

The Influence of Process Parameters of Injection on Nano-mechanical Properties of Polypropylene

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Abstract. Injection of polymers is one of the most widely used technology in the production of plastic parts. During injection moulding it is important to analyse the individual factors of the injection process so that the optimal injection parameters can be set from these established process conditions. When injecting, it is important to achieve the optimal production process to reach optimal production costs, increasing the quality of the product and eliminating possible defects in the products. The presented work deals with the investigation of the influences of the process parameters of the injection process (holding pressure and mould temperature) on resulting nano-mechanical properties. To measure nano-mechanical properties by the DSI method, a polypropylene sample was chosen. Measurements were performed on the Nano-Combi-Tester. From the results of this study it is clear that optimal nano-mechanical properties are required to optimize the process parameters of the whole injection moulding process.

1. Introduction

Polypropylene is a common thermoplastic polymer, largely used in industrial applications for the variety of its properties, which makes it versatile. PP components are semi-rigid, translucent, fatigue and heat resistant, tough and chemically durable. The main manufacturing processes for polypropylene parts are extrusion and injection moulding (IM). Through these technologies a numerous kind of products are available: buckets, bowls, crates, toys, medical components, washing machine drums, battery cases, bottle caps, etc. In the large-scale industrial production world, plastic parts made by injection moulding re getting a key role, because of their affordability and lightness, especially when there are no requirements for mechanical properties. Although the process optimization often focuses on reducing the cycle time (in accordance with dimensional and aesthetic specs), more and more frequently it's fundamental that the manufactured parts have mechanical performances. These an be affected by process parameters, which can induce residual stresses to the component due to deformation at high shear rates, temperature and pressure. Right combination of these parameters can optimize the properties of the component. In general, research activity on injection moulded polymers' characterization by process parameters has been developed by several groups and different approaches have been used. Typically, IM input parameters are: injection speed, melt temperature, mould temperature, packing time, packing pressure, cooling time. [1]

Injection Moulding is one of the most advanced polymer processing technologies. It enables the production of finished products, which do not require any further operations. The tools used for their production - the injection moulds - are very complicated assemblies that are made using several technologies and materials. [2]

The fluidity of all polymers during injection moulding cycle is affected by many parameters (mould design, melt temperature, mould temperature, injection rate, pressures, etc.) and by the flow



properties of polymers. A plastic nucleus is formed by due to character of laminar flow, which enables the compression of the melt in the mould and consecutive creeping. A constant flow rate given by the axial movement of the screw is the choice for most of the flows. During filling of the mould cavity the plastic material does not slide along the mould surface but it is rolled over. This type of laminar flow is usually described as a “fountain flow” (Figure 1). [2]

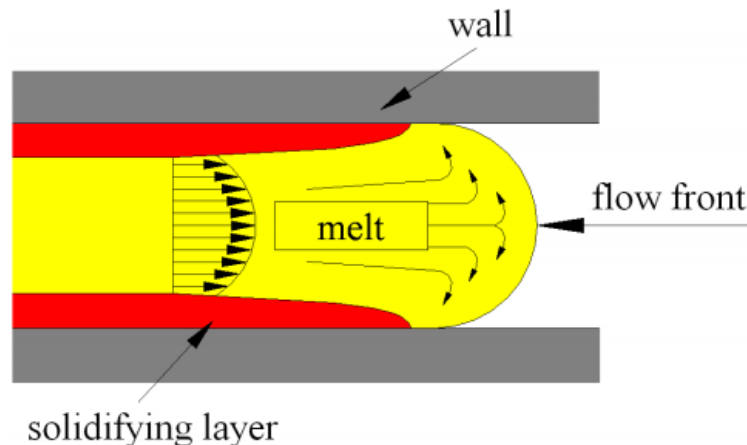


Figure 1. Fountain flow.

The article deals with the influence of processing parameters of the injection moulding technology (holding pressure and mould temperature) on nano-mechanical properties (hardness, modulus) of the surface layer of tested PP.

2. Experimental

Measurement of all properties mentioned above was performed 10 times to ensure statistical correctness.

2.1. Material

Polypropylene PP IM 5580 TST was used for this experiment.

2.2. Injection molding process

The samples were made using injection moulding technology on an Arburg Allrounder 470H injection moulding machine (Loßburg, Germany). The normalized specimens, with dimensions of (80 x 10 x 4) mm, were used (Figure 2). The process parameters were set according to the manufacturer's recommendations; see Table 1 and Table 2.

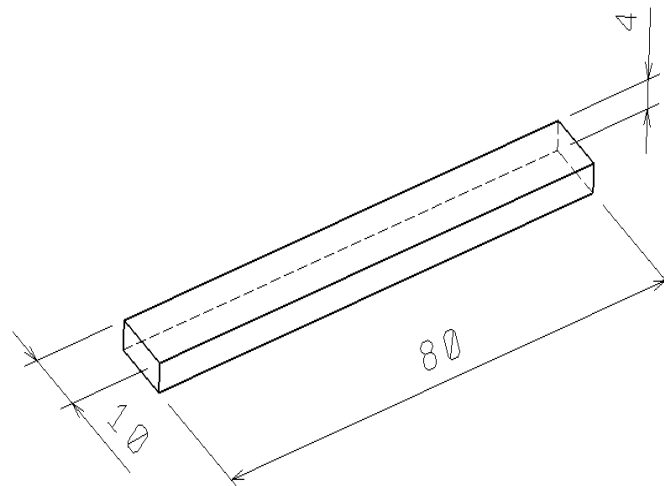


Figure 2. Tested specimens.

Table 1. Process parameters – changing of holding pressure.

Parameter	Unit	Value
Injectionpressure	bar	900
Holding pressure	bar	300, 400, 500, 600, 700, 800
Holding time	s	15
Coolingtime	s	35
Fill speed	mm/s	40
Temperature T1	°C	200
Temperature T2	°C	210
Temperature T3	°C	220
Temperature T4	°C	230
Mouldtemperature	°C	80

Table 2. Process parameters – changing of mould temperature.

Parameter	Unit	Value
Injectionpressure	bar	900
Holding pressure	bar	700
Holding time	s	15
Coolingtime	s	35
Fill speed	mm/s	40
Temperature T1	°C	200
Temperature T2	°C	210
Temperature T3	°C	220
Temperature T4	°C	230
Mouldtemperature	°C	30 , 40, 50, 60, 70, 80, 90

2.3. Nano-indentation test

Nano-indentation properties were measured by means of Nano Combi Tester NHT³ (Figure 3) made by Anton Paar (Graz, Austria), according to the CSN EN ISO 14577 standard. On tested material at least ten indents were made and the results were statistically processed. Standard simple loading-unloading mode was used. From the obtained “load vs. depth of penetration” curves values of nano-indentation properties were calculated according to Oliver and Pharr. The measured parameters were the values of the maximum load 50mN and the loading rate (and unloading rate) was 100mN/min. The holding time was 90 s at the indentation.

**Figure 3.** Nano-indentation tester.

The indentation hardness (H_{IT}) was calculated as maximum load (F_{max}) to the projected area of the hardness impression (A_p) and the indentation modulus (E_{IT}) was calculated from the Plane Strain modulus (E^*) using an estimated sample of Poisson's ratio (ν) according to [3-10]:

$$H_{IT} = \frac{F_{max}}{A_p} \quad (1)$$

$$E_{IT} = E^* \cdot (1 - \nu_s^2) \quad (2)$$

3. Results and discussion

Holding pressure is one of the most important processing parameters of the polymer injection moulding technology, which significantly influences the quality of the injected product. After the phase of cavity filling the phase of holding pressure follows, which has the task to compensate the lowering of the volume (shrinkage) of the product during the polymer cooling in the mould. It is only possible to perform this process until it is impossible to fill the injection moulding cavity with the polymer melt. A bad choice of the holding pressure value can influence the mechanical properties of the resulting product.

Looking at the holding pressure results in the dependence on the nano-indentation hardness (Figure 4) it is clear, that holding pressure significantly influences the properties of the product surface layer. At the lowest value of holding pressure (300 bar), the nano-hardness was 60 MPa. The higher value of holding pressure, the higher values of nano-hardness up to 85 MPa. Higher holding pressure than 85 MPa causes the drop of nano-hardness. As it can be seen from the figure, as the optimal value of holding pressure is in range from 600 bar to 700 bar where the highest values of nano-hardness of the surface layer were measured.

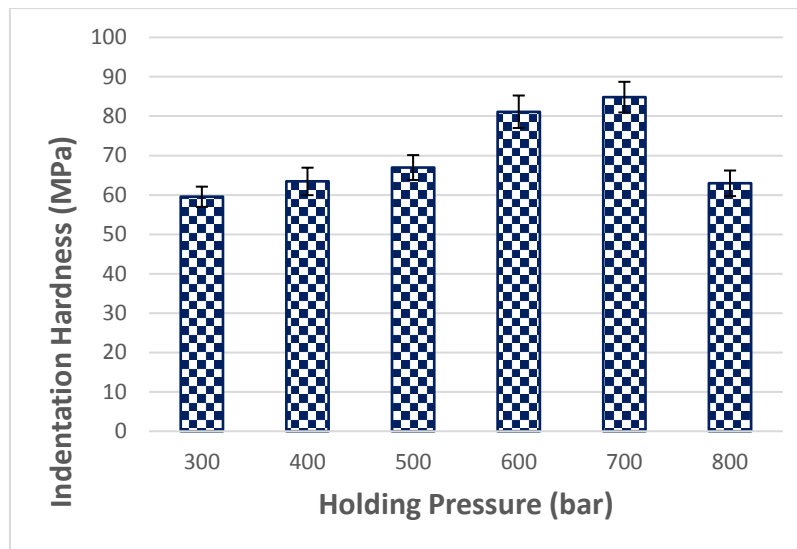


Figure 4. Indentation hardness vs. holding pressure.

Indentation modulus values that were measure yielded similar results to indentation hardness, Indentation modulus characterizes the stiffness of the surface layer as it is shown in figure 5. During instrumental test of nano-hardness the lowest value of modulus was measured at holding pressure 300 bar (1.12 GPa), while the highest value was at holding pressure 700 bar (1.63 GPa). The difference between the lowest and the highest value of modulus is 45 %. The higher value of holding pressure causes lower indentation modulus.

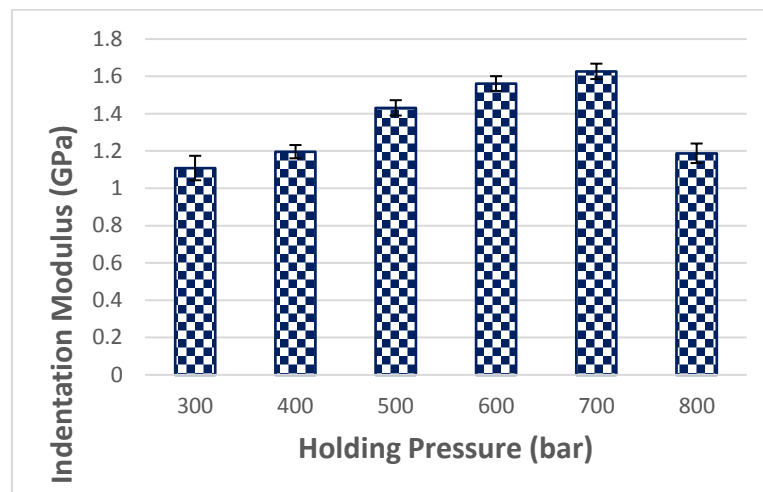


Figure 5. Indentation modulus vs. holding pressure.

Appropriate choice of tempering agent, its construction and dimensioning can achieve the required quality of the injected products, dimensionally accurate parts, quality surface, required physical and mechanical properties, minimal deformation, shortening of the injection cycle as a result of shorter cooling times and last but not least optimal production costs. The temperature and its time course influence the behaviour of the melt, (during and after process) including the resulting properties (mechanical, shrinkage, surface quality, degree of crystallinity, mass and density). Temperature over time also affects magnitude of internal stress and last but not least (both for amorphous and semicrystalline plastics) the total cycle time of the injection cycle, where the heat dissipation (cooling phase) occupies its predominant part.

As well as the pressure, the temperature of the mould has a significant effect on nano-mechanical properties of the surface layer of tested PP. As can be seen in figure 6, the low mould temperature causes indentation hardness reduction. Conversely, the higher mould temperature results in an increase in indentation hardness. The lowest indentation hardness value was measured at a mould temperature of 30 °C (60 MPa), on the other hand the highest at 80 °C (102MPa). As an optimal mould temperature range for PP injection, 60 °C to 80 °C appears to have the highest measured hardness value. The difference between mould temperature at 30 °C and 80 °C is 70%.

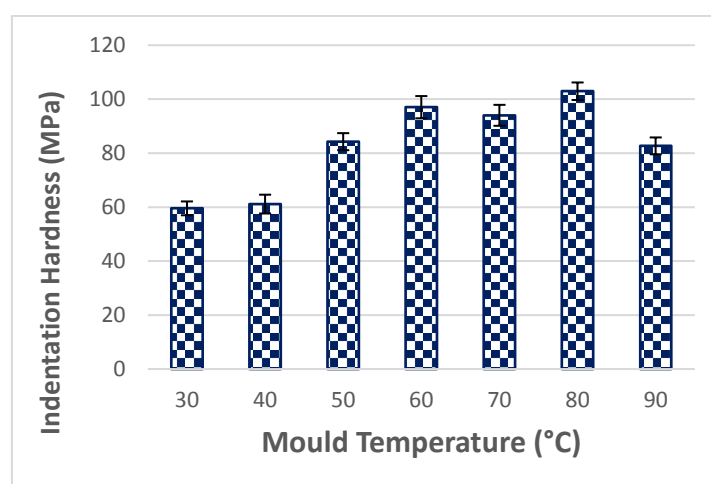


Figure 6. Indentation hardness vs. melt temperature.

From the results of the indentation modulus of elasticity, it is obvious that the optimal value of the mould temperature for tested PP is 80 °C (1.76 GPa). At a lower temperature, the modulus decreased significantly.

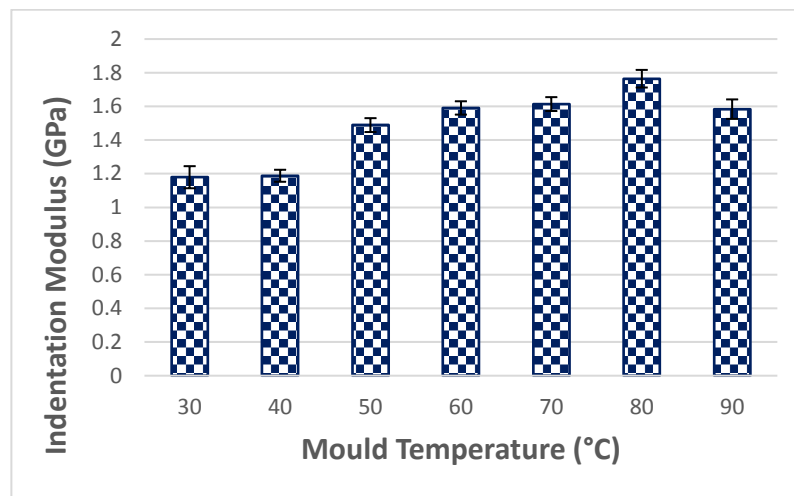


Figure 7. Indentation modulus vs. melt temperature.

4. Conclusions

To measure nano-mechanical properties by the DSI method, polypropylene sample was selected. Measurements were performed on CSM's Nano-Combi-Tester. When changing the pressure and temperature of the mould to resulting mechanical properties of the product was measured.

When changing the pressure, the nano-mechanical properties changed. The low holding pressure has manifested in indentation hardness and modulus values by decreasing the values compared to the higher holding pressure. This means that the ideal holding pressure is in range between 600 and 700 bar. Below 700 bar, its mechanical properties are the highest. At low pressure, the mould may be insufficiently filled, resulting in hardness reduction. The high value impact was manifested by extruding the melt out of the mould cavity.

Changes in mould temperature change the properties determined by the DSI method. At low mould temperatures, the hardness and modulus values are very low compared to the increasing mould temperature. The ideal mould temperature is at 80 °C, here it achieves maximum of its mechanical properties.

Acknowledgments

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