluidic Device

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Atomic-Scale Simulation on Material Removal Mechanism according to Material Type in CMP Process

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The dishing phenomenon occurs due to the difference in material removal rates between copper and silicon during the Chemical Mechanical Polishing (CMP) process. This negatively impacts the quality of Cu-Cu bonding and device reliability. Understanding the material-specific removal characteristics at atomic level is therefore essential for process optimization. This study used Molecular Dynamics(MD) simulations to analyze the atomic-scale removal mechanisms of Cu and Si substrates during CMP. A SiO_2 sphere was modeled to simulate the abrasive in the CMP process and rectangular Cu and Si substrates were modeled to analyze the difference in material removal rates between the two materials. EAM potential was used to simulate behavior of the Cu substrate, and Tersoff potential was used for the Si substrate. The Lennard-Jones potential was applied for Cu-Si and Cu-O interactions. To simulate CMP process, the SiO_2 sphere was indented into the substrate and moved horizontally. A Si substrate of which dimension was similar to that of the Cu substrate model was used for comparative analysis under identical indentation depth and normal load conditions. Simulation results showed that during the horizontal sliding process, the Cu substrate generated approximately one-third frictional force of the Si substrate. The Cu substrate exhibited a high MRR of around 8%, whereas the Si substrate showed a low MRR of approximately 5%. In conclusion, the Cu substrate demonstrated a 1.6 times higher MRR than the Si substrate, despite experiencing lower frictional force. This confirms the higher removal characteristic of copper in CMP and provides fundamental data for understanding the dishing phenomenon observed in actual processes.

Keywords: CMP; Dishing; Friction; HBM; Molecular Dynamics

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Molecular Dynamics Study on the Tribological and Mechanical Characteristics of Doped DLC Nanocomposite Coatings

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The automotive industry is rapidly transitioning toward eco-friendly mobility, driven by the increasing global demand for sustainable development and stricter carbon emission regulations. Electric vehicles (EVs) are at the forefront of this shift, gaining attention as the future of mobility due to their high energy efficiency and eco-friendliness. However, EVs present unique technical challenges stemming from their distinct operating environments, which differ significantly from traditional internal combustion engines (ICE) vehicles. These challenges include issues like electric corrosion due to high-voltage inverter operation and wear in low-viscosity lubrication environments, all of which can degrade the EV powertrain's performance and lifespan. While high-hardness coatings, such as Diamond-like Carbon(DLC) coatings, have been widely used to enhance the durability of dynamic mechanical components, the different working conditions of EVs limit the effectiveness of carbon alone coatings. To overcome these complex tribological characteristics, this study investigates the application of doping elements within the DLC coating to simultaneously achieve low friction and high toughness. Using molecular dynamics (MD) simulation, a model for DLC nanocomposite coatings doped with various elements (such as Zr, Ti, and Cu) was constructed to predict its mechanical and tribological characteristics. The simulation results revealed that as the content of the doping increased, the material exhibited a trend of increased friction force and decreased elastic modulus. This research contributes to the fundamental design of coatings optimized for extreme EV environments by characterizing complex material properties through MD simulation.

Keywords: Molecular Dynamics Simulation; Friction; Diamond-like Carbon(DLC); Metal Doping

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Poster Session 3 Tribology, Surface Engineering **PP3-41**

Copper-Based Surface Modification for Enhancing Corrosion Resistance of Magnetocaloric Materials

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$La(Fe,Si)_{13}$-based magnetocaloric materials (MCMs) are promising candidates for solid-state cooling systems due to their excellent magnetocaloric effect near room temperature. However, their inherent susceptibility to corrosion in water-based heat transfer fluids significantly limits their practical applications.To address this limitation, electroless copper plating was employed as a surface modification strategy to enhance the corrosion resistance of La-based MCMs. Unlike polymer coatings, metallic copper layers provide a dense, conductive, and adherent barrier that offers mechanical robustness with minimal sacrifice in thermal conductivity. Corrosion characteristics were evaluated using potentiodynamic polarization (Tafel plot) in 3.5 wt% NaCl solution. Additionally, immersion tests in distilled water were conducted to monitor real-time degradation behaviors. Surface wettability was characterized by water contact angle measurements to detect any surface energy changes due to corrosion. Cross-sectional imaging was also used to assess the depth and progression of corrosion. The uncoated $La(Fe,Si)_{13}$ alloy exhibited rapid degradation upon water exposure, while copper-coated samples showed a notably slower and more gradual corrosion pattern. This stark contrast highlights the effectiveness of the copper barrier layer in delaying the corrosion kinetics in aqueous environments. These results suggest that copper-based metallization can serve as a practical and scalable method for improving the chemical durability of magnetocaloric materials without compromising thermal performance, paving the way toward more robust magnetic refrigeration technologies.

Keywords: Magnetocaloric Materials; Corrosion Resistance; Electroless Copper Plating; Surface Modification; Wettability and Degradation Analysis

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Micro-Hierarchical Structure Fabrication Method Using Water Vapor Condensation

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Superhydrophobic surfaces are commonly defined as those exhibiting a water contact angle greater than 150°. Such surfaces show low adhesion to water and possess excellent water repellency and self-cleaning capabilities, with the lotus leaf being a representative example. These characteristics arise from micro–/nanoscale hierarchical structures, which offer significant potential advantages across various industrial applications. However, conventional fabrication processes for superhydrophobic surfaces suffer from limitations such as high cost and fabrication complexity due to their reliance on precision equipment and intricate patterning steps. In this study, we propose a simple and cost-effective method for fabricating superhydrophobic surfaces by inducing water vapor condensation onto pre-fabricated microstructures. First, pillar-shaped microstructures were fabricated using imprint lithography. Water vapor was then condensed onto the microstructures using a thermoelectric cooler, and the resulting hierarchical structures were replicated with polydimethylsiloxane (PDMS). The structures were further replicated with polyurethane acrylate (PUA) to enhance reproducibility and simplify the overall process. The contact angle of the resulting surface could be tuned by controlling the condensation time under constant humidity and temperature, thereby adjusting the size and morphology of the condensed droplets. The fabricated surfaces exhibited superhydrophobic behavior with contact angles exceeding 150°, as verified using deionized water. Additionally, sliding angle measurements showed an approximate 55% reduction in sliding angle.

Keywords: Superhydrophobic Surface; Hierarchical Structure; Wettability; Condensation

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An Overview of Marine CO_2 Transport and Injection Technologies

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This research presents two ongoing studies on marine CO_2 transport and injection conducted by the Korea Institute of Geoscience and Mineral Resources (KIGAM). The 'Independence of Core Technology for Marine CO_2 Injection System' project focuses on the design of a system and operational process for injecting CO_2 into the seabed. To this end, KIGAM has established a vertical CO_2 flow line that simulates a subsea injection system, enabling investigation of the flow behavior and phase transitions of liquid CO_2. The 'Multi-functional Ship Design for Grand-Scale CO_2 Capture, Transport, and Injection' project aims to develop a multifunctional vessel capable of CO_2 capture, transport, and injection, along with the design and validation of floating offshore CO7 injection technologies. In support of this effort, KIGAM is conducting maritime validation studies using experimental facilities that simulate floating CO_2 temporary storage. These studies are expected to facilitate the acquisition of core technologies for subsea CO_2 injection, enhance the efficiency of CO_2 transport and injection processes, and provide essential technical insights for cost reduction.

Keywords: CO_2 Injection, Pipeline, CO_2 Transport, CCS

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Feasibility Test for Mechanical Reinforcement of Aramid Paper

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Aramid nanofibers (ANFs) are polymer-based nanofibers that exhibit high tensile strength and modulus, excellent thermal and chemical stability, and outstanding insulating properties, and have therefore attracted attention as next-generation insulating and reinforcing materials. In this study, an ANF coating layer was applied to the surface of an aramid paper substrate to enhance its tensile strength and overall mechanical performance, and to examine accompanying changes in dielectric withstand properties. Commercial aramid fibers were deprotonated to prepare an ANF suspension, which was then coated onto the paper and dried to fabricate ANF-coated specimens. Tensile tests were carried out to evaluate the strength and fracture behavior of the specimen. This study demonstrates the potential of ANF-based coatings for the mechanical reinforcement of the paper and is expected to provide fundamental design guidelines for sheet-type materials that combine structural and insulating functions.

Keywords: Aramid Nanofiber; Meta Aramid Paper; Mechanical Reinforcement; Coating

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Effect of Deep Cryogenic Treatment and Subsequent Aging on the Fatigue Performance and Microstructural Stability of Inconel 718 Alloy

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Inconel 718 is a precipitation-strengthened nickel-based superalloy widely used in aerospace, power generation, and defense industries due to its excellent high-temperature strength and corrosion resistance. However, the increasing demand for extended service life and higher fatigue reliability under extreme environments has revealed the limitations of conventional solution and aging treatments. This study investigates the combined effects of deep cryogenic treatment (DCT) and subsequent aging on the mechanical properties and fatigue behavior of Inconel 718 alloy. Hardness tests were conducted using specimens treated under a single DCT condition (−160 °C for 9 h) and compared with as-received, aged-only, and DCT-only specimens. The DCT and DCT-aging specimens exhibited average hardness values of approximately 505 HV and 503 HV, representing an increase of about 12% and 11% compared with the as-received (≈452 HV), respectively. These improvements are attributed to residual stress relaxation and microstructural homogenization induced by DCT. Microstructural analyses using SEM and EBSD were performed to clarify the correlations among heat-treatment parameters, microstructural evolution, and fatigue behavior. This integrated heat-treatment route is expected to improve both fatigue resistance and microstructural homogeneity, providing practical guidelines for optimizing the design and processing of high-performance Inconel 718 components.

Keywords: Deep Cryogenic Treatment; Aging; Fatigue Performance; Microstructural Stability; Inconel 718

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Poster Session 4 Advanced Materials, Composites **PP4-3**

Geometry-Dependent Luminance of DLP 3D-Printed $FAPbBr_3$/Polymer Lattice Structures

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Formamidinium lead bromide ($FAPbBr_3$) halide perovskites have attracted significant attention for next-generation light-emitting applications owing to their high photoluminescence efficiency and narrow emission bandwidth. However, their poor environmental stability especially against moisture, heat, and ultraviolet (UV) light causes rapid degradation and restricts practical device use. In addition, their powder and thin-film forms suffer from mechanical fragility and limited structural control, hindering the realization of durable and shape-tunable photonic systems. In this work, a mechanically robust and optically stable perovskite–polymer composite was developed by incorporating surface-ligand-treated $FAPbBr_3$ powders into a photocurable resin via digital light processing (DLP) 3D printing. Oleic acid (OA) and oleylamine (OAm) surface passivation enhanced both photoluminescence efficiency and dispersion stability, while the polymer matrix provided environmental protection and mechanical reinforcement. Systematic studies on perovskite concentration and printing thickness revealed that 0.5 wt% loading and 0.5 mm thickness yielded the maximum emission intensity by minimizing scattering and reabsorption losses. Using these optimized parameters, lattice-structured composites exhibited uniform green emission selectively activated under UV light and a clear dependence of brightness on lattice geometry. These results demonstrate that combining chemical stabilization with structural engineering enables UV-activated, mechanically durable, and optically stable light-emitting composites. This approach offers a promising route toward optical encryption, anti-counterfeiting, and secure photonic applications based on perovskite–polymer hybrid architectures.

Keywords: $FAPbBr_3$ Perovskite; Surface Ligand Treatment; DLP 3D Printing; UV-triggered Luminescence; Photostability

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Comparative Study of Silicon-on-Nothing (SON) Structures Fabricated via Metal-Assisted Chemical Etching and Deep Reactive Ion Etching

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Silicon-on-Nothing (SON) technology, which involves creating buried cavities within a silicon substrate, serves as a vital platform for high-performance MEMS devices. Typically, SON structures are fabricated by forming initial trench arrays followed by high-temperature annealing to induce coalescence. While Deep Reactive Ion Etching (DRIE) is the industry standard for trench formation, it requires expensive high-vacuum equipment and suffers from drawbacks such as RIE lag and sidewall scalloping. Although the subsequent annealing process can heal these plasma-induced defects, the high process cost and complexity remain significant challenges. To address these issues, this study introduces Metal-Assisted Chemical Etching (MACE), performed at room temperature and atmospheric pressure, as a cost-effective alternative to DRIE. We conducted a comparative analysis of SON structures fabricated using both methods. Our results indicate that MACE rapidly forms high-aspect-ratio trenches utilizing a chemical mechanism without the need for vacuum equipment. Following identical vacuum annealing steps, both the DRIE-processed and MACE-processed samples successfully transformed into defect-free single-crystal silicon membranes with comparable surface roughness and structural integrity. In conclusion, this study demonstrates that the MACE-based SON process achieves structural quality comparable to the conventional DRIE method while significantly reducing equipment dependency and process costs. Thus, MACE serves as a highly efficient and practical alternative for the mass production of large-area SON platforms.

Keywords: Silicon-on-Nothing(SON); Metal-Assisted Chemical Etching(MACE); Deep Reactive Ion Etching(DRIE)

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Metamaterial Adhesive-Integrated Triboelectric Nanogenerators with Tunable and High-Performance Charge Generation and Adhesion

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Although triboelectric nanogenerators (TENGs) are effective at harvesting energy from contact separation, achieving enhanced and programmable output via controlled separation remains a challenge. To address this, we introduce a metamaterial adhesive-integrated TENG (MetaAdh-TENG) featuring nonlinear cut patterns within a silver nanowire (AgNW)-embedded adhesive film. This unique architecture facilitates spatially programmable and amplified triboelectric generation and adhesion. By accelerating local crack velocity via crack trapping and reverse crack propagation mechanisms, the MetaAdh-TENG delivers a 12.8-fold increase in peak voltage (7.3 V) and a 34.8-fold improvement in peel adhesion (202.3 N m^{-1}) compared to planar counterparts. Furthermore, the cut geometry allows for independent, local control over charge output, adhesion strength, and directionality. These tunable properties enable diverse applications, including battery-free smart monitoring systems and continuous roll-type energy harvesters.

Keywords: Interfacial Crack; Kirigami; Mechanical Metamaterials; Smart Adhesive; TENG

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Growth and Optical Analysis of Carbon Nanofiber Black Coatings on Aluminum Alloys

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Carbon nanofiber (CNF) forests were synthesized on aluminum alloy substrates to realize ultra-black coatings with broadband low reflectance. Vertically aligned CNFs were grown by thermal chemical vapor deposition, while systematically varying the growth parameters such as catalyst thickness, growth temperature, and growth time to optimize the morphology and areal density of the CNF forests. The resulting coatings were characterized using scanning electron microscopy and UV–vis–NIR spectrophotometry to correlate structural features with optical performance. In the near-infrared regime, the CNF forests were treated as an effective medium, and their effective refractive index was extracted using the Maxwell–Garnett approximation. Reflectance simulations based on this model showed good agreement with the measured spectra, confirming that a graded effective index and high aspect ratio are key to suppressing Fresnel reflections. In contrast, in the UV–visible range, the experimentally observed reflectance was dominated by enhanced scattering from the fibrous nanostructure. This behavior was analyzed using a Mie-type scattering approach combined with finite-difference time-domain (FDTD) simulations, which revealed how CNF diameter distribution and packing density control the balance between absorption and scattering at shorter wavelengths.

Keywords: Carbon Nanofiber Forest; Black Coating; Aluminum Alloy; Maxwell–Garnett; Mie Scattering; FDTD; Reflectance

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ZIF-67@Carbon Black In-situ Biomass Based Biodegradable Film with High Flexibility and Mechanical Properties for Ammonia Gas Sensing

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Biomass (BM) based biosensor is fabricated using in-situ hybridization, which is completely biodegradable and non-harmful to environment. Mild base hydrolysis enabling utilization of biomass containing cellulose-hemicellulose and lignin without any external addition and wastage. The film fabricated showed flexible properties with mechanical properties. Embedded within the hydrophilic biomass matrix, this hierarchical architecture exhibits enhanced redox kinetics and efficient ammonia (NH_3) adsorption, enabling sensitive, room-temperature electrochemical detection. To impart selective gas sensing, ZIF-67@CB network was formed using ZIF-67 nanocrystals are nucleated in situ on carbon black (CB), resulting in a coherent with strong interfacial coupling, a high electroactive surface area, and continuous electron-transport pathways. The optimized BM–CB–ZIF film achieves sub-ppm ammonia sensing down to 1 ppb (0.001 ppm), exhibits excellent operational stability over 3500 s, and demonstrates strong selectivity against structurally similar or food-derived interferents. For real time application shrimp was used eluates demonstrate a clear correlation between electrochemical output, pH drift, and total volatile basic nitrogen (TVBN) accumulation during spoilage, confirming early-stage detection capability. This study establishes a sustainable pathway for high-performance gas sensors by coupling total biomass valorization with interface-engineered nanoarchitectures for intelligent food-packaging applications.

Keywords: Carbon Black; ZIF-67; Biomass; Ammonia Gas Sensing; Biomass Composite

Evaluation of the Potential of an Oil-Immersion-Based Drying Process for Nanocellulose Bulk Fabrication

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Nanocellulose bulk materials have attracted increasing interest as eco-friendly structural resources with potential applications in various fields, and the drying process plays a critical role in determining their final shape quality and dimensional stability. In this study, an oil-immersion-based drying process was introduced as a new approach to the drying stage. The specimens were completely immersed in oil and dried at a controlled temperature, without the temperature and humidity-controlled drying used in the previous study. The oil-immersion approach shows promising potential for simplifying the process, reducing equipment dependence, and exploring a new drying mechanism. This study serves as a preliminary examination to assess the applicability of an oil-immersion drying approach to nanocellulose drying processes.

Keywords: Nanocellulose; Eco-friendly; Drying Process; Oil-immersion; Material Process Design

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Ultrafast Laser Processing for High-Resolution Side Electrodes for Large Area Display

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The increasing demand for large-scale displays in environments, such as conference rooms, broadcasting studios, and public information systems, has accelerated the need for highly efficient and scalable manufacturing technologies. Conventional fabrications using large area glass substrates suffer from low space utilization and significant yield loss due to size effect. To overcome these limitations, modular display architectures—where small display units are tiled into a seamless large panel—have gained attention. A critical challenge in this approach is minimizing the bezel between modules to avoid visible gaps. In this paper, we present ultrafast metal electrodes patterning with ~10 μm resolution across roughed and curved glass edges. The process integrates coating, patterning, and side-wall interconnection within a mask-free workflow, ensuring continuous electrical pathways and strong adhesion. This approach significantly support bezel-free integration of large area display, offering a practical pathway toward high-quality, high-productivity large-display manufacturing.

Keywords: Ultrafast Laser Processing; Side-wall Electrode; Large Area Display; Glass Side Interconnection; Modular Display Integration

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Laser-Induced Fabrication of Silicon Microstructures with Diverse Morphological Specification

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Silicon microstructures, characterized by their high surface-area-to-volume ratio, are essential components in various fields such as energy storage and biosensing, where they significantly enhance performance. However, conventional top-down fabrication methods—typically based on semiconductor processing—are complex, costly, and environmentally restrictive due to the use of hazardous chemicals, high-vacuum systems, and cleanroom conditions. In this study, we propose an eco-friendly, ambient-condition bottom-up approach to fabricate diverse silicon microstructures using laser processing. The method involves coating silicon nanoparticles onto a copper foil, followed by pulsed laser irradiation to induce fragmentation and sintering of the particles, resulting in the formation of distinct microstructures. By controlling laser power and pulse intervals, we successfully demonstrated the formation of three types of structures: (1) bump, (2) double bump, and (3) hierarchical structures. This process operates entirely under atmospheric pressure and room temperature, enabling high-speed, high-resolution patterning via localized irradiation. It also offers advantages in reducing process time and improving energy efficiency. This work presents a novel strategy for silicon microstructure fabrication by enabling precise structural control through laser parameter tuning. The approach shows great potential for expansion toward high-performance device applications and scalable, large-area manufacturing technologies.

Keywords: Silicon Microstructures; Laser-induced Fabrication; Bottom-up Manufacturing

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Integrated Thrust–Temperature Prediction Model for Ultrasonic Vibration–Assisted Drilling of Unidirectional CFRP Laminates

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This study develops an integrated thrust–temperature prediction model for ultrasonic vibration–assisted drilling (UVAD) of unidirectional CFRP. By discretizing the chisel edge and main cutting edges and introducing an ultrasonic influence coefficient together with fiber-orientation–dependent specific cutting energy, a thrust model capable of capturing intermittent cutting and ploughing effects is established. The chisel edge and main cutting edges are further modeled as a circular and a conical moving heat source, respectively. Combined with the predicted thrust forces and the anisotropic thermal conductivities of CFRP, a three-dimensional transient heat-transfer model is formulated, and heat-partition coefficients are identified using a conjugate gradient inversion method. Experimental validation shows that the model accurately reproduces half-revolution thrust oscillations and temperature evolution, achieving prediction errors of 5.34% for thrust and 4.98% for peak temperature, while correctly capturing the 15–20 °C temperature reduction enabled by ultrasonic assistance. The enhanced predictive accuracy demonstrates the model's capability to reflect the coupled thermo-mechanical behavior of UVAD and provides a robust theoretical foundation for improving drilling quality, suppressing thermal damage, and guiding parameter optimization in composite machining.

Keywords: Ultrasonic vibration–assisted drilling; Unidirectional CFRP; Thrust prediction; Anisotropic heat conduction; Temperature modeling

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Conformal Skin Bioelectronics with Leakage Resistance Using Self-Adhesive Tip-Structured Liquid Metal Channel Patch

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Conformal skin bioelectronics require intimate and durable skin interfaces, yet conventional gel- and dry-type electrodes often suffer from dehydration, insufficient conformity, skin irritation, and interfacial delamination under motion, which severely limit long-term performance. Here, we introduce a self-adhesive liquid metal channel (S-LMC) patch that enables conformal and leakage-resistant skin bioelectronics through tip-structured microarchitectures. The patch integrates open-bottom Galinstan microchannels and micropillar arrays, both incorporating re-entrant tip geometries that promote robust skin adhesion while suppressing liquid metal leakage. A vertical via-hole interconnect allows direct signal transmission through the patch, eliminating bulky lateral wiring and supporting compact system integration. The S-LMC patch exhibits strong and reusable skin adhesion (>60 kPa), low skin–electrode contact impedance (7.35 kΩ·cm^2 at 10 Hz), and minimal skin irritation during prolonged wear. Compared with commercial Ag/AgCl gel electrodes, the patch demonstrates over fivefold lower impedance, more than twofold higher ECG signal fidelity under motion (20.23 dB vs. 9.03 dB), and a 2.4-fold improvement in adhesion retention after seven days. Moreover, the tip-structured channel design significantly enhances Galinstan confinement, yielding more than a twofold increase in the critical leakage pressure. These results establish self-adhesive, tip-structured liquid metal channels as an effective strategy for conformal, leakage-resistant skin bioelectronics with high signal stability and long-term reliability.

Keywords: Health monitoring; Liquid metal; Skin electrode; Via-hole interconnects; and Wearable electronics

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High-Performance Piezoelectric Nanogenerator Realized by Multistackable CNT Scaffolds Hybridized with BTO-P(VDF-TrFE)

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This study presents a multilayer-stackable piezoelectric nanogenerator (PENG) architecture enabled by domino-overlapped carbon nanotube (CNT) scaffolds homogeneously hybridized with $BaTiO_3$ (BTO) and poly(vinylidene fluoride-co-trifluoroethylene) (P(VDF-TrFE)). Vertically aligned CNT pillars are patterned through a domino geometry and subsequently transformed into freestanding hybrid PENG layers via capillary-force-driven infiltration of BTO nanoparticles and P(VDF-TrFE) solution. This hybridization not only preserves the nanoscale alignment and inherent porosity of the CNT scaffold but also facilitates the formation of the β-phase within the composite polymer matrix, thereby enhancing the efficiency of piezoelectric charge generation and transfer. The mechanical–electrical performance of the resulting CNT-based PENG (CPENG) is systematically evaluated with respect to CNT scaffold length and stacking configuration. The output voltage increases monotonically with CNT length until 120 μm and shows a substantial boost when multiple CPENG layers are stacked. A four-layer device with optimized CNT scaffolds (1 cm × 1 cm size) generates a maximum open-circuit voltage of 12.3 V and maintains high operational stability for over 2000 mechanical cycles. The device also exhibits robust output under diverse real-world mechanical inputs, including finger tapping and foot pressing, demonstrating its practical ability to convert human motions into reliable electrical energy. Furthermore, the CPENG sustains stable operation across a wide temperature range from −20 to 100 °C, underscoring its applicability in harsh or variable environments. Overall, this work establishes a mechanically resilient CNT-based multilayer PENG platform with high piezoelectric output, structural tunability, and environmental durability, offering promising potential for self-powered sensing, wearable electronics, and flexible energy-harvesting systems.

Keywords: Piezoelectric Nanogenerator; Carbon Nanotube Scaffold; Homogeneous Hybridization; Multilayer Stacking; Wearable Device

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Reliable Manufacturing of Multidimensional CNT Structures Based on Catalyst Nanoparticle Analysis and Generative Adversarial Network-Based Prediction

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We investigate how the catalyst nanoparticle (NP) morphology established during annealing governs whether CNT forests reach the crowding threshold required for dense, vertically aligned growth. Using Fe/Al_2O_3 catalysts on patterned and unpatterned substrates, we systematically vary annealing temperature, time, and catalyst areal coverage, then quantify three descriptors from SEM images: perimeter (size proxy), circularity (shape regularity), and areal count (number density). SEM data are normalized by Gaussian blur and histogram equalization to ensure consistent contrast and robust contour extraction at a fixed field of view (1280 × 896 pixels, ×100,000). Across 750-800 °C and multiple annealing times, NP morphology evolves under coupled Ostwald ripening and subsurface diffusion, but the relations are strongly nonlinear and do not extrapolate reliably to untested conditions, particularly for geometrically patterned catalysts. To overcome this barrier, we develop a condition-aware GAN that accepts four annealing factors (temperature, time, pattern geometry) and generates high-fidelity NP images at the origin SEM resolution. Condition sensitivity is preserved at all scales via feature-wise linear modulation in the generator, while a projection discriminator and an auxiliary regression head enforce agreement with the input condition. A lightweight statistic-matching loss aligns edge density and frequency content with SEM texture. Predicted NP morphologies agree with post-annealed experiment data within acceptable error, enabling proactive selection of annealing windows that deliver targeted CNT forest density, alignment, and maximum attainable height. The workflow reduces experimental sweeps, shortens optimization time, and provides a general route to translate annealing-stage descriptors into process windows for application-specific CNT forests.

Keywords: Carbon Nanotube Forests; Catalyst Nanoparticle Morphology; Ostwald Ripening; Subsurface Diffusion; Generative Adversarial Network

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High-Throughput Manufacturing of Flexible Transparent Heaters via Facile Soft-Contact Solution Printing of Ag Microgratings

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We present a scalable manufacturing route for flexible, transparent Joule heaters based entirely on solution processing and soft-contact micro-patterning, suitable for integration on arbitrary surfaces. Instead of brittle, vacuum-deposited indium tin oxide, we employ an ionic Ag solution that is molded and reduced into micropatterned conductors through a soft-contact printing and patterning (SCOP) process. In SCOP, a polydimethylsiloxane (PDMS) mold with microtrenches is conformally pressed onto a thin ionic Ag layer on the target substrate and annealed under controlled temperature and pressure, yielding Ag microgratings without photolithography or etching. We systematically varied the SCOP temperature and pressure and examined how these conditions affected pattern fidelity, sheet resistance, and optical transmittance, thereby defining a practical process window for manufacturing. An intermediate range of process conditions is identified that suppresses residual layers while ensuring complete reduction, producing well-defined Ag lines with high transparency. Sequential orthogonal SCOP steps convert 1D line arrays into 2D mesh heaters, and an airbrushed carbon nanotube (CNT) overlayer is introduced to enhance electrical continuity and mechanical robustness. The resulting heaters exhibit tunable trade-offs between transparency and heating efficiency. On glass substrates, 1D structures maintain ~80% transmittance while reaching 130 °C at 8 V operation. 2D meshes with CNT reinforcement achieve lower sheet resistance and can exceed 250 °C at 6 V, at reduced transmittance. Additionally, fabrication on polymer films and curved glass confirms reliable operation under bending and curvature. Overall, the SCOP-based approach provides a high-throughput platform for transparent flexible heaters and other printed electronic components.

Keywords: Flexible and Transparent Heater; Soft-contact Printing and Patterning; Ionic Metal Solution; Printable Device; Scalable and Solution-processable Fabrication

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Fabrication of Microlens Arrays with Nanopattern-Induced Light Scattering for Suppression of Optical Leakage

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The human eye possesses a convex lens-shaped crystalline structure that enables a wide field of view and simultaneous acquisition of visual information from a broad region. Similarly, most living organisms on Earth perceive visual information through convex lens-shaped eyes. In particular, insects such as dragonflies have multiple small convex lenses, providing them with an even wider field of view. Inspired by such compound-eye systems, a microlens array (MLA) consists of thousands to tens of thousands of microlenses arranged in a periodic pattern and has demonstrated wide applicability in fields such as automotive headlights and optical focusing systems. MLAs fabricated via laser machining, precision cutting, or the reflow process can be easily replicated using nanoimprint lithography (NIL), which also enables flexible integration on curved surfaces. However, undesired light leakage often occurs between adjacent lenses due to the gap regions, and filling these inter-lens voids remains a significant challenge in NIL processes. In this study, to address this issue, nanostructures such as line, hole, and pillar arrays were introduced beneath the MLA pattern during NIL replication to induce intentional light scattering, thereby suppressing optical leakage. Additionally, photocurable resins with different refractive indices were employed to enhance the scattering effect. Experimental results confirmed that MLAs with embedded nanopatterns exhibited reduced light leakage between lenses due to scattering effects, as verified by two-dimensional focal intensity distributions. The findings of this study provide fundamental insights for optical systems utilizing MLAs and light-focusing mechanisms across various mechanical and photonic applications.

Keywords: Microlensarray(MLA); Nanoimprint Lithography(NIL); Nano Pattern; Light Scattering

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Scalable Dual-Layer Silicon Anode Architecture Fabricated via UV Nanoimprint Lithography-Based Roll-to-Plate Process

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Silicon anodes for lithium-ion batteries have attracted significant attention due to their high theoretical capacity; however, severe volume expansion during repeated lithiation and delithiation leads to unstable solid–electrolyte interphase (SEI) formation and dendritic growth, resulting in rapid performance degradation and safety concerns. In this study, a scalable dual-layer silicon anode architecture was designed using a UV nanoimprint lithography (UV-NIL)-based roll-to-plate process, enabling large-area fabrication with high structural uniformity. The proposed anode consists of two functional layers. The first layer comprises silicon and carbon particles uniformly dispersed in a UV-curable resin binder, providing enhanced particle distribution and strong adhesion to the copper current collector. This configuration ensures mechanical integrity and electrical connectivity during electrochemical cycling. The second layer is a porous planar structure formed by blending a UV-curable resin with polyethylene glycol (PEG), which acts as a sacrificial porogen. After curing, the resulting sponge-like porous layer serves as a mechanical buffer that effectively accommodates silicon volume expansion and mitigates stress accumulation at the electrode interface.

This dual-layer design simultaneously improves interfacial stability and structural resilience, suppressing SEI instability and dendrite-related degradation. The UV-NIL-based roll-to-plate process offers a promising manufacturing route for next-generation silicon anodes by combining scalability, precise structural control, and enhanced electrochemical reliability.

Keywords: Si Anode; Lithium-ion Battery; UV-NIL; R2P; Porous Structure

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A Micromagnetic Approach to Local Heating Mechanisms in Cu–Cu Direct Bonding

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As solder-based semiconductor packaging approaches its technical limits, Cu–Cu direct bonding is gaining attention as a promising process for next-generation three-dimensional (3D) packaging. However, the high temperature required for bonding, typically above 350 °C, can cause damage to existing devices. To address this issue, we suggest a local heating approach that uses the magnetic loss of ferromagnetic materials under an alternating magnetic field to generate heat only at the bonding interface.

Through a combination of micromagnetic simulations and supporting experiments based on the Landau–Lifshitz–Gilbert equation, we examine how magnetization dynamics affect heating efficiency and how resonant magnetic fields influence the internal energy of magnetic materials. The study aims to understand and optimize localized heating behavior, providing a possible route for applying magnetically induced local heating to Cu–Cu bonding in future 3D packaging technologies.

Keywords: Micromagnetics; Magnetization Dynamics; Cu-Cu Direct Bonding

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Study on Multiple Radially Distributed High-Aspect-Ratio Structures Using One-Step Exposure Based on the SPPW Process

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Surfaces patterned with microscale HAR(high aspect ratio) structures exhibit a high surface-area-to-volume ratio, multiple light reflections, and liquid-repellent behavior, and are widely used in applications such as microneedles, fluidic sensors, and light-absorbing layers. To fabricate such HAR structures, the SPPW(self-propagating photopolymer waveguide) process, which exploits total internal reflection arising from the refractive index contrast between cured and uncured polymer during a single UV exposure, has attracted attention as a fast, simple fabrication method. However, conventional SPPW processes are mainly used to form single HAR structures, and further SPPW-based geometric control is required to enhance their functional performance. In this study, we present a method for fabricating radially distributed HAR structures in a single exposure using a radial UV-LED exposure system with a square array of UV-LED sources. To elucidate parametric trends in their formation, we systematically varied the exposure distance, the number of active UV-LEDs, and the exposure time. Increasing the exposure distance increased the number of LEDs contributing through each mask aperture, leading to a larger number of HAR bundles, while increasing the exposure time increased both the diameter and height of the individual structures within each bundle. The results show that SPPW-based processes can be extended from single to multiple HAR structures in a single exposure, yielding a substantially increased surface area compared with conventional single pillars. This approach enables rapid fabrication of more complex architectures such as micro-lattices, broadening the application space of SPPW and potentially enhancing performance in various microstructured-surface applications.

Keywords: Self Propagating Photopolymer Waveguide; Radial UV LED; Multiple Radial Structure

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Selective Photo-Exposure-Based Fabrication of Slippery Surfaces for Enhanced Particle Aggregation

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High-sensitivity biosensors have become essential technologies in various fields, including early disease diagnosis, environmental monitoring, and food safety management. However, conventional biosensors often have limited sensitivity, making it difficult to accurately detect analytes in highly dilute solutions. To address this limitation, surface modification techniques such as metal coating and microstructuring have been explored, but these fabrication processes are generally complex, time-consuming, and costly. In this study, we fabricated slippery surfaces with locally designed non-slippery regions through a simple selective exposure process using a digital mask. This method not only enables precise control of surface wettability but also significantly reduces fabrication time and cost compared to conventional approaches. When various colloidal droplets containing mixtures of inorganic and organic particles were evaporated on the fabricated surfaces, analytes were observed to selectively aggregate within the non-slippery regions. In this process, particles in low concentrations were effectively concentrated on the non-slippery areas, resulting in amplified signal intensity. Moreover, because these regions were not covered by lubricating oil, signal interference was minimized, leading to improved measurement accuracy. By spatially designing the non-slippery regions, particle aggregation could be effectively induced at specific target locations, enabling selective analysis within designated areas. These findings demonstrate that digitally patterned slippery surfaces can serve as promising substrates for high-sensitivity biosensors and suggest their potential for extension to a variety of applications.

Keywords: Slippery Surface; Digital Patterning; Evaporation Dynamics; Particle Aggregation; High-Sensitivity Biosensors

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Noise-Reduced SERS Detection Enabled by Liquid-Infused Microcavity Patterns with Air-Lifted Analyte Membrane

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Nature-inspired superhydrophobic and slippery liquid-infused porous surface (SLIPS) interfaces have emerged as essential design components in microfluidic systems, including microfluidic chips, self-cleaning surface, and biosensors. Owing to their low contact angle hysteresis, droplets can move and evaporate with minimal pinning, facilitating the concentration of analyte particles. When combined with plasmonic nanoparticles, these surfaces simultaneously provide electromagnetic enhancement and solute enrichment, evolving into highly sensitive surface-enhanced Raman scattering (SERS)-based detection platforms. However, SLIPS-based SERS substrates often exhibit reduced sensitivity because lubricants encapsulate analytes or metallic nanoparticles. In addition, lubricant depletion during repeated use and the complexity of fabrication hinder their practical applications. Superhydrophobic surfaces also require additional coating processes after pattern formation, resulting in low process efficiency and scalability, thereby calling for new surface design strategies. In this study, an organogel-based microcavity surface was fabricated to achieve localized aggregation of colloidal solutions while promoting air-lifting of analytes toward the top of the patterned surface. This configuration enhances detection sensitivity while minimizing substrate-induced noise. The microcavity surface was replicated using photocurable polydimethylsiloxane (PDMS), silicone oil, and UV nanoimprint lithography. A mixture of polystyrene nanoparticles and gold nanoparticles dispersed in DI water was deposited as a 2 μL sessile droplet on the surface. After complete evaporation, SERS measurements revealed a significant suppression of substrate signals, demonstrating the potential of this approach as a next-generation SERS platform that overcomes the limitations of conventional detection schemes.

Keywords: Organogel; Colloidal Droplet; Evaporation Dynamics; Particle Aggregation; Membrane Formation

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Effects of Coating Thickness on the Durability and Recovery of Hydrophobic Coatings in Electrowetting-on-Dielectric (EWOD) Applications

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Hydrophobic fluoropolymer coatings are widely used in electrowetting-on-dielectric (EWOD) devices due to their low surface energy and smooth interfaces. However, these coatings can degrade over time under environmental exposure, leading to reduced device performance. Previous studies have explored thermal annealing to recover damaged coatings, showing partial restoration of hydrophobicity after submersion. However, these studies mainly focused on the recovery process rather than long-term durability. Moreover, as EWOD devices are increasingly applied in outdoor environments, there is a need to consider more realistic damage mechanisms beyond simple submersion. In this study, the durability of hydrophobic coatings with different thicknesses was examined through a raindrop simulation that reproduced environmental exposure. Damaged samples were heated at 200 °C for 24 hours to recover hydrophobicity and contact angle (CA) and contact angle hysteresis (CAH) were measured to quantify performance changes. Long-term durability was evaluated by repeating the damage–recovery cycle multiple times. After the first cycle, all samples recovered 96–98% of their initial CA. After the second cycle, the 1.0 μm sample, which is a thicker coating, recovered 7–8% more than the 0.1 and 0.5 μm coatings. After the third cycle, all samples exhibited significant degradation, revealing the limitations of repeated recovery. These results show that thicker coating enhances long-term durability under environmental exposure. However, it remains necessary to consider the higher actuation voltage when designing applications due to coating thickness. This study provides quantitative insight into the trade-off between durability and efficiency, offering design guidance for open-air EWOD applications.

Keywords: Hydrophobic Coating; Contact Angle; Contact Angle Hysteresis; Damage-recovery Cycle; Durability

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4D-Printed Bistable Platform for Integrated TENG-Capacitive Multi-Sensing and Acoustic Energy Harvesting

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This study introduces an innovative three-layer integrated sensor platform featuring a bistable structure, fabricated via 4D printing technology and Laser-Induced Graphene electrodes. The platform integrates a Capacitive Sensor and two distinct Triboelectric Nanogenerators within a single architecture, enabling multi-scale sensing and energy conversion. The system exhibits two operating modes. In Bistable 1, the 3x3 FEP-based TENG array on the top surface of the third layer provides touch position mapping and fine pressure detection. Concurrently, the Capacitive Sensor, comprising the bottom electrode on the first layer and the top electrode on the second layer, quantitatively measures deep pressure or structural deformation, ensuring a hierarchical sensing range. The second mode, Bistable 2, is realized as the structure mechanically transitions, causing the second and third layers to pop-up along the Z-axis. The resulting deflection in the linkage structures optimizes the system for acoustic vibration response. In this state, the internal TENG, comprised of paper on the second layer and an FEP film on the bottom of the third layer, is actively engaged to harvest acoustic energy. This multi-functional platform, combining 4D printing and bistable architecture, opens a novel path for sensing a wide range of mechanical stimuli and harvesting energy within a single device.

Keywords: Triboelectric Nanogenerator; Capacitive Sensor; Laser Induced Graphene; Bistable; 4D Printing

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Effect of Heat-Treatment on Gentamicin-Loaded Polyvinyl Alcohol/Chitosan/Gelatin Freeze-Dried Porous Sponge for Biomedical Applications

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The development of porous sponges with enhanced mechanical integrity, tunable degradation, and sustained drug release is critical for biomedical applications, such as wound dressings and tissue-engineered materials. In this study, freeze-dried sponges composed of polyvinyl alcohol (PVA), chitosan (CS), and gelatin (GEL) were developed and loaded with gentamicin as a model antimicrobial agent. Heat treatment at 100 °C for 2 h was used to enhance crosslinking and structural integrity. Evaluation of the untreated and heat-treated sponges demonstrated that thermal treatment significantly improved their structural and functional characteristics. Scanning electron microscopy revealed a highly interconnected porous structure with porosity exceeding 90%. Compressive strength notably improved from 0.198 ± 0.037 MPa in the untreated sponges to 0.255 ± 0.011 MPa after heat treatment. The sponges exhibited high swelling capacity and efficient water uptake, consistent with their open-pore structure. Additionally, the heat-treated samples showed a 40% reduction in degradation rate over three weeks compared to untreated samples. Drug release studies revealed a significant reduction in initial burst release following heat treatment, yielding a prolonged and sustained gentamicin release profile over 72 h. Kinetic analysis indicated that the release mechanism closely followed the Korsmeyer–Peppas model with a diffusional exponent of $n < 0.45$, confirming Fickian diffusion-controlled release. These results demonstrate that heat treatment effectively enhances the mechanical and physicochemical properties of PVA/CS/GEL sponges, providing prolonged antibiotic release and underscoring their potential in advanced biomedical applications.

Keywords: Freeze Drying; Gentamicin; Heat Treatment; Polyvinyl Alcohol; Porous Sponge

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Sustainable PVA/Bi_2Te_3/CD Nanocomposite Films with Enhanced Mechanical and Active Packaging Functions

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This study presents the development of polyvinyl alcohol (PVA) nanocomposite films reinforced with bismuth telluride (Bi_2Te_3) nanoparticles and carbon dots (CDs) derived from apple peel waste for advanced food packaging applications. The nanocomposite films were prepared using a solution casting method to form single- and multilayer architectures. In single-layer films, the uniform dispersion of Bi_2Te_3 nanoparticles within the PVA matrix increased the tensile strength of the films by approximately 105%. It reduced their water vapor transmission rate by about 42%, verifying improved passive barrier characteristics. Incorporating CDs provided additional functionalities, including UV shielding, enhanced optical durability, and antioxidant activity, which contribute to active preservation behavior. The multilayer films, produced by sequential casting, exhibited improved interfacial adhesion and hydrogen bonding, resulting in greater dimensional stability and reduced moisture uptake compared to single-layer films. Optical characterization confirmed that the coexistence of Bi_2Te_3 and CDs modified the light absorption behavior and surface photoreactivity, indicating potential photoresponsive behavior under visible light. Overall, the present PVA/Bi_2Te_3/CD nanocomposite films effectively balance mechanical reinforcement, barrier efficiency, and active preservation capability, demonstrating their potential as a sustainable and multifunctional food packaging system.

Keywords: Multilayer Structures; Bismuth Telluride; Carbon Dots; Polyvinyl Alcohol; Food Packaging

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Homogeneous and Transparent GNR-CNC Composite Films: Scalable Production and Flexible Photothermal Performance

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Gold nanorods (GNRs) are promising photothermal materials due to their strong plasmonic absorption; however, achieving uniform nanoparticle distribution over large areas remains challenging as evaporation-driven flows often induce unwanted aggregation. In this study, we report a universal shear-induced blade coating strategy to fabricate highly homogeneous GNR-cellulose nanocrystal (CNC) composite films. By employing a binary solvent system, selective evaporation triggers solutal Marangoni flows that suppress outward capillary transport, facilitating self-aligned nanoparticle assembly without the "coffee-ring" effect. This scalable approach enables the consistent production of transparent and uniform plasmonic films, demonstrated here on a representative scale of 4.5 cm × 4.5 cm across a diverse range of substrates, including acrylics, silicon wafers, fabrics, and polyurethane. Under one-sun broadband illumination (100 mW/cm2), the films exhibit a reproducible photothermal temperature increase of ~9°C, reaching 30°C within 5 minutes at a heating rate of ~ 1.8 °C/min. Furthermore, polymer-laminated films maintain their robust photothermal response even under severe mechanical deformations, including stretching, rolling, and crumpling. Given its compatibility with various surfaces and industrial coating processes, this strategy provides a highly translatable route toward large-area photothermal devices, such as wearable heaters, smart windows, and energy harvesting systems.

Keywords: Gold Nanorod; Cellulose Nanocrystal; Large-area Coating; Binary Solvent; Universal Patterning

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Optimization of Drying Performance of an Active Greenhouse Solar Dryer

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Drying is an important process of food preservation as it reduces the water content of food items to a level at which microbial growth cannot occur. This paper assessed the performance of an active greenhouse solar dryer using sponge samples under different load densities and spacings (12 sponges, 5 in; 15 sponges, 3 in; 18 sponges, 1 in) over three days in Universiti Malaysia Sabah's tropical environment. Performance of the dryer was assessed against OSD based on drying rate, moisture ratio, and energy efficiency. The results highlights that chamber temperature and drying uniformity were significantly affected by the intensity of solar irradiance. The larger spacing (5 in) resulted in better top layer drying (MR = 0.06; 94% removed) at the expense of larger vertical temperature gradients, while small spacing (1 in) at high irradiance yielded a more uniform drying pattern (MR = 0.10–0.24). The higher amount of water removed was observed at 1.35 kg with an efficiency of 80.1% for 18 sponges subjected to 741 W/m^2 radiation. Overall, the solar dryer reduced drying time by up to 40% and improved energy use by more than 150% compared to the OSD. These results showed that optimized product spacing coupled with appropriate load density can result in significant improvement in the drying efficiency and layer-to-layer uniformity of greenhouse solar dryers.

Keywords: Active Greenhouse Solar Dryer; Thermal Performance; Drying Efficiency; Solar Irradiance; Load Density

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Effect of Gas Pressure and Temperature on Particle Size Distribution in Gas Atomization of SUS316L

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This study investigates the influence of gas pressure and temperature on the particle size distribution produced by gas atomization of SUS316L. In semiconductor processes, gas filters are essential components for delivering high-purity gases, and metallic particles generated through atomization play a key functional role in achieving efficient purification. Gas atomization is widely used for large-scale production of metal particles; however, operating parameters such as gas pressure and temperature critically affect the resulting particle size distribution. To analyze these effects, a numerical model incorporating the Volume of Fluid (VOF) method and the Discrete Phase Model (DPM) was developed using ANSYS Fluent. Parametric simulations were conducted to quantify the relationships between operating conditions and the characteristics of atomized particles. The results provide insight into optimal atomization conditions for producing metal particles suitable for high-purity gas filtration applications.

Keywords: Gas Atomization; Metal Powder; Computational Fluid Dynamics; Gas Filter

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Thermal–Fluid Analysis for Geometry Optimization of Cooling Plates in Heavy-Duty Truck Battery Packs

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Write Previous studies on battery cooling systems have primarily focused on optimizing the geometry and flow-path design of cooling plates for small passenger vehicles, and various design methods have been proposed to enhance their thermal performance. However, in the case of large vehicles such as trucks, the increased length of the cooling plate causes single-channel configurations to exhibit a pronounced deterioration in heat transfer performance and cooling efficiency in the middle and downstream regions. This limitation can lead to reduced battery reliability and safety in heavy-duty electric vehicles that require prolonged high-power operation.

In this context, the present study proposes a new design concept to overcome the structural limitations of large cooling plates by dividing the plate into two lateral flow channels and adopting a bi-directional inlet–outlet configuration. This design aims to ensure a more uniform distribution and circulation of the coolant, thereby improving heat removal performance over the entire plate area. Furthermore, the thermo-fluid characteristics of the proposed structure are quantitatively evaluated through CFD-based detailed simulations, and the results are used to suggest an optimized design direction for battery cooling systems in heavy-duty trucks.

Keywords: Heavy-duty Electric Truck; Battery Thermal Management; Cooling Plate Geometry; Dual-channel Flow Distribution; CFD Simulation

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Flash-Boiling-Based Oil-Water Separation System

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In this study, a vacuum flash-boiling-based oil–water separation system was developed to efficiently remove moisture contamination that continuously accumulates in hydraulic and lubricating oils due to ingress of ambient air and leakage during operation, thereby enabling oil reuse. The system combines the advantages of vacuum dehydration and thermal evaporation by maintaining the chamber pressure below atmospheric conditions. This pressure control regulates the equilibrium between the saturation vapor pressure of water and the external pressure, thereby inducing boiling at relatively low temperatures. In addition, moisture removal efficiency and oil reusability are enhanced by promoting evaporation through oil atomization via a nozzle and heating of the chamber plate. To simulate industrial-level contamination, 1 L of hydraulic oil (Kixx RD HD 46) was mixed with 1 mL of water (1,000 ppm) using a heating and centrifugal mixer at 900 rpm and 60 °C. Experiments were performed under an oil tank temperature of 80 °C, chamber plate temperature of 80 °C, and an internal pressure of −0.8 bar, with the connecting line thermally insulated to minimize heat loss. Moisture content was measured by Karl Fischer Coulometric titration (MKC-710, Kyoto Electronics), which showed that the initial 1,000 ppm decreased to below 100 ppm after five dehydration cycles. The developed system effectively removes accumulated moisture and contaminants, thereby extending equipment life, maintaining hydraulic performance, and reducing maintenance costs. These findings demonstrate the potential of the proposed vacuum flash-boiling system as an efficient dehydration and purification solution for hydraulic oil applications.

Keywords: Hydraulic Oil-Water Separation; Flash Boiling Dehydration; Vacuum Dehydration; Boiling Point Reduction; Atomization

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Phase Flow Rate Measurement Method Using Distributed Optical Fiber Sensor in Horizontal Stratified Flow

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Gas-liquid stratified flow is commonly encountered in horizontal pipelines across essential industries. Accurately determining the individual phase flow rates in real-time is crucial for optimizing process efficiency and ensuring operational safety. However, conventional flowmeters have a fundamental limitation in precisely measuring the flow rate of each phase because they fail to account for the phase fraction and spatial distribution inherent in the separated structure of stratified flow. This study proposes a measurement methodology for individual phase flow rates utilizing a Distributed Optical Fiber Sensor (DOFS). The proposed device consists of a heating wire and an optical fiber sensor(OD 0.155 mm), which are inserted within an STS tube(ID 0.2 mm) and positioned perpendicular to the flow direction. The DOFS provides continuous multi-point temperature data along its entire length at a high resolution of 0.65 mm spatial and 15.61 Hz temporal frequency. The method exploits the difference in heat transfer characteristics arising from the distinct thermal properties (e.g., specific heat capacity and density) of the gas and liquid phases. By applying a constant heat flux to the heating wire, the resulting differences in the rate of temperature change are analyzed to estimate the interface position and the average velocity of each phase, thereby enabling the calculation of the individual phase flow rates. An experimental system simulating air-water stratified flow was constructed, capable of operating with water flow rates up to 13 L/min and air flow rates up to 55 L/min. Interface detection validation identified the interface position as the region exhibiting an abrupt change in the temperature rate. In flow rate experiments, a relationship was observed: the slower the flow rate, the higher the maximum temperature due to a longer heat accumulation time. This phenomenon was quantitatively analyzed using Netwon's Law of Cooling, where the derived cooling constant (k) showed an increase with flow velocity, conforming to theoretical predictions. The results demonstrate the experimental validity of the proposed DOFS-based methodology for individual phase flow rate determination in stratified flow environments.

Keywords: Air-Water Fraction; Interface Detection; Flow Velcoity Measurement; Distributed Temperature Sensing; Rayleigh Backscattering

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Thermo-Mechanical Optimization and Data-driven Prediction of TGV Geometries for 3D Semiconductor Packaging

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Through-glass vias (TGVs) are increasingly considered a viable alternative to through-silicon vias (TSVs) for high-density 3D semiconductor integration due to their favorable thermal properties, reduced interface complexity, and suitability for large-area packaging. However, ensuring thermo-mechanical reliability requires coordinated optimization of via geometry, material selection, array configuration, and bonding conditions. In this study, we present a data-driven thermo-mechanical optimization framework that integrates finite element analysis (FEA), multi-objective genetic algorithms (MOGA), and machine-learning-based prediction to systematically evaluate TGV structures. Circular and polygonal (15-sided) TGVs were modeled together with TSV references under identical thermal loads, bonding pressures, and array sizes (2×2, 3×3, and 4×4). MOGA was employed to minimize three coupled objectives-temperature uniformity, deformation, and von Mises stress-while also maintaining feasible fabrication constraints based on realistic process considerations. The resulting datasets were then used to train a machine-learning model capable of rapidly estimating temperature, deformation, and stress with markedly reduced computation time compared to conventional FEA-based workflows. The results show that TGVs consistently achieve lower peak stresses than TSVs because of reduced thermal expansion mismatch and simplified material interfaces. Polygonal TGVs further demonstrate effective stress dispersion and stable deformation across larger arrays, indicating strong scalability for high-stack 3D integration. The machine-learning model accurately reproduces the primary optimization trends, enabling efficient exploration of design variations and rapid evaluation of thermo-mechanical behavior. Overall, the integrated approach provides a practical and computationally efficient pathway for developing reliable TGV architectures suited for next-generation high-bandwidth memory systems and multilayer chiplet packaging technologies.

Keywords: Laser-assisted Debonding; Wafer-level Packaging; Physics-informed Neural Network; Thermomechanical Behavior; Process Optimization

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Streamlined Droplet-Inspired Channels in PEM Fuel Cell

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Efficient liquid water management is a critical requirement for achieving stable and durable operation in polymer electrolyte membrane fuel cells (PEMFCs). While sufficient membrane hydration is essential for maintaining ionic conductivity, excessive water within the cells can impede gas transport pathways and cause flooding. These interdependent requirements have prompted continuous efforts to develop the flow field for effective liquid water removal. Recent research trends have adopted biomimetics. Nature offers numerous examples of efficient fluid-transport structures, and this study explores a channel design inspired by a falling droplet. The streamlined droplet geometry provides a gradual cross-sectional variation, creating flow paths that promote continuous water migration while minimizing disruption to oxygen transport. To assess the characteristics of this structure, two-phase flow behavior was visualized using high-speed imaging, and polarization measurements were conducted to evaluate the electrochemical performance. The droplet-shaped channel demonstrated enhanced removal of accumulated water, reduced formation of stagnant liquid water, and sustained superior oxygen diffusion at high current densities. The reduced pressure drop also suggests potential advantages in large-scale systems where parasitic power losses are critical. The findings indicate that biomimetic flow field concepts, such as droplet-inspired structure, can enhance PEMFC stability and efficiency by improving liquid evacuation through naturally guided flow pathways.

Keywords: Polymer Electrolyte Membrane Fuel Cell(PEMFC); Nature-inspired Flow Channel; Water Management; Oxygen Diffusion; Flooding

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Assessment of Pre-Osteoblastic Cell Line Behaviors under Low Shear Stress Conditions

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Bone remodels continuously through the coordinated actions of osteoclasts, osteoblasts, and osteocytes, with their behavior shaped by mechanical cues via mechanotransduction. Although relatively high shear stresses (>1 Pa) are well documented to enhance pre-osteoblast/osteoblast function, the effects of lower shear (<1 Pa) remain poorly defined. Here, we examine how low shear stresses (0.01 and 0.1 Pa) influence a pre-osteoblastic cell line using a custom microchannel system engineered to deliver precise flows. Numerical modeling guided the optimization of channel parameters to achieve the target shear while preserving sufficient internal volume for cell viability. CCK-8 and ALP assays showed that low shear significantly increased pre-osteoblast proliferation but progressively suppressed differentiation into osteoblasts. Consistent with this, immunofluorescence and SEM revealed a contracted cell morphology with increased alignment under low shear, suggesting proliferation is promoted via facilitation of mitotic rounding. Together, these findings highlight low shear stress as a key regulator of pre-osteoblast behavior and offer practical guidance for bone tissue engineering strategies that seek to mimic physiological interstitial fluid flow.

Keywords: Pre-osteoblast; Low Shear Stress; Morphology; Fluid Flow; Mechanotransduction

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Experimental and Theoretical Analysis of Electrostatic Effect Degradation in Respiratory Masks under Environmental Exposure

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The recent COVID-19 pandemic has highlighted the importance of Personal Protective Equipment (PPE) and increased public awareness of respiratory masks. These masks require low inspiratory resistance for comfortable breathing, achieved through filtration utilizing electrostatic effects. However, current testing standards only measure mechanical filtration efficiency after removing electrostatic effects, providing limited insight into performance changes during actual use or by particle size. In real-life conditions, masks are easily exposed to moisture such as water or saliva, which can affect their electrostatic performance. This study experimentally investigated how such environmental factors influence the electrostatic filtration efficiency of KF94, KF80, and procedure masks. A Differential Mobility Analyzer (DMA) and a Condensation Particle Counter (CPC) were used to measure size-dependent filtration performance, while Isopropyl Alcohol (IPA), artificial saliva, and deionized water were applied to evaluate changes in filtration efficiency and inspiratory resistance. The results confirmed that environmental exposure reduces the electrostatic effects of the masks. To further understand this mechanism, additional layer-by-layer experiments were conducted. By analyzing Penetration efficiency variations, the weakening of electrostatic effects in contaminated filter layers was verified. Furthermore, an extended SFFE (Single Fiber Filtration Efficiency) theoretical model incorporating electrostatic forces was developed to derive the surface charge density of each layer, providing a quantitative understanding of electrostatic behavior within the mask structure.

Keywords: Respiratory Mask; Electrostatic Effect; Environmental Factor; SFFE(Single Fiber Filtration Efficiency) Theory

CFD Simulation of the Hydraulic Snubber Locking Phenomenon

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This study used CFD to analyze the internal flow of a hydraulic snubber and determine its locking speed. The simulation applied inlet velocity conditions to a model based on actual geometry. Pressure distribution near the valve cone was examined, and the locking point was defined as the balance between hydraulic and spring forces. Results demonstrate that CFD effectively evaluates snubber flow characteristics.

Keywords: Computational Fluid Dynamics(CFD); Hydraulic Snubber; Lockup Velocity

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Development of a Method for Monodisperse Particle Classification and Dry Coating of Active Materials

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Improving the efficiency of energy storage devices is a crucial goal from an Environmental, Social, and Governance (ESG) perspective. In particular, enhancing the performance and efficiency of electric batteries has become increasingly essential. Dry electrode manufacturing technology is gaining significant attention due to its environmental, economic, and energy-efficiency advantages, as it eliminates the solvent used in conventional wet processes, thereby reducing substantial thermal energy consumption during the drying stage. However, current dry powder-spray techniques for electrode fabrication face limitations, such as difficulty in achieving monodispersity of active material particles and precise control over uniform deposition. These limitations lead to microstructural non-uniformities in the electrode and ultimately degrade electrochemical performance. To address these challenges, this study developed a multi-stage particle-size classifier for monodisperse particle separation and a dry coating system for fast and uniform particle deposition. The multi-stage particle-size classifier was employed to obtain monodisperse active material particles and classify them by size, while the dry coating system enabled the particles to be focused and uniformly deposited through a slit nozzle. Computational fluid dynamics simulations were performed to predict particle trajectories within both the classifier and the coating system. The numerical results were validated through experiments. The electrode manufacturing method developed in this study is expected to contribute significantly to improving battery performance and advancing future dry electrode processing technologies.

Keywords: Monodisperse Particles; Active Material; Particle Size Classification; Dry Electrode Coating; Slip Nozzle

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Heat Pipe–Assisted Passive Cooling for LED Lighting Fixtures in Plant Factories

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Effective thermal management of high-power light-emitting diode (LED) lighting fixtures is a critical challenge in plant factory environments, directly impacting fixture reliability, longevity, and overall energy efficiency. This study presents the design and experimental validation of a novel passive cooling solution that integrates a heat pipe with a rectangular-fin heatsink structure. An experimental investigation was conducted to evaluate the cooling performance of several configurations, including a reference model and the proposed designs targeting key heat sources such as the switched-mode power supply (SMPS). The thermal performance was systematically quantified by measuring surface temperatures and calculating thermal resistance. The results demonstrated a significant enhancement in heat dissipation. The optimal configuration, which employed heat pipe-fin structures at both the SMPS and the fixture end, achieved a 30.3% reduction in thermal resistance compared to the reference model, corresponding to a maximum surface temperature decrease of 7.2 °C under operational load. This performance improvement is attributed to the heat pipe's high thermal conductivity effectively spreading heat from localized hot spots, combined with the fins' increased surface area for enhanced natural convection. The proposed system offers a simple, cost-effective, and zero-power solution to improve the thermal stability and reliability of LED lighting in demanding plant factory applications.

Keywords: Plant Factory; LED Lighting; Passive Cooling; Heat Pipe; Heat Dissipation; Thermal Resistance

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Relative Humidity Effects on Electrostatic Precipitator Performance

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Electrostatic precipitators (ESPs) are dust collectors that capture and remove particles using an electric field. They are widely used for pollutant removal in various industrial applications, including power plants, due to their advantage in treating large volumes of exhaust gas. The collection efficiency and power consumption of ESPs are influenced by their discharge characteristics. Changes in relative humidity affect ionization of moisture in the air and ion mobility, thereby altering the corona discharge characteristics. Since these changes lead to variations in the electric field distribution and collection efficiency, understanding the influence of relative humidity is a crucial factor in evaluating ESP performance. In this study, the collection efficiency, discharge current under different applied voltages, and ozone generation of an ESP were measured and compared under various relative humidity conditions. Furthermore, the changes in electrical characteristics were simulated by incorporating the effect of relative humidity into the numerical model. The experimental results revealed that high collection efficiency can be achieved by ensuring high discharge efficiency at an appropriate level of relative humidity. This study is expected to contribute to designing optimal operating conditions by improving the understanding of ESP collection efficiency, discharge characteristics, and ozone generation behavior under different humidity conditions.

Keywords: Electrostatic Precipitator; Collection Efficiency; Relative Humidity; Discharge Current; Ozone Generation

Acknowledgement: This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20217010100110).

Development of an Isokinetic Sampling Probe for UAV-Based Atmospheric Aerosol Measurement

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Precise measurement of fine particulate matter (PM) concentration in the atmosphere is crucial for both meteorological forecasting and public health responses. Mobile measurement platforms such as unmanned aerial vehicles (UAVs) operate primarily within the troposphere (approximately 0.3–1 atm pressure) under high-speed conditions, where achieving representative isokinetic sampling becomes challenging. In this study, an isokinetic sampling probe was developed to overcome the limitations of conventional single-shrouded probes and to ensure stable intake performance even under low-pressure and high-speed conditions. Numerical simulations were conducted to predict variations in the aspiration ratio, and a dedicated wind tunnel was constructed to reproduce airflow speeds up to 300 km/h and tropospheric pressure conditions for experimental validation. As a result, the probe achieved isokinetic sampling of PM2.5 with less than 10% error at speeds up to 300 km/h. In addition, the aspiration ratio decreased with increasing angle of attack, and the results were successfully nondimensionalized using the Stokes number. The isokinetic sampling probe developed in this study significantly reduces sampling errors compared to single-shrouded designs and can be applied to various mobile measurement systems, thereby enabling reliable aerosol sampling across diverse flow velocities and pressure conditions within the troposphere.

Keywords: Isokinetic Sampling; Troposphere; Aspiration Ratio; PM2.5; Sampling Probe

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Development and Validation of a Liquid Level Indicator Using Distributed Optical Fiber Sensor

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This research proposes a novel liquid level measurement system capable of reliably detecting the level of liquids exhibiting large temperature-dependent density fluctuations. To overcome the limitations of conventional liquid level sensors, this study applied a Rayleigh scattering-based distributed fiber optic sensor with high spatial resolution, which enables accurate interface detection by utilizing the distinct heat transfer characteristics between liquid and vapor phases. The proposed liquid level sensor uses a high precision distributed fiber optic sensor based on Rayleigh scattering. A linear heater wire, installed at a specified distance from the sensor, is energized by a power supply, generating heat that is transmitted through the surrounding medium to the fiber optic sensor for temperature measurement. Because water and air differ in their heat transfer mechanisms—conduction and convection—their temperature change rates are distinct. This difference allows clear phase discrimination and precise identification of the liquid–vapor interface. Various experiments were conducted under different heating and cooling conditions to validate the measurement performance, and the results were analyzed considering the thermal behavior of water and air. To further enhance reliability, a moving average technique was applied to raw temperature data, effectively minimizing noise and improving signal clarity. Systematic analysis of heater power, sensor configuration, and data processing algorithms confirmed that the proposed optical fiber-based sensing system provides superior spatial resolution, robustness, and adaptability, making it a promising solution for advanced industrial applications. Future work will focus on optimizing the sensor design and validating its performance in extreme environmental conditions.

Keywords: Liquid Level Sensor; Rayleigh Scattering Distributed Fiber Optic Sensor; Heat Transfer Characteristics; Flexible Installation; Proof-of-concept Experiment

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Electrospun Fibrous Sphere Architectures for Personal Thermal Regulation

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In this study, we present a novel fibrous sphere architecture nanofabric with a bilayer design consisting of a hydrophilic polyacrylonitrile-silicon dioxide layer and a hydrophobic polyvinylidene fluoride-titanium dioxide-aluminum oxide layer, which was fabricated by electrospinning. This engineered nanofabric demonstrates exceptional multifunctional properties, including high solar reflectivity, directional water transport capabilities, and superior thermal and moisture management performance. These properties make it highly suitable for personal cooling applications. Its distinctive fibrous architecture, which strategically embeds bead structures, achieves remarkable optical properties. It exhibits exceptional solar reflectivity of 93% in the solar spectrum and high thermal emissivity of approximately 0.95 in the atmospheric transparency window. Under real-world outdoor conditions with direct solar irradiation, the nanofabric demonstrated substantial cooling performance, reducing skin temperature by 15 °C compared to a conventional cotton textile. This highlights its potential for mitigating heat stress. Furthermore, the nanofabric exhibits impressive subambient radiative cooling capacity, achieving temperature reductions of 5 °C below ambient during peak noon hours and maintaining 2 °C cooling at night. This demonstrates its consistent passive cooling performance throughout the day. The synergistic integration of the hydrophilic-hydrophobic bilayer structure enables efficient unidirectional moisture transport, facilitating rapid sweat evaporation and enhancing wearer comfort. This innovative nanofabric, which has a fibrous sphere architecture, provides a scalable approach to the development of next-generation radiative cooling textiles that manage perspiration and moisture. It has great potential for personal thermal management and suitable cooling in a warming climate.

Keywords: Electrospinning; Radiative Cooling; Personal Thermal Regulation; Nanofabrics

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Development and Verification of an Integrated Operation Control System for Offshore Drilling Equipment Using Hardware-in-the-Loop Simulation

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Developing Hardware-in-the-Loop Simulation (HILS)–based verification technology is essential for ensuring the safety and reliability of offshore drilling and production plants. In recent years, HILS has been widely applied across various engineering fields, including wave energy converters, power take-off systems, aircraft components, and safety-critical equipment. By integrating real-time numerical simulations with physical hardware, HILS provides an effective framework for optimizing system design and performance under realistic operating conditions. The Drilling Control System (DCS) plays a central role in integrating, monitoring, and controlling multiple pieces of equipment in offshore operations. Owing to the complexity and large scale of such systems, operational errors may result in severe accidents. Consequently, comprehensive verification of operational logic and equipment control logic, together with the application of visual validation methods, is required prior to field deployment to improve system reliability and operational safety. This paper investigates the development of an integrated operation control system for offshore drilling equipment as part of a national initiative on offshore plant localization, with a particular focus on logic design and control system verification using HILS.

Keywords: Hardware-in-the-Loop Simulation (HILS); Offshore Drilling Equipment; Drilling Control System (DCS); Control System Verification

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