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Technical Note

Effect of Mould Temperature on Mechanical and Thermal Properties of Polypropylene Processed on the Xplore IM 12 Pro Injection Moulder

A. Sohrabi, N. Karayaka, B. Liebau and G. Ozkoc

Abstract

This application note investigates the influence of mould temperature on the mechanical and thermal properties of injection-moulded polypropylene (PP). Test specimens were produced using the Xplore IM 12 Pro micro injection moulder at two mould temperatures (10 °C with chiller connection, and 60 °C) while keeping all other processing parameters constant. Tensile strength, tensile strain at break, and Young's modulus were evaluated, alongside differential scanning calorimetry (DSC) measurements of the melting behavior. The results demonstrate that mould temperature significantly affects the crystalline microstructure of PP and, consequently, its mechanical performance. Higher mould temperatures lead to an increase in Young's modulus and tensile strength, while slightly reducing the strain at break, reflecting a higher degree of crystallinity. The study highlights the capability of the IM 12 Pro to precisely control mould temperature, including sub-ambient cooling via chiller, making it a powerful tool for systematic polymer screening.

1. Introduction

Injection moulding is one of the most widely used manufacturing processes for thermoplastic polymers. Among the key process parameters, mould temperature plays a particularly important role in determining the final microstructure and properties of semi-crystalline polymers such as polypropylene (PP) [1]. Unlike amorphous polymers, the properties of semi-crystalline materials are strongly governed by the degree and type of crystallinity, which in turn is sensitive to the cooling rate experienced by the polymer melt during solidification.

When the mould temperature is low, the melt solidifies rapidly, providing less time for polymer chains to organize into ordered crystalline structures. This results in a lower degree of crystallinity, smaller and less perfect spherulites, and a finer morphology. Conversely, higher mould temperatures slow down the cooling rate, affording polymer chains sufficient mobility to form well-developed crystalline lamellae, larger spherulites, and a higher overall crystallinity. These structural differences manifest in markedly different mechanical behaviours: higher crystallinity typically yields higher stiffness (Young's modulus) but reduced ductility (strain at break), while lower crystallinity favors more ductile, flexible behaviour.

For PP specifically, mould temperature has been reported to influence the type of crystalline phase formed. At lower temperatures, the β-phase may be kinetically favored under certain conditions, whereas the α-phase predominates at higher temperatures during slow cooling. These phase differences further modulate the mechanical response and thermal characteristics such as melting point and heat of fusion, which can be readily characterized by differential scanning calorimetry (DSC) [2].

To conduct such systematic investigations in a laboratory setting, the Xplore IM 12 Pro Injection Moulder (Xplore Instruments, Sittard, The Netherlands) provides an ideal platform (Figure 1). The IM 12 Pro is a compact, bench-top micro injection moulder with a 12 ml shot volume, designed for rapid and reproducible screening of small quantities of materials, particularly valuable when working with new or expensive formulations. A key feature of the IM 12 Pro is its advanced thermal management system: the mould housing can be heated to 150 °C in under 10 minutes, representing approximately four times faster heating compared to conventional heated mould systems. In addition, the IM 12 Pro offers optional active cooling via connection to a standard laboratory chiller, enabling mould temperatures as low as sub-ambient levels. Water-assisted cooling can bring the mould temperature back down just as rapidly as it was heated, enabling efficient cycling between temperature setpoints. The transfer unit independently reaches 150 °C in under 5 minutes and can operate up to 450 °C, covering a broad range of thermoplastic materials. A programmable pressure profile (1–16 bar) and integrated USB data acquisition further enhance reproducibility and experimental control.

Figure 1. IM12 Pro and the view of a mould (for ISO 527 type 1)

Motivated by the unique thermal capabilities of the IM 12 Pro, the present study aims to investigate the effect of mould temperature on the mechanical and thermal properties of a commercial PP grade (PP 519 A, Sabic). This work serves as a demonstration of the IM 12 Pro's versatility in enabling mould temperature-dependent morphology and property studies at the laboratory scale.

2. Experimental

2.1 Material

The material used in this study was PP 519 A, a commercial isotactic polypropylene grade supplied by Sabic. This is a general-purpose PP homopolymer grade suited for injection moulding applications. The material was used in pellet form as received, without any drying pretreatment.

2.2 Sample Preparation

Tensile test specimens (dog bone geometry) were produced using the Xplore IM 12 Pro micro injection moulder. The material was melted in an Xplore MC15 HT at a barrel temperature of 230°C under collectively controlled mode at 100 rpm screw speed with a residence time of 3 minutes. The melt transfer temperature was set to 230°C. Samples were moulded at two mould temperatures: 10°C (with chiller connection) and 60°C. For both conditions, the same pressure profile was applied: 10 bar for 4 s, 12 bar for 2 s, and 12 bar for 10 s.

2.3 Mechanical Testing

Mechanical tests were performed using an Instron 5kN universal testing machine. The croshead speed was 50 mm/min. In order to measure the Young's Modulus, a clip on gage apparatus is used at a 1 mm/min deformation rate. At least 5 parallel specimen were tested to get a statistically meaningful result [3].

2.4 Differential Scanning Calorimetry (DSC)

DSC experiments were conducted using a Mettler Toledo DSC 1 Star instrument. The heating rate was 10°C/min.
The $T_{m,onset}$, $T_{m,peak}$ and deltaH_m were obtaine d from the DSC heating curves. The crystallinity was calculated using the area under the meting curve [4].

3. Results and Discussion

3.1 Mechanical Properties

The mechanical properties of PP moulded at 10 °C and 60 °C are presented in Figures 1–3. A clear influence of mould temperature on all three measured parameters is observed.

Figure 1 shows the tensile strength as a function of mould temperature. Specimens moulded at 60 °C exhibit a slightly higher tensile strength (~28 MPa) compared to those moulded at 10 °C (~26 MPa). Although the difference is moderate and overlapping within error bars, it is consistent with the expected trend: higher mould temperatures allow more complete crystallization, which increases the resistance to deformation under tensile stress.

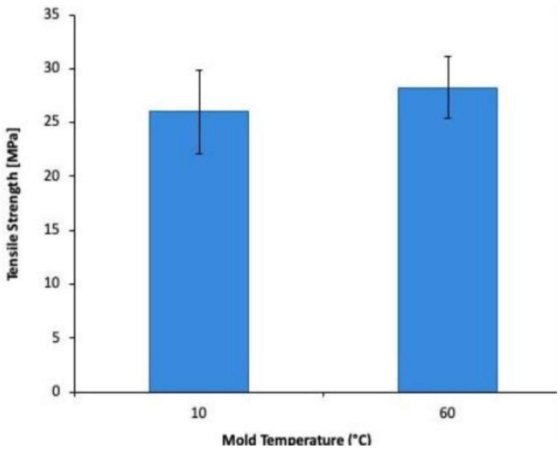


Figure 2. Tensile strength of PP as a function of mould temperature

The tensile strain at break, shown in Figure 2, exhibits the opposite trend. Specimens processed at 10°C show a higher strain at break (~710%) compared to those moulded at 60°C (~660%). This behavior is characteristic of PP with lower crystallinity: a more amorphous or less perfectly crystallized microstructure allows for greater plastic deformation before fracture, resulting in higher elongation at break. At 60 C, the enhanced crystallinity restricts chain mobility under stress, leading to earlier failure.

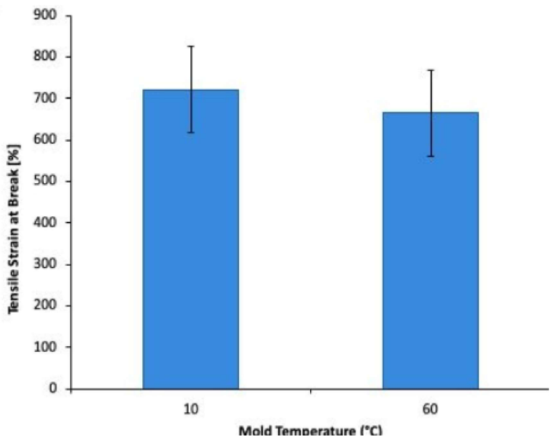


Figure 3. Tensile strain at break of PP as a function of mould temperature

The most pronounced effect of mould temperature is observed in the Young's modulus (Figure 3). Specimens moulded at 60°C show a substantially higher stiffness (~1,400 MPa) compared to those produced at 10°C (~1,130 MPa). This approximately 24% increase in Young's modulus is directly attributable to the higher crystallinity achieved at elevated mould temperatures. In semi-crystalline polymers, the crystalline phase acts as a reinforcing element, significantly increasing the elastic stiffness. The rapid quenching at 10 °C suppresses crystallization, yielding a more flexible material with lower modulus.

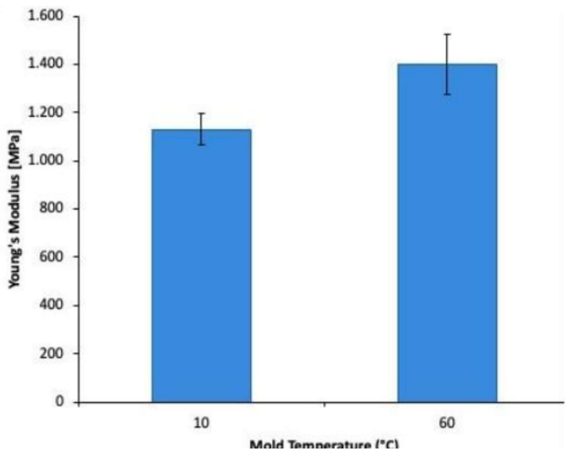
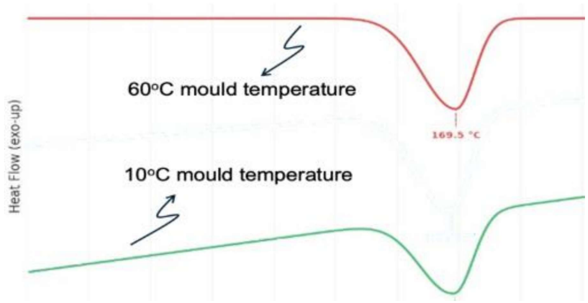


Figure 4. Young's modulus of PP as a function of mould temperature

3.2 Thermal Analysis (DSC)

DSC measurements were performed on specimens from both mould temperature conditions to probe differences in crystalline structure. The melting endotherms for PP moulded at 10°C (green, bottom curve) and 60 °C (red, top curve) are shown in Figure 5.



Parameter	Unit	PP 10°C	PP 60°C
Melting Onset	°C	157,3	158,5
Melting Peak	°C	169,5	169,2
Melting Endset	°C	175,1	174,8
Normalized Enthalpy	J/g	60,5	80,9
Crystallinity (Xc)	%	29,2	39,1

Figure 5. DSC heating curves of PP specimens moulded at 10°C (green) and 60°C (red).

The DSC data reveal a clear influence of mould temperature on the crystalline microstructure of PP. The normalized enthalpy of melting increases substantially from 60.5 J/g at 10°C to 80.9 J/g at 70°C, and the degree of crystallinity (Xc) follows the same trend, rising from 29.2% to 39.1%, an increase of approximately 10 percentage points or roughly 34% relative. This is the most consequential finding from the thermal analysis, as it directly underpins the mechanical property differences observed in tensile testing: the higher crystallinity achieved at 70°C explains the increased stiffness and tensile strength, since the crystalline phase acts as a reinforcing network within the PP matrix, while the lower crystallinity at 10°C, resulting from rapid quench cooling via the chiller, yields a more amorphous microstructure with greater chain mobility under stress, reflected in the higher strain at break. The melting peak temperature shows only a marginal shift (169.5°C at 10°C vs. 169.2°C at 70°C), suggesting that the predominant crystalline polymorph is the same under both conditions, with mould temperature primarily governing the extent of crystallization rather than its nature. Overall, the DSC results confirm that mould temperature is an effective parameter for tuning the crystalline microstructure of PP in the IM 12 Pro, with a 60°C difference in mould temperature producing a crystallinity change of approximately 10 percentage points under the conditions studied.

4. Conclusion

This study demonstrates the significant influence of mould temperature on the mechanical and thermal properties of injection-moulded polypropylene. Using the Xplore IM 12 Pro micro injection moulder, specimens were produced at 10 °C (chiller-cooled) and 60 °C under otherwise identical processing conditions. The key findings are:

• Higher mould temperature (60 °C) results in increased tensile strength and Young's modulus, reflecting a higher degree of crystallinity.

• Lower mould temperature (10 °C) produces specimens with higher strain at break, indicative of a more ductile, less crystalline microstructure.

• DSC analysis confirms a slightly higher melting temperature for the 60°C sample, consistent with thicker and more perfect crystalline lamellae formed during slower cooling.

• The IM 12 Pro's ability to rapidly heat the mould (4× faster than conventional systems) and actively cool to sub-ambient temperatures via chiller integration enables controlled mould temperature studies that would be difficult to perform on standard laboratory equipment.

These results underscore the importance of mould temperature as a key processing parameter for tuning the properties of semi-crystalline polymers and highlight the IM 12 Pro as a versatile and capable tool for such systematic material screening studies at the laboratory scale.

References

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Xplore Instruments BV
Arendstraat 5
6135 KT, Sittard
The Netherlands

Tel: +31 46 208 97 70
Fax: +31 46 208 97 71

info@xplore-together.com
www.xplore-together.com
Trade Register: 60040114

Find out more at
www.xplore-together.com