Advances in Injection Molding Processes and Materials for Engineering Applications

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Abstract:

This collection of research papers covers various topics in polymer processing and manufacturing, including injection molding, powder injection molding, and compression molding. The papers highlight different aspects of these processes, such as the effects of gas-assisted heating and melt and mold temperatures on the solidification behavior of HDPE, the role of gas penetration in the morphological formation of polycarbonate/polyethylene blends, and the impact of binders on the viscosity of low-pressure powder injection molded superalloys. Other papers investigate the deformation behaviors of nanostructures in the demolding process of micro-injection molding and the rheological properties of alumina feedstocks for low-pressure injection molding. Finally, a paper examines the viscoelastic behavior variation of glass mat thermoplastics in compression molding. Overall, these papers offer insights into the challenges and advancements in polymer processing and manufacturing.

Keywords: Injection molding, Gas-assisted injection molding, Water-assisted injection molding, Low-pressure injection molding

1. INTRODUCTION

Injection molding is a popular manufacturing process in which molten materials are injected into a mold cavity to produce a part of desired shape and size. This process has been widely used in various industries, including automotive, aerospace, medical, and consumer goods. To improve the quality and efficiency of injection molding, researchers have been exploring various techniques and technologies, such as gas-assisted injection molding, water-assisted injection molding, and low-pressure injection molding.In this review, we will discuss several research articles that investigate different aspects of injection molding, including the use of gas and water assistance, the effect of temperature on the solidification behavior of polymers, the role of binders in powder injection molding, and the rheological properties of feedstocks for low-pressure injection molding. These articles provide valuable insights into the fundamental principles and practical applications of injection molding, which can be beneficial for both researchers and industry practitioners.

Gas-assisted injection molding (GAIM) is a technique that uses gas pressure to assist the injection molding process. Chen et al. (2009) investigated the feasibility of using gas-assisted heating for mold surface temperature control during injection molding. Their study showed that gas-assisted heating can effectively control the mold surface temperature and improve the quality of injection-molded parts. Yang et al. (2009) studied the effect of melt and mold temperatures on the solidification behavior of high-density polyethylene during gas-assisted injection molding. Their results indicated that the solidification behavior of the polymer is strongly influenced by the melt and mold temperatures. Water-assisted injection molding (WAIM) is another technique that has gained attention in recent years. Liu (2009) provided a comprehensive review of water-assisted injection molding, including its advantages, challenges, and potential applications. He concluded that water-assisted injection molding has great potential for producing high-quality, complex parts with reduced warpage and shrinkage.

Low-pressure injection molding (LPIM) is a specialized technique for producing net-shape ceramic and metallic parts with high dimensional accuracy and surface finish. Loebbecke et al. (2009) investigated the rheological properties of alumina feedstocks for the low-pressure injection molding process. Their study showed that the feedstock viscosity is a crucial factor in determining the quality of the molded parts. Powder injection molding (PIM) is another variant of injection molding that involves the molding of powdered materials with a binder to form a green part, which is then sintered to form a final part. Demers et al. (2015) investigated the impact of binders on the viscosity of low-pressure powder injection molded Inconel 718 superalloy. Their study showed that the viscosity of the feedstock can be significantly affected by the type and amount of binder used. Finally, Schlechtriemen et al. (2009) demonstrated the manufacturing of net-shape reaction-bonded ceramic micro parts by low-pressure injection molding. Their study showed that low-pressure injection molding can be used to produce complex ceramic parts with high accuracy and reproducibility. In summary, these research articles provide valuable insights into the principles and practical applications of different injection molding techniques. The use of gas and water assistance, the effect of temperature on solidification behavior, the role of binders in powder injection molding, and the rheological properties of feedstocks for low-pressure injection molding are some of the important factors that can influence the quality and efficiency of injection molding. By understanding these factors, researchers and industry practitioners can optimize the injection molding process and produce high-quality, complex parts with reduced cost and time.

2. Literature review

Desai et al.'s (2018) research article explores the use of injection molding technology for tablet coating, and investigates the optimization of coating formulation attributes and process parameters. The study found that the injection molding process was capable of producing uniformly coated tablets with controlled release profiles, and that the optimization of coating formulation attributes and process parameters could significantly influence the coating quality and performance. The authors' findings suggest that injection molding technology may offer an alternative, cost-effective and scalable method for tablet coating in the pharmaceutical industry. Overall, this research article presents valuable insights into the optimization of tablet coating using injection molding technology.

Liu et al.'s (2020) research article investigate the energy consumption of injection molding machines driven by five different types of electro-hydraulic power units. The study found that the energy consumption of the injection molding machine was significantly affected by the type of electro-hydraulic power unit used, with the permanent magnet synchronous motor and hydraulic accumulator system showing the highest energy efficiency. The authors' findings suggest that selecting the appropriate type of electro-hydraulic power unit for injection molding machines can significantly reduce energy consumption and improve overall energy efficiency. Overall, this research article presents important insights into the energy consumption of injection molding machines and offers practical solutions for reducing energy consumption in the industry.

Liu et al.'s (2015) research article explores the mouldability of various zirconia micro gears in micro powder injection molding. The study found that the type of zirconia powder used, the binder content, and the debinding process all significantly affected the mouldability and dimensional accuracy of the micro gears. The authors' findings suggest that optimizing the powder composition and debinding process can improve the mouldability and dimensional accuracy of micro gears produced by micro powder injection molding. Overall, this research article presents important insights into the mouldability of zirconia micro gears and offers practical guidance for optimizing the micro powder injection molding process for the production of high-precision micro gears.

Ni et al.'s (2013) research article investigates the injection molding and debinding process of micro gears produced by micro powder injection molding. The study found that the optimal injection molding and debinding parameters varied depending on the specific powder composition and binder content used. The authors' findings suggest that optimizing the injection molding and debinding process parameters can significantly improve the dimensional accuracy and mechanical properties of micro gears produced by micro powder injection molding. Overall, this research article presents valuable insights into the production of high-precision micro gears using micro powder injection molding, and provides practical guidance for optimizing the injection molding and debinding process parameters.

Marcomini et al.'s (2016) research article focuses on improving the mechanical properties of injection-molded poly(etheretherketone) and hydroxyapatite nanocomposites. The study found that the incorporation of hydroxyapatite nanoparticles into the poly(etheretherketone) matrix significantly improved the short- and long-term mechanical properties of the nanocomposite material. The authors' findings suggest that the addition of hydroxyapatite nanoparticles can enhance the mechanical performance of poly(etheretherketone) nanocomposites, making them potentially useful for biomedical applications. Overall, this research article presents valuable insights into the development of high-performance polymer nanocomposites and their potential applications in the biomedical field.

Oh and Song's (2017) research article explores the use of a thermal insulation film to strengthen the surface of injection-molded parts. The study found that applying a thin thermal insulation film to the surface of injection-molded parts significantly improved their surface hardness and scratch resistance. The authors' findings suggest that this approach can be a cost-effective way to enhance the surface properties of injection-molded parts without compromising their dimensional accuracy. Overall, this research article presents an innovative approach to improving the surface properties of injection-molded parts, which has the potential to enhance their performance and durability in a variety of applications.

Bledzki and Faruk's (2006) research article investigates the effect of different endothermic foaming agents on microcellular injection-molded wood fiber-reinforced polypropylene composites. The study found that the addition of foaming agents resulted in significant reductions in the density of the injection-molded composites without compromising their mechanical properties. The authors' findings suggest that the use of endothermic foaming agents can significantly reduce the weight of wood fiber-reinforced polypropylene composites, making them potentially useful for lightweight structural applications. Overall, this research article presents valuable insights into the development of lightweight, high-performance polymer composites, which have the potential to be used in a range of industrial applications.

Zhou, Su, and Turng's (2017) research article investigates the impact of water-foaming technology on the mechanical properties, fiber orientation, and length distribution of glass fiber-reinforced polypropylene parts. The study found that the use of water-foaming technology significantly improved the mechanical properties of the injection-molded parts, while also promoting more uniform fiber orientation and length distribution. The authors' findings suggest that the use of water-foaming technology can be an effective way to enhance the performance of glass fiber-reinforced polypropylene parts, making them potentially useful for a range of industrial applications. Overall, this research article presents valuable insights into the development of high-performance polymer composites, which can be tailored to specific industrial requirements.

Bex, Six, Laing, De Keyzer, Desplentere, and Van Bael's (2018) research article examines the effect of process parameters on adhesion strength in two-component injection molding of thermoset rubbers and thermoplastics. The study found that both mold temperature and injection pressure significantly affect the adhesion strength between the two materials. The authors' findings provide valuable insights into optimizing process parameters to achieve desired adhesion strength, which can be used to develop improved materials for a variety of applications, such as in the automotive and aerospace industries. Overall, this research article is a valuable contribution to the field of polymer science and engineering, providing new knowledge that can be applied to the development of high-performance materials.

(Wang et al., 2018) The research article investigated the production of thermoplastic elastomers (TPEs) from recycled polyethylene (PE) and ground tire rubber (GTR). The effect of compatibilizer addition on the morphology and mechanical properties of TPEs was also studied. The results showed that the addition of a compatibilizer improved the dispersion of GTR in the PE matrix and enhanced the interfacial adhesion between the two phases, leading to an increase in the tensile strength and elongation at break of the TPEs. The study demonstrated the feasibility of using recycled PE and GTR as raw materials for producing TPEs, and the potential of compatibilizer addition to improve the properties of the resulting materials.

The research article by **(Bex et al., 2017)** explores the use of wetting measurements as a tool for predicting the compatibility between thermoplastic and thermoset rubber in two-component injection molding. The study investigates the influence of different process parameters, such as temperature and mold design, on the wetting behavior of the two materials. The results demonstrate that wetting measurements can provide useful insights into the compatibility between the materials and that the use of certain additives can significantly improve the adhesion between them. This study provides valuable information for optimizing the production of two-component injection-moulded parts and can contribute to the development of new materials with improved properties.

(Chen et al., 2009) This research article investigates the feasibility of gas-assisted heating for mold surface temperature control during the injection molding process. The authors conducted numerical simulations and experiments to study the effects of gas-assisted heating on the mold surface temperature and the quality of the molded parts. The results indicate that gas-assisted heating can significantly improve the mold surface temperature uniformity and reduce the temperature gradient, which can lead to a better quality of the molded parts. The study provides valuable insights for improving the injection molding process and enhancing the quality of molded parts. Overall, this is a well-conducted research article with practical implications for the industry.

(Liu, 2009) This research article provides a comprehensive review of the water-assisted injection molding (WAIM) process, which is a relatively new technology in the field of polymer processing. The article discusses the advantages of WAIM, such as its ability to produce hollow parts, reduce sink marks, and increase part strength. The article also discusses the challenges associated with WAIM, including the need for specialized equipment and the potential for surface defects. Overall, the article provides a useful overview of the WAIM process and highlights its potential for use in a variety of applications.

The research article by **(Yang et al., 2009)** investigates the effect of melt and mold temperatures on the solidification behavior of HDPE during gas-assisted injection molding. The study utilized an enthalpy transformation approach to examine the thermal behavior of HDPE during the gas-assisted injection molding process. The findings reveal that the solidification behavior of HDPE is significantly influenced by the melt and mold temperatures. The study also shows that the enthalpy change during the solidification process is mainly determined by the melt temperature. Overall, this study provides insights into the thermal behavior of HDPE during gas-assisted injection molding, which can contribute to optimizing the process parameters and improving the quality of molded products.

(Zheng et al., 2007) This research article investigates the influence of gas penetration on the morphological formation of polycarbonate/polyethylene blend molded by gas-assisted injection molding. The authors analyzed the effects of mold temperature, gas pressure, and holding time on the quality of the molded parts. The study found that increasing the gas pressure and holding time can improve the quality of the molded parts, while an increase in mold temperature had a negative effect. The research provides valuable insights into the optimization of process parameters for gas-assisted injection molding of polymer blends. The study highlights the importance of considering gas penetration when designing the mold and process parameters.

The article "Molecular Dynamics Study on the Deformation Behaviors of Nanostructures in the Demolding Process of Micro-Injection Molding" by **Weng et al. (2019)** investigates the deformation behavior of nanostructures in the demolding process of micro-injection molding. The study is based on molecular dynamics simulations and considers the effect of process parameters such as mold temperature, injection speed, and cooling rate on the deformation behavior of the molded nanostructures. The results show that the deformation behavior of the nanostructures is highly influenced by the process parameters, and that the optimal process conditions for micro-injection molding can be determined through a systematic study. The article provides valuable insights for the optimization of micro-injection molding processes.

(Demers et al., 2015) This research article explores the impact of binders on the viscosity of low-pressure powder injection molded Inconel 718 superalloy. The authors investigate how different binder materials and their concentrations affect the rheological properties of the powder-binder mixture. They found that the viscosity of the mixture increased with the concentration of binder, and that certain binder materials led to higher viscosities than others. The results provide valuable insights for optimizing the powder injection molding process for Inconel 718 superalloy and other similar materials. Overall, this study contributes to a better understanding of the role of binders in powder injection molding and their impact on material properties

(Loebbecke et al., 2009) The research article investigates the rheological properties of alumina feedstocks for the low-pressure injection molding process. The study focuses on the effect of solid loading, particle size distribution, and the amount of the dispersing agent on the flow properties of the feedstocks. The research employs a rheometer to investigate the flow behavior of the feedstocks. The results indicate that the feedstocks exhibit pseudoplastic behavior with a power-law dependence on shear rate. Moreover, the study demonstrates that the dispersing agent and solid loading significantly affect the viscosity and flow behavior of the feedstocks. Overall, the article provides valuable insights into the rheological properties of alumina feedstocks and can be beneficial for improving the low-pressure injection molding process.

(Schlechtriemen et al., 2009) The article discusses the manufacturing of net-shape reaction-bonded ceramic microparts using low-pressure injection molding. The authors investigate the effect of various processing parameters, such as binder content, mold temperature, and holding pressure, on the properties of the resulting ceramic parts. The study shows that the use of low-pressure injection molding leads to the production of high-quality ceramic microparts with complex shapes and dimensions. The research provides valuable insights into the optimization of low-pressure injection molding parameters for the fabrication of ceramic microparts, which has important implications for a wide range of industrial applications. Overall, the article is well-written and presents important findings in the field of low-pressure injection molding.

(Huang et al., 2019) The research article investigates the viscoelastic behavior of glass mat thermoplastics (GMT) during compression molding. The authors explore the variation of viscosity during the manufacturing process and the influence of temperature and pressure on the flow behavior of GMT. The study results suggest that GMT exhibits non-Newtonian viscoelastic behavior, and the flow properties are highly dependent on the mold temperature and pressure. The findings provide a better understanding of the processing behavior of GMT and can be used to optimize the manufacturing process to obtain better mechanical properties and higher quality products. The article is well written and provides useful insights into the compression molding of GMT.

3. Research gap

Based on the review of the research articles, some potential research gaps in the field of polymer processing and injection moulding include:

1. Lack of studies on the impact of processing conditions on the mechanical properties of molded parts.
2. Limited research on the effect of different types of additives on the processing and properties of injection molded parts.
3. Inadequate investigations on the optimization of mold design and tooling for various polymer materials.
4. Limited studies on the role of different types of gases and gas-assisted injection molding techniques on the morphology and properties of molded parts.
5. Lack of understanding of the impact of processing conditions on the crystallization behavior and properties of thermoplastic polymers.

6. Insufficient research on the characterization of rheological properties of feedstocks used in low-pressure injection molding.
7. Need for further research on the optimization of process parameters for the production of ceramic microparts through low-pressure injection molding.
8. Limited studies on the viscoelastic behavior of glass mat thermoplastics in compression molding and its effect on the mechanical properties of molded parts.

4. Conclusion

In conclusion, the reviewed research articles in the field of injection molding and related processes provide insights into various aspects of these processes and their applications. The studies covered a range of materials, including plastics, ceramics, and superalloys, and examined different aspects such as the effect of processing conditions on the properties of the final product, the behavior of nanoscale structures during the molding process, and the role of binders and additives in controlling the viscosity of the feedstock.One of the common themes across the studies was the importance of optimizing processing conditions to achieve desired properties in the final product. For example, Liu (2009) discussed the use of water-assisted injection molding as a means of improving the quality and efficiency of the process, while Yang et al. (2009) examined the effect of melt and mold temperatures on the solidification behavior of HDPE during gas-assisted injection molding.Another key theme was the use of additives and binders to control the properties of the feedstock and achieve desired characteristics in the final product. Demers et al. (2015) explored the impact of binders on the viscosity of low-pressure powder injection molded Inconel 718 superalloy, while Loebbecke et al. (2009) investigated the rheological properties of alumina feedstocks for the low-pressure injection molding process.The studies also highlighted the potential for injection molding to produce complex and intricate shapes with high precision and accuracy. For example, Schlechtriemen et al. (2009) discussed the use of low-pressure injection molding to manufacture net-shape reaction-bonded ceramic microparts, while Weng et al. (2019) used molecular dynamics simulations to study the deformation behaviors of nanostructures in the demolding process of micro-injection molding.

Overall, the reviewed research articles demonstrate the importance of understanding the underlying physics and chemistry of injection molding processes and optimizing processing conditions to achieve desired properties in the final product. The insights provided by these studies can help inform the development of new materials and manufacturing techniques, as well as improve the efficiency and quality of existing processes.

5. Future Scope:

The reviewed research articles have shed light on several aspects of injection molding processes, such as the effect of process parameters on the material properties, the role of additives and binders on viscosity and morphological behavior, and the development of new techniques such as low-pressure injection molding and water-assisted injection molding. These studies have opened up new possibilities for optimizing injection molding processes for various applications, including microfabrication, ceramic and metal parts production, and high-performance thermoplastic materials.One of the future scopes for research in this area could be to develop more advanced modeling techniques that can accurately predict the behavior of the material during the injection molding process. This will require a deeper understanding of the complex physics involved in the process, including the flow and thermal behavior of the material, as well as the interactions between the material and the mold surface. Advanced modeling techniques can also be used to optimize the design of the mold for specific applications, which can result in more efficient and cost-effective production.Another important future scope could be to explore the use of novel materials for injection molding processes. For example, the use of biomaterials and biodegradable polymers can offer a sustainable alternative to conventional materials. Additionally, the development of new additives and fillers can further enhance the properties of the material, such as thermal and mechanical stability, electrical conductivity, and flame retardancy.Another potential area of future research is the development of new techniques for injection molding, such as 3D printing or additive manufacturing. These techniques can offer greater flexibility in the design and production of complex geometries, as well as reduce waste and increase production efficiency. Furthermore, the integration of advanced sensors and monitoring systems can enable real-time monitoring of the process, which can improve quality control and reduce defects.In conclusion, the reviewed research articles have highlighted the importance of understanding the material behavior and the process parameters in injection molding processes. The studies have provided valuable insights into the optimization of the process for various applications, including microfabrication, ceramic and metal parts production, and high-performance thermoplastic materials. Future research in this area should focus on developing advanced modeling techniques, exploring the use of novel materials, and developing new techniques for injection molding, such as 3D printing or additive manufacturing. These efforts can lead to more efficient and sustainable production processes, as well as the development of new and improved materials for various applications.

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