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Editorial: Injection molding of polymeric and composite materials

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Editorial on the Research Topic
Injection molding of polymeric and composite materials

Injection molding is the most commonly used net-shape manufacturing process for materials. For polymers and some of their composites, injection molding can mass-produce high-precision parts with complex geometry at a very low cost. Injection-molded products have been widely used in various fields of human life, including daily necessities, baby care products, medical devices, electronic appliances, the automobile industry, aviation, aerospace, etc. With the continuous emergence of new polymeric and composite materials, more and more materials, including thermoplastics, thermosets, elastomers, engineering plastics, recycled plastics, and their composites with fibers and additives, are used in injection molding to meet the increasing demand for different plastic products. Injection molding involves the interdisciplinary intersection of materials, processes, molds, machines, and controls. This Research Topic is to explore the latest developments in injection molding of polymeric and composite materials and to advance the understanding of the potential benefits, challenges, and theoretical implications of injection molding in the mass manufacturing of polymeric products with various geometry and functions.

The integration of new technologies and methodologies, as highlighted in the articles featured in this Research Topic, underscores the dynamic nature of research and development in this field. Here, we explore five notable contributions that advance our understanding and capabilities in injection molding, focusing on fiber orientation modeling, residual stress analysis, electrical conductivity, thermal warpage control, and multiscale feedback systems. The relevant polymeric and composite materials include glass fiber-reinforced polyamide composites, polycarbonate, polypropylene/polyamide 6/carbon black composites, polypropylene, and polyethylene. The relevant injection-molded products include Venturi tubes, goggles, dumbbell-shaped microparts, flat parts, and rectangular samples for X-ray scattering.

Short fiber-reinforced plastic (SFRP) composites used in injection molding present complex mechanical behavior due to their anisotropic nature. Accurately predicting the overall mechanical response is essential at an industrial level to ensure the real-world performance of the designed components. In this context, Rienesl et al. introduced a novel automated metamodel optimization approach to calibrate fiber orientation models for short glass fiber-reinforced polyamide components. Using the Informed Isotropic (IISO) equation, the study demonstrated significant improvements in the accuracy of fiber orientation predictions, which are crucial for structural simulations and local mechanical property assessments. By applying their method to a Venturi tube geometry, the authors highlighted the potential for future advancements, such as higher CT resolution and Bayesian inference, to further refine simulation capabilities. This work lays the foundation for more precise and efficient injection molding simulations.

Wang et al. presented an innovative combination of photoelasticity and digital image processing, termed PDIP, to qualitatively characterize residual stress in transparent injection-molded polycarbonate goggles. Validated through numerical simulations, the technique offers real-time residual stress identification and holds significant promise for industrial applications. The authors advocated for the integration of machine learning techniques to enhance stress analysis, emphasizing the importance of accurate stress characterization in improving the performance and reliability of molded components.

Lei et al. explored the fabrication of electrically conductive microparts using polypropylene/polyamide 6/carbon black composites under high shear conditions in microinjection molding. Their study revealed the critical role of shear-induced phase separation in achieving a carbon black-rich network and, consequently, electrical conductivity. By correlating experimental findings with simulations, the research provided valuable insights into the design and production of functional microparts, highlighting the potential for scalable applications in electronics and sensor technologies.

Wang et al. delved into the local thermal warpage deformation of polypropylene injection-molded flat parts. Using an experimental mold with nine local heating sections, the study investigated the nonlinear relationship between temperature distribution and warpage deformation. By employing neural network modeling, the authors achieved a prediction accuracy of up to 97%, showcasing the potential of machine learning in addressing complex thermal behaviors. Their findings underlined the utility of local heating techniques and neural networks in controlling deformation and optimizing part quality.

Massano et al. proposed a paradigm shift in injection molding by integrating time-resolved X-ray scattering into the process. This innovative approach facilitates dynamic multiscale feedback, enabling precise control over operational parameters and laying the groundwork for digital twin technology. The study highlighted the potential of X-ray techniques to enhance pressure control, reduce material damage, and improve recyclability. By bridging traditional injection molding with Industry 4.0 concepts, the authors paved the way for a fully digitalized and optimized manufacturing process.

Injection molding has long been a cornerstone of modern manufacturing, enabling the mass production of polymeric and composite materials with precision and efficiency. This well-established process is continually evolving to meet the demands of advanced materials, complex geometries, and sustainable practices. The articles in this Research Topic collectively demonstrate the transformative potential of innovative technologies in injection molding. From advanced simulation techniques and stress analysis methods to functional micropart fabrication and digital feedback systems, these contributions highlight the multifaceted advancements driving this field forward. As researchers and practitioners continue to address the challenges of material performance, process optimization, and sustainability, injection molding remains at the forefront of modern manufacturing innovation.

We hope this Research Topic inspires further exploration and collaboration in the pursuit of excellence in polymeric and composite material processing. Together, these efforts will shape the future of injection molding, ensuring its relevance and impact in a rapidly evolving industrial landscape.

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