Morphological characterization of injection molded parts in Ren Shape® 5166 polyurethane inserts for rapid tooling

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ABSTRACT: The Rapid Tooling techniques have been emerging to produce rapid moulds for injecting plastics parts. Among the current solutions, material removal by milling machining of polymeric resin or polymeric composites is an attractive alternative for manufacturing moulds for injecting short series of products. This work assesses the morphology of parts injected in mould cavities manufactured by a polyurethane resin (PUR) Ren Shape 5166, as an alternative for Rapid Tooling, and the parts injected in cavities manufactured by the ordinary mould steel. Both cavities were used for injecting the parts with polypropylene. The specimens were characterized by Optical Microscopy and Differential Scanning Calorimetry, to observe the morphology and the resulting degree of crystallization from the moulding process. The results show the differences in the microstructure structure from the parts injected in both cavities. It was observed that the parts injected in the PUR cavities are slightly more crystalline and display morphology different than the parts injected in the mould steel.

1 INTRODUCTION

The use of plastic product has been growing drastically in the last decades. These products are made especially by injection processes using moulds (Ogliari et al. 2004). Lead-time reduction and shorter lifetime of these products are also a market goal today. According to Boujelbene et al (2004), in a production chain of a plastic product, the mould manufacturing phase represents a key position in this segment. The mould manufacturing phase impacts severely in the costs of the final product, its quality and lead-time. Then, any innovation in mould industries is very welcome.

The association of very different materials and manufacturing techniques originated the designation of hybrid moulds (Mateus et al. 2001; Pouzada, 2009). There are several techniques for obtaining the hybrid molds. CNC machining process of resins and other easy machinability materials is commonly applied. The machining process to obtain rapid tooling can be explained by the large spread of CNC machines in the die and mould industries (Volpato et al. 2007).

The polymeric resins epoxy and polyurethane were developed for hybrid moulds, with different physicochemical properties depending on its composition and the fillers added (Derenievicki, 2007). The quality of the resins has strong influence on the quantity, type and shape of reinforcing filler. The interfacial interaction between the resin and the reinforcing filler also changes the composite mechanical performance (Vasconcelos et al. 2006). Several researches have been conducted in recent years using polymer resin for making inserts in injection molds, mainly by casting technique. Most of them aim to analyze the resins mechanical and thermal behavior and the effect of adding reinforcing filler in the composite (Ma et al. 2007, Sabino et al. 2008). Other researches were performed to identify the reinforced resins machinability and the behavior of these materials during the injection process (Lanz et al. 2002, Westrupp 2008). Cavalheiro (2007) and Martinho et al (2009) studied the morphological and mechanical behavior of moulded parts injected in metal fillers inserts. However there is a lack of information about morphology of parts injected in polyurethane reinforced resin inserts. This work evaluates the morphology parts injected in Ren Shape 5166 polyurethane (PUR) moulding blocks manufactured by machining and compared with a similar conventional steel (AISI P-20) mould.

2 ALTERNATIVE MATERIALS FOR RAPID TOOLING

Machining is a method to obtain rapid tooling by removing material from a blank to the desired final shape using an easy machinability material (Kochan et al. 1999). While the additive material techniques are limited as the raw material used, machining allows the application of many different materials such as aluminum, zinc alloys and polymer resins. The dimensional accuracy and surface finish are also best in machined inserts (Wohlers & Grimm, 2004).

Considering the potential application of polymeric resins machined to obtain rapid tooling, some studies have been developed over the last decade in order to analyze and compare the behavior of these materials.

Some care must be taken during resin machining to prevent its chipping. Feed and depth of cut parameters must be optimized (Lanz et al. 2002). However, depending on the part geometry, the manufacturing cost of resin inserts can be 50% less than aluminum inserts (Siegel et al. 2008). Polymeric resins for machining inserts can be added with metal, fiber or ceramic fillers. Usually these fillers increase the composite mechanical and thermal properties, making these materials more suitable for plastic injection process (Tomori et al. 2004, Westrupp 2008).

Derenievicki (2007) analyzed the injection process behavior of three different commercial resins: PN 1007 (Hard), Ren Shape 5166 (Huntsman) e LAB 1000 (Axson) for PP and ABS materials. The LAB 1000 and RS 5166 composites presented better behavior during injection process. The demoulding agent must be used to enable ABS injection process in these resin inserts. The results also indicated that the resins can be machined on conventional CNC machines, using CAD / CAM / CNC technology, performing preliminary tests to determine the machining parameters.

3 EXPERIMENTAL

3.1 Materials of the cavities evaluated

In order to evaluate the properties of the injected product, two materials were used for manufacturing the mould`s cavities. First it was used an ordinary steel for mould application and then an alternative resin. The mainly characteristic of both materials are presented as following.

3.1.1 Resin

The commercial resin Ren Shape 5166 was used For the development of moulding block for hybrid mould a. This material is polyurethane resin (PU) filled with 68.7% (w/w) trihydrate alumina (THA). Its main characteristics are shown in Table 1.

Table 1. Characteristics of the Polyurethane system (Ren Shape 5166)

Properties	RenShape 5166
Density (g/cm^3)	1.7
Shore D Hardness	85-90
Compression Strenght (MPa)	90-100
High temperature distortion (HDT) (ºC)	75-80
Thermal conductivity (W/m.K)	0.51
Coefficient of thermal expansion (mm/mm ºC)	45-60x10^{-6}

Table 2. Thermal properties of AISI P-20 Steel

Properties	AISI P-20 Steel
Specific heat (J/kg.K)	460
Thermal conductivity (W/m.K)	29
Coefficient of thermal expansion (mm/mm ºC)	12×10^{-6}

3.2 Mold design and Machining

The workpiece used in this work is shown at Figure 1. This geometry has five equidistant cavities interconnected by a thickness of 2 mm and 140 mm overall diameter. The sprue dimensions are: 60 mm total length, 6.5 mm diameter around the product and an angle of 2 degrees.

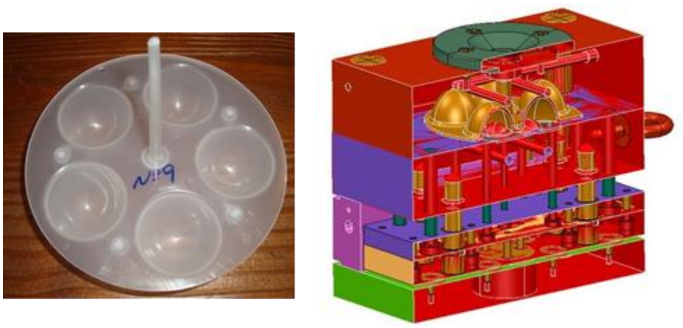


Figure 1. Workpiece injected and the mould

The cavities for injecting the workpiece on Figure 1 was machined in PU resin using a machining center Feller FV-600. Figure 2 shows bothe cavities machined in PU resin.

Figure 2. PU resin moulding blocks.

The hybrid and steel moulds used in this work were instrumented with four temperature sensors Type-K thermocouples, as shown in Figure 2. The temperature values were collected with data logger system 5000 B Ecil.

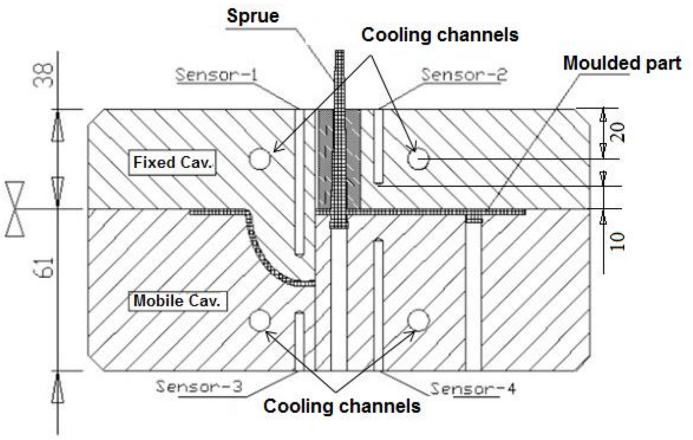


Figure 2. Moulding block and sensors locations.

3.3 Injection Moulding Process

A Haitian Saturn Series - SA 1200/410 injection machine was used in this experimental study. The clamping force and screw diameter are 120 t and 40 mm respectively. The cylinder temperature profile is shown in Figure 3. The material used for samples injection was Braskem PP H 201. This is a high flow homopolymer PP (20 g / 10 min), suitable for injection moulding.

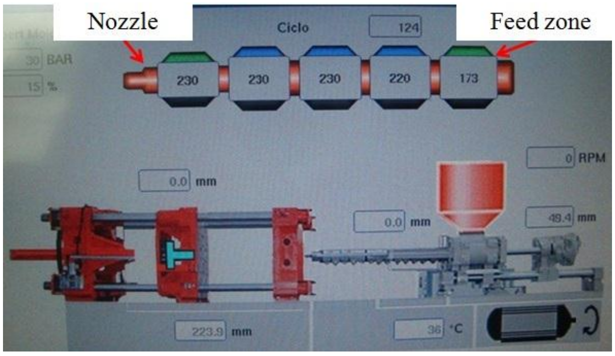


Figure 3. Cylinder temperature profile (ºC).

The process parameters applied in the experiments were obtained by Moldflow Insight 2010 CAE software simulation (Table 2). The clamping force had to be increased from the CAE simulation to avoid flash in the injected samples. The cooling water flow was established at 1.5×10^{-4} m³ / s.

Table 2. Injection process parameters by moldflow and real data.

	Moldflow		
	Steel Insert	PU Resin Shape	
Injection time (s)	0,7	0,7	
Holding time (s)	4,0	19,0	
Cooling time (s)	11,0	600,0	
Clamping force (t)	11,0	11,0	
Injection Pressure (bar)	159,7	146,9	25
Cooling water temperature (ºC)	28,0	28,0	26,5
Material Flow (cm³/s)	64,6	64,6	64

* Corresponds to injection machine hydraulic cylinder pressure.

3.4 Injected Samples Microstructural Characterization

The microstructural characterization of the injected parts in both molding blocks was carried out by polarized light microscopy. Morphology of the injection moulded specimens, particularly the skin thickness and the spherulite size, was observed with the aid of polarized light microscope Olympus model BH2. The samples were cut with a Leitz 1401 microtome at room temperature. Figure 4 shows the specimen obtaining from the cross section of injected part.

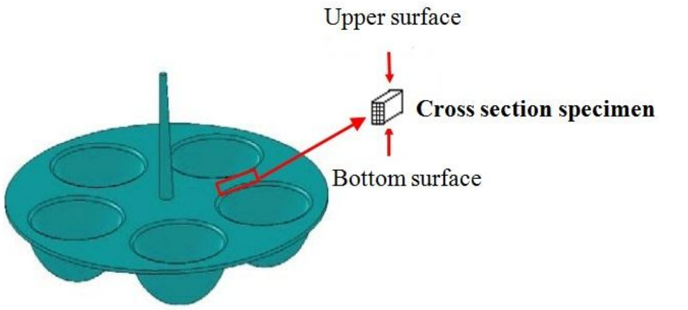


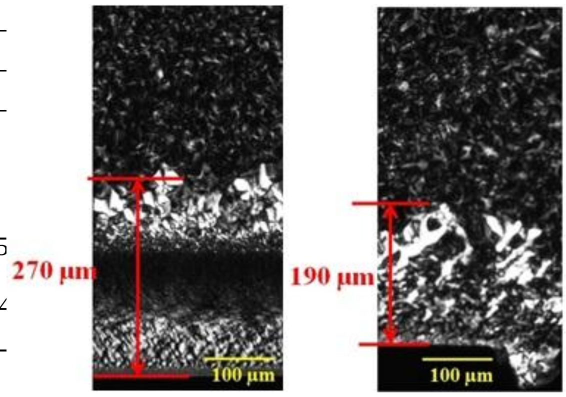
Figure 4. Specimen obtaining from the cross section of injected part for morphological characterization and crystallinity degree measurement.

3.5 Crystallinity Degree of Injected Samples

The crystallinity degree determination of the polypropylene (PP) injected parts in steel and PUR molding blocks was performed using a differential scanning calorimetry (DSC) by "TA Instruments", model Q20. The tests were performed at the temperature range 25 °C to 300 °C, with a heating rate of 10 °C / min.
The degree of crystallinity (Xc) of PP can be determined from the enthalpy obtained using the Equation 3.

$$\%C = [\frac{\Delta Hfa}{\Delta Hf\,100\%}].100 \qquad (3)$$

where ΔH_{fa} is the apparent enthalpy of each PP sample, $\Delta H_{f100\%}$ is the extrapolated value of the enthalpy

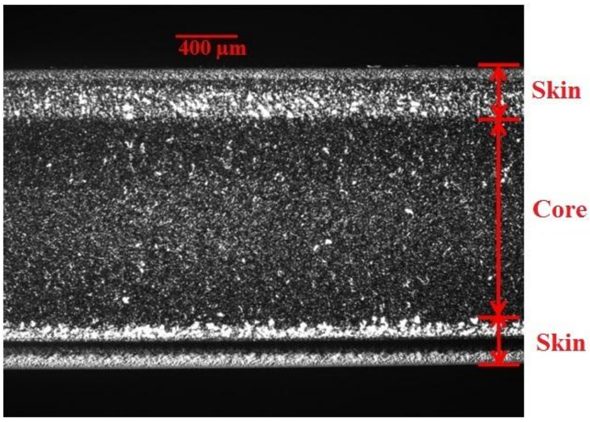


corresponding to the melting of 100% crystalline sample. A value of 209 J/g has been chosen for $\Delta H_{f100\%}$ for PP (Canevarolo 2003).

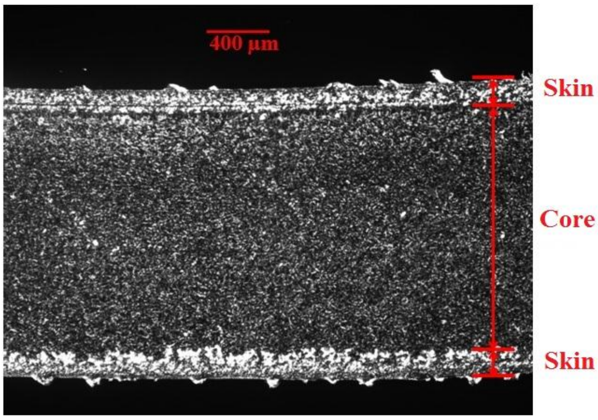
4 RESULTS AND DISCUSSIONS

4.1 *Morphological Analysis of Injected Parts*

The morphological analysis performed by optical microscopic technique aimed the qualitative identification samples structure over the thickness and the quantitative skin thickness. Figure 5 shows a micrograph from the molded parts in steel and PUR inserts. It is clear that under both conditions, there are structures composed by two skin layers and a core. The two skin layers correspond to inserts and injected material contact areas.



(a) Steel Insert



(b) PUR Insert

Figure 5. Steel inserts and PUR inserts moulded parts. 4 × magnification.

The skin thickness in steel insert moulded part is thicker than the PUR insert moulded part. This difference can be linked to heat flow between the workpiece and the insert material. The higher thermal conductivity and therefore a higher cooling rate of steel insert moulded part tends to form a thicker oriented layer composed by very thin spherulitic structure. Figure 6 shows the skin thickness for samples injected in steel and PUR inserts.

Figure 6. Skin thickness for steel insert injected sample (on the left) and PUR insert injected sample (on the right). 20 × magnification.

The skin of the part injected in the steel cavities is approximately 42% higher than its counterpart, the PUR. The measured values were 270 µm and 190 µm respectively. In addition to different skin thicknesses, the morphological characteristics also differ. By Figure 7 it is possible to identify the skin structural distribution of the samples.

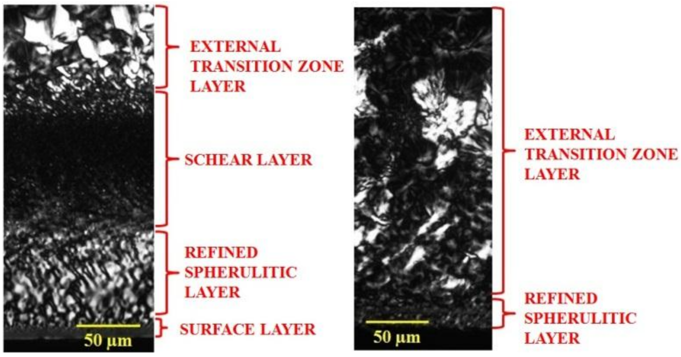


Figure 7. Skin structural distribution of the samples injected into steel inserts (on the left) and PUR (on the right). 40 × magnification.

The steel insert injected samples skin layers are clearly defined and composed by four sublayers. The surface layer comprises a highly oriented frozen material layer which is in contact with insert material. Next, there is a refined spherulitic structure layer and therefore a shear zone. The toplayer indicates the transition zone between the skin and core. The analysis performed at the samples injected in PUR insert does not have well-defined layers, thus hindering their interpretation. It is suggested that there is no highly oriented surface layer formation at this sample. The surface has a refined spherulitic structure and then the outer layer of the transition zone. It is not possible to identify evidence of a significant shear layer through this morphological analysis. This fact can be linked with the low heat flow between the insert material and the moulded part.

The workpieces core morphology also differs. Figure 8 shows the cores parts micrographs.

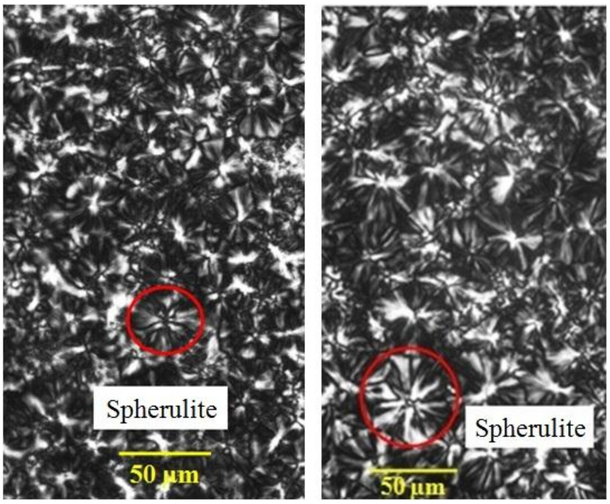


Figure 8. Core sample morphology injected into steel insert (on the left) and PUR insert (on the right). 40 × magnification.

There are spherulites formations at the core in both cases. However it was noted that the spherulites of the PUR insert injected sample is larger than steel insert injected sample. Thus, it was identified that the core in the PUR insert injected sample has a coarser spherulitic structure and more suitable for crystallisation comparing to steel insert moulded part. Again, this behavior is attributed to a smaller heat flow between PUR insert and injected workpiece, resulting in spherulites increasing nucleation and growth, due to longer cooling time of the moulded part.

4.2 *Crystallinity Degree of Injected Parts*

The crystallinity degree of the steel and PUR insert moulding parts was calculated by Equation 3. Therefore, it was measured the samples melting enthalpy in both conditions. Table 3 shows the results.

Table 3. Melting enthalpy results and crystallinity degree calculation.

Insert Material	Melting Enthalpy (J / g)	Crystallinity (%)
Steel	96,12	46,0
PUR	111,90	53,5

The PUR insert moulded parts showed a higher crystallinity percentage. The degree of crystallinity for this condition was 7.5% higher comparing to samples injected into steel inserts. It is suggested that this difference is about the insert materials thermal conductivity, which are 29 W / mK for steel and 0.51 W / mK for PUR. Therefore, the PUR conductivity in the study is 56.8 times lower than the steel. The slower thermal flow between the mould and the moulded part, longer the polymer molecules to recalibrate the structure in an orderly manner, thus increasing the degree of crystallinity (Jesus, 2005).

5 CONCLUSIONS

Due to the low thermal conductivity, the Ren Shape 5166 resin took a cycle time 34.5 higher than the cycle using the cavities of P-20 steel.

Unless the cycle time, the resin Ren Shape 5166 had a reasonable behavior for injecting Polypropylene, since there was neither fatigue, adhesion nor deformation after injecting a dozens of workpiece.

The optical microscopy analysis showed that the steel insert moulded parts was approximately 42% greater than PUR insert moulded parts. The layers are clearly defined and mainly composed by four sub-layers: surface layer, refined spherulitic structure, shear zone and the transition zone between the skin and core. However the PUR insert moulded samples did not have well-defined layers. The surface had a refined spherulitic structure and then the external transition zone layer. These differences are linked to heat flow between the parts and insert materials. The samples core morphology also differs. It was found that the sample injected in PUR has a coarse spherulitic structure and more suitable to crystallisation in relation to the steel insert molded part. The crystallinity degree for the samples injected into the PUR insert resin was 7.5% higher comparing to the sample injected into the steel insert. This difference is also related to the insert materials thermal conductivity.

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