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The Effect of Injection Molding Process Parameters on the Mechanical Properties of ABS and PP Polymer

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Abstract

Injection molding parameters play a crucial role in minimizing defects and optimizing part quality. Factors like melt temperature, mold temperature, injection pressure, packing pressure, and cooling time influence the flow, orientation, and solidification of the plastic, ultimately affecting the part's properties and potential defects. By carefully controlling these parameters, manufacturers can achieve consistent, high-quality parts with minimal defects.

This study investigated the effects of injection molding parameters on the mechanical properties of polypropylene and acrylonitrile butadiene styrene (ABS plastic) materials by changing the melt temperature and maximum injection pressure. One-factor-at-a-time experimental designs are drawn using two factors and two levels. Moldex3D software was used for the simulation of each experiment. The results show that maximum filling volumetric shrinkage, maximum packing volumetric shrinkage, time to reach maximum ejection temperature, cooling efficiency, and maximum total displacement increase in both ABS and PP material with an increase in melt temperature from 240 ºC and 270 ºC, while maximum filling shear stress, maximum packing shear stress, and maximum von Mises stress decrease for both ABS and PP material with an increase in the melt temperature. The increase in melt temperature did not show significant impact on the filling time, packing time, or cooling time of the PP material. The results show that filling and packing volumetric shrinkage, packing time, cooling efficiency, maximum total displacement, and maximum warpage density of PP material are higher than those of ABS material under the same conditions.

The results show that the materials behave differently when melt temperature changes. Interestingly, these conditions remain unchanged while pressure is only increased. Modifying injection pressure does not lead to observable modifications, suggesting a need for further investigation into the extent of pressure changes to create significant effects on the studied parameters.

1. Introduction

Melt temperature, the temperature of the molten plastic before injection, generally dictates flowability. Higher melt temperatures enhance mold filling and surface finish, but excessive temperatures can lead to thermal degradation, reducing mechanical strength and introducing potential defects. Injection pressure, the pressure applied to the molten plastic during injection, influences packing density. Higher injection pressures pack the plastic more densely, improving surface finish and reducing shrinkage, but excessive pressures can cause stress marks and flash, compromising aesthetics and potentially weakening the part. Each parameter plays a pivotal role in shaping the microstructure, crystallinity, and stress distribution within the part, ultimately affecting its mechanical properties.

Optimization of injection molding parameters is crucial for achieving the desired mechanical properties and minimizing defects in ABS (Acrylonitrile-Butadiene-Styrene) and PP (Polypropylene) materials. Each parameter plays a significant role in shaping the microstructure, crystallinity, and stress distribution within the injection-molded part, ultimately affecting its performance and durability.

In this study, a 2.5-inch length, 2.5-inch width, and 1.5-inch height of a 0.05-inch thickness of a hollow part is simulated suing Moldex3D software. A total of eight separate individual simulations were run, with each simulation varying a single parameter, to observe the effect of the two different melt temperatures (240 ºC and 270 ºC) and injection pressures (155 MPa and 300 MPa) on the injection molding parameters of ABS and PP.

2. Literature Review

Researchers examined the impact of the mechanical properties of ABS and PP materials by adjusting various injection molding parameters. G. Kalay and M.J. Bevis (1997) studied the influence of holding pressure, cooling time, melt temperature, and injection speed on different molded parts and reported a substantial increase in Young's modulus of the produced parts with the increase of parameters.[1]

Acrylonitrile butadiene styrene (ABS) is a versatile thermoplastic polymer widely used in various applications due to its favorable combination of mechanical properties, thermal stability, and processing flexibility. However, achieving the desired mechanical properties in ABS parts often requires optimizing the injection molding process parameters. In this regard, Ozcelik et al. (2010) conducted a comprehensive study to investigate the effect of injection parameters on the mechanical properties of ABS material. He identified melt temperature as the most significant factor influencing the mechanical properties of ABS material.[2] An increase in melt temperature led to a decrease in the modulus of elasticity and tensile strength but an increase in tensile strain at yield and tensile strain at break. This behavior is attributed to the increased chain mobility at higher melt temperatures, resulting in lower stiffness and higher elongation. The study by Sreedharan et al. (2018) performed an optimization for the injection molding process in order to reduce the molding defects of ABS material and identified melt temperature as one of the most significant factors influencing shrinkage in ABS parts.[3]

Foltuţ et al., 2023 conducted a comprehensive study to investigate the impact of melt temperature, mold temperature, packing pressure, and cooling time on the mechanical properties of FDM-printed ABS specimens. The study showed that melt temperature was one of the most influential factors affecting the mechanical properties of FDM-printed ABS specimens. An increase in melt temperature led to a decrease in tensile strength, yield strength, and modulus of elasticity, while increasing elongation at break.[4] This behavior is attributed to the softening of the ABS material at higher temperatures, resulting in reduced stiffness and increased ductility.

Polypropylene (PP) is a widely used thermoplastic polymer due to its excellent mechanical properties, low cost, and ease of processing. However, the presence of weld lines, which are formed when two or more melt fronts meet and join during injection molding, can significantly reduce the mechanical strength of PP parts. Ozcelik et al. (2011) conducted an experimental study to investigate the effects of melt temperature, packing pressure, and injection pressure on the mechanical properties of PP specimens with and without weld lines. They revealed that injection pressure and melt temperature were the most significant factors affecting the maximum tensile load and elongation at break of PP specimens with and without weld lines.[5] An increase in injection pressure resulted in an increase in maximum tensile load for both specimens with and without weld lines.

Studies conducted by Farotti et al. (2018) have laid the foundation for understanding the role of melt temperature in shaping the mechanical properties of PP polymers.[6] Their findings suggest that variations in melt temperature significantly impact the tensile strength and other mechanical attributes of the polymer.

D. Kusić and A. Hančič (2016) observed six molding conditions (melt temperature, packing time, cooling time, injection speed, packing, and injection pressures) to reduce the shrinkage and warpage of a standardized test specimen.[7] Feldmann (2016) controlled only one injection molding parameter, melt temperature, on polypropylene and found that Young's modulus is independent of melt temperature.[8] This study examines the mechanical properties of ABS and PP materials under different melt temperatures and maximum injection pressures.

3. Methodology

3.1 Simulation setting up.

A total of eight separate individual simulations were run, with each simulation varying a single parameter, to observe the effect of the two different melt temperatures (240 ºC and 270 ºC) and injection pressures (155 MPa and 300 MPa) on the injection molding parameters of ABS and PP.

3.2 Material selection

In this simulation ABS and PP are used for their following properties. ABS (Acrylonitrile-Butadiene-Styrene) is a versatile material. It known for toughness, impact resistance, and excellent flow properties. It exhibits amorphous structure. It is transparent and easy to process. It has a higher glass transition temperature (Tg). It is less ductile, more rigid than PP. PP (Polypropylene) is a semi-crystalline polymer. It has superior stiffness, tensile strength, and chemical resistance. It has a crystalline structure for enhanced durability and dimensional stability. It is more flexible and impact-resistant than ABS and it is less heat-resistant, more susceptible to creep.

3.3 Molding parameters

Melt temperature is the temperature of molten plastic before it is injected into the mold. The melt temperature must be high enough to make the plastic flow, but not so high that it degrades. The ideal melt temperature for ABS is between 230 °C and 260 °C. The ideal melt temperature for PP is between 180 °C and 230 °C.

Injection pressure is the pressure that is applied to the molten plastic to force it into the mold. The injection pressure must be high enough to fill the mold completely, but not so high that it causes flashing or other defects.

The specific melt temperature and injection pressure that are used depend on the specific grade of ABS or PP that is being used, as well as the size and complexity of the part. It is important to experiment with different parameters to find the optimal settings for each application.
This study focuses on the effects of the melt temperature and injection pressure on the mechanical properties of ABS and PP materials. Melt temperature varies from 240 °C to 270 °C, and injection pressure varies from 155 MPa to 300 MPa.

3.4 Geometries

2.5-inch length, 2.5-inch width and 1.5-inch height of a 0.05-inch thickness of a hollow part is drawn in SolidWorks which is then simulated through the Moldex3D software.

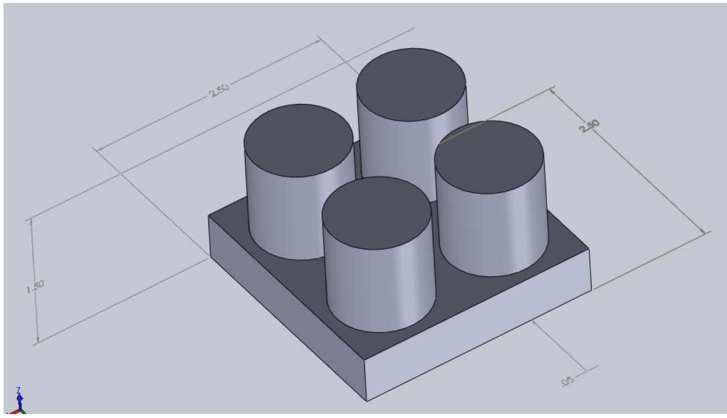


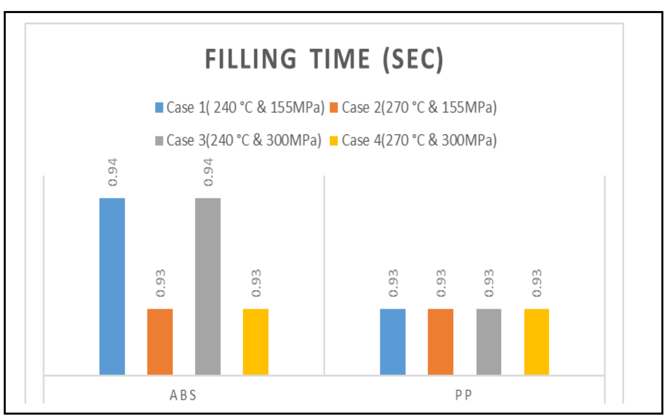
Figure 1: SolidWorks model of Injection Molded parts.

4. Results and Discussion

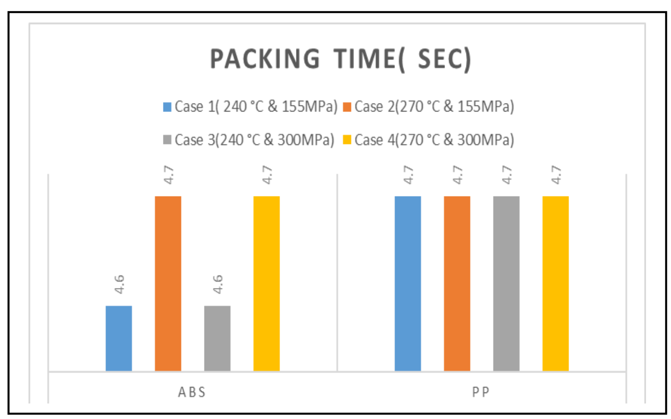
4.1 Effect of Melt Temperature and Pressure on Filling, Packing and Cooling time

Packing time increases (Figure 2. (a)) with melting temperature for ABS material, but filling and cooling times decrease. Higher melt temperature in ABS makes it flow faster for quicker filling and cooling, but also causes more shrinkage demanding longer packing time (Figure 2. (a)) to compensate and maintain part accuracy.

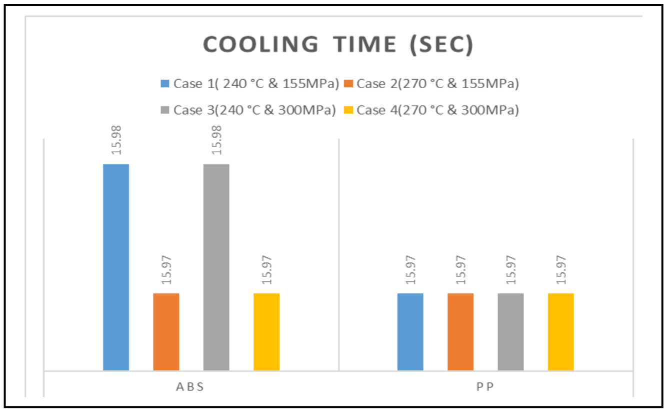
Higher melt temperature makes the ABS less viscous, allowing it to flow faster and fill the mold quicker. However, this increased fluidity also leads to greater shrinkage as the part cools and solidifies. To counteract this shrinkage and maintain the desired part dimensions, a longer packing time is needed to apply continuous pressure and pack the material more densely.



(a)



(b)



(c)

Figure 2: (a) Filling time, (b)Packing time and (c) Cooling time of ABS and PP

The higher temperatures keep the material fluid for longer. This in turn allows for faster filling and initial cooling of the surface layer. However, the thicker layer of molten material inside takes longer to cool completely due to the insulating effect of the solidified surface.

Therefore, the seemingly contradictory behavior of packing time with melt temperature in ABS injection molding can be explained by the trade-off between faster filling and cooling due to greater flowability and the necessity for longer packing to manage increased shrinkage.

In simulation the increase of maximum injection pressure from 155 MPa to 300 MPa did not show any impact on filling, packing, cooling time.

4.2 Effect of Melt Temperature and Pressure on Volumetric Shrinkage of ABS and PP

Increase of Melt temperature from 240 ºC to 270 ºC increases filling and packing shrinkage of both ABS and PP material (Figure 3). Increased melt temperature reduces melt density and delays crystallization, both contributing to higher filling and packing shrinkage in ABS and PP.

Higher crystallinity in PP compared to ABS leads to denser packing (Figure 3(b)). during crystallization, amplifying shrinkage as compared to the less-shrinking amorphous regions in ABS.

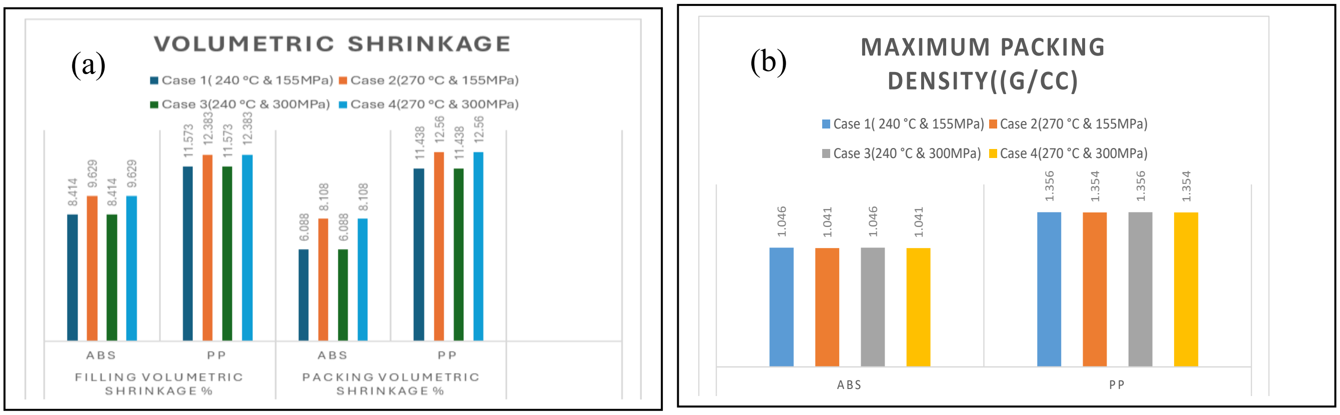


Figure 3: Volumetric Shrinkage (a) and Maximum packing density(b) of ABS and PP

4.3 Effect of Melt Temperature and Pressure on Filling and Packing Shear stress of ABS and PP

Both ABS and PP exhibit a decrease in maximum filling and packing shear stress with an increase in temperature. (Figure 4).

As temperature rises, the viscosity of both ABS and PP decreases. This makes the molten material flow more easily and reduces the resistance it offers to filling the mold cavity. This, in turn, lowers the shear stress needed for complete filling and packing.

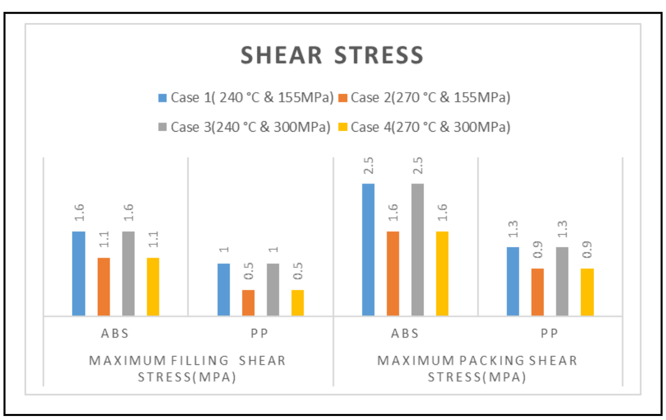


Figure 4: Filling and Packing shear stress of ABS and PP material.

Higher temperatures weaken the intermolecular forces between polymer chains within the material. With their weakening, the polymer offers less resistance to the injection pressure, leading to a lower shear stress requirement. As the temperature increases, both ABS and PP experience slight thermal expansion. decreasing the amount of material needed to completely fill it and reducing the necessary shear stress for packing.

While lower shear stress simplifies processing and improves mold filling, it can lead to increased shrinkage and maximum total displacement after cooling due to the increased melt flow. Finding the optimal processing temperature window is key for balancing ease of processing and final product quality. Under the same conditions, the maximum shear stress of PP is lower than that of ABS material due to the difference in their yield strengths. ABS has a higher yield strength than PP, meaning that it can withstand more stress before it begins to deform plastically. This is why the maximum shear stress of ABS is higher than that of PP. Increase of maximum injection pressure did not show any impact on the maximum filling and packing shear stress of ABS and PP.

4.4 Effect of melt temperature and pressure on Time to reach Maximum ejection temperature and cooling efficiency.

The time to reach maximum ejection temperature and cooling efficiency increases with increasing temperature for both ABS and PP, while remaining the same for pressure (Figure 5). Under the same conditions, ABS has a longer time to reach maximum ejection temperature but lower cooling efficiency than PP.

The time to reach maximum ejection temperature (TMT) increases with increasing temperature due to the competing effects of temperature on the melt viscosity and the heat transfer rate.

As temperature increases, the melt viscosity of a polymer decreases. Lower melt viscosity would lead to a faster TMT, as the polymer can move more easily through the mold and reach the ejection temperature more quickly. However, the decrease in melt viscosity is offset by the decrease in heat transfer rate at higher temperatures.

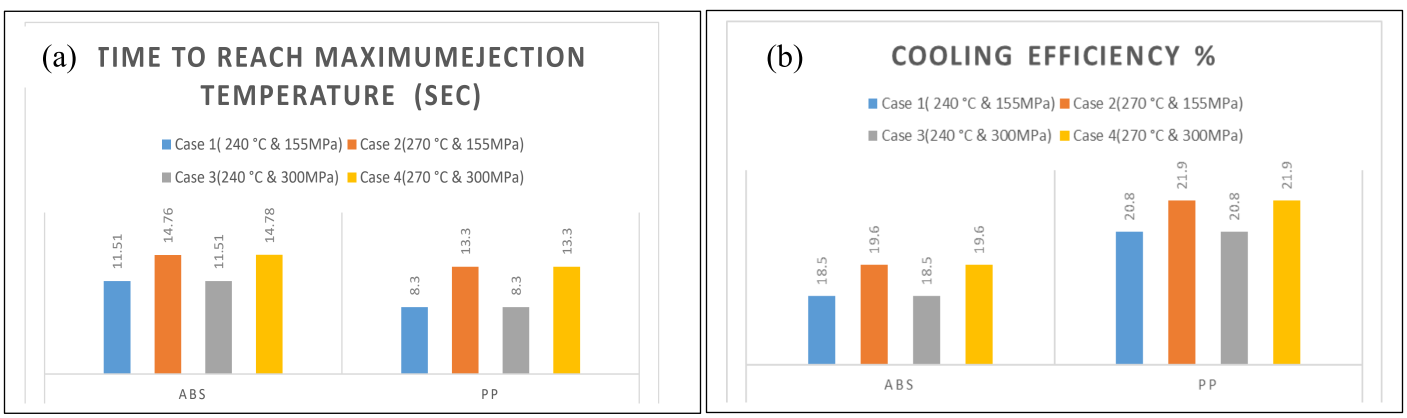


Figure 5: Time to reach maximum ejection temperature(a) and cooling efficiency (b) for ABS and PP material.

The higher thermal conductivity of PP allows it to absorb heat from the mold more quickly than ABS, resulting in a shorter TMT. This difference in thermal conductivity is also why PP has a higher cooling efficiency than ABS.

4.5 Effect of melt temperature and pressure on the warpage conditions of ABS and PP

Maximum total displacement increases and Von Mises stress decreases with increasing melt temperature for both ABS and PP material (Figure 6). However, the maximum total displacement of PP material is higher than that of ABS material under the same conditions. As temperature increases, this increased mobility makes the material more flexible and less stiff, which leads to an increase in total displacement.

The yield strength of both materials decreases with increasing temperature. Under the same conditions, the maximum Von Mises stress for ABS material is higher than for PP material. Because ABS material has a higher yield strength than PP material and can withstand more stress before it begins to deform plastically.

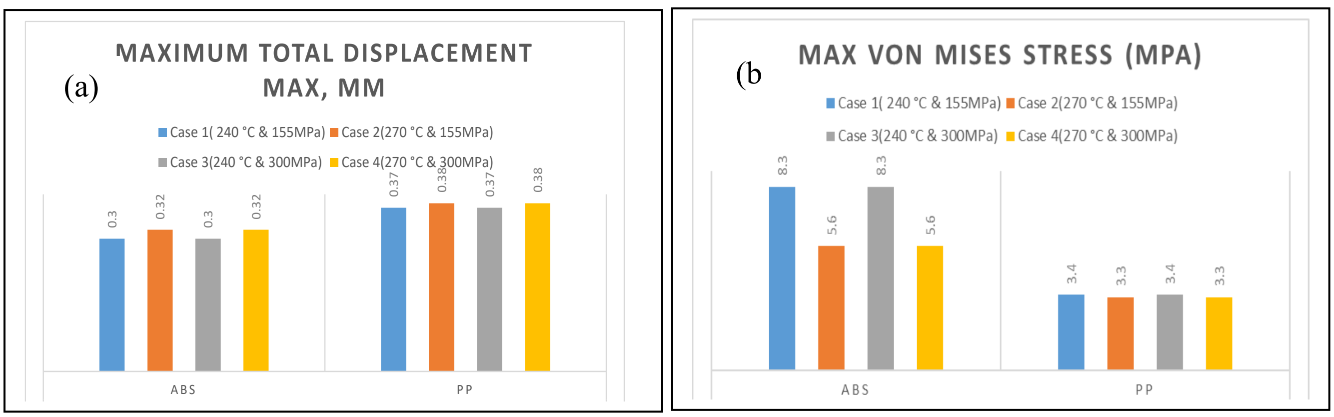


Figure 6. Maximum total displacement (a) and von mises stress (b) of ABS and PP

In simulation, the increase in maximum injection pressure from 155 MPa to 300 MPa does not show any impact on filling time, packing time, cooling time, shear stresses, or warpage conditions of injection molding. However, higher injection pressure lowers melt viscosity and increases thermal conductivity, reducing cooling time. In this study, the pressure might not have increased enough to show any impact of injection molding parameters.

4 Conclusion

Increasing melt temperature from 240 ºC to 270 ºC in injection molding simulations led to higher packing times, shrinkage, and displacement for both PP and ABS, while reducing filling time, cooling time, and shear stress due to the increase of thermal expansion and reduction of viscosity with an increase in temperature. However, PP exhibited more shrinkage and warpage than ABS under similar conditions, suggesting potential differences in their mechanical properties due to melt temperature variation. The result shows the Von Mises stress of ABS is higher than that of PP because of the higher yield strength of ABS compared to PP, which can withstand more stress before it begins to deform plastically. Modifying the injection molding pressure from 155 MPa to 300Mpa does not result in any modifications; this could be because the pressure has not increased enough in this investigation to demonstrate any changes.

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