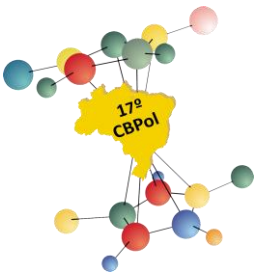

COMPARATIVE ANALYSIS OF ROTOMOLDING AND INJECTION PROCESSES FOR THE MANUFACTURE OF HDPE PRODUCTS

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Abstract – HDPE is widely used and can be shaped using various techniques. Rotational molding offers complex geometries and hollow profiles, while injection molding provides high speed and dimensional stability. This study compares the effects of these processes on HDPE in its properties. Results show that rotomolded samples had higher crystallinity (59.76%) and elastic modulus (647.87 MPa), while injected samples performed better in the impact test (55 kJ/m²). The choice of molding process should consider specific product requirements.
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Introduction

High-density polyethylene (HDPE) is a widely used thermoplastic due to its excellent combination of properties, such as chemical resistance, high mechanical strength compared to other commodity polymers, rigidity and ease of processing (low melting temperature), among others [1]. For this reason, HDPE can be found in various industrial sectors, including pipelines, cable coatings, automotive components, storage tanks, a standard household products like bottles, toys and packaging. Its versatility and range of properties make it the top choice for applications requiring mechanical and chemical resistance, low cost, impermeability and non-toxicity [2].

HDPE can be molded using different manufacturing processes, with the leading techniques being rotational molding and injection molding. Rotational molding involves heating a filled hollow mold and rotating it to distribute the material uniformly along the walls. After cooling, the mold is opened and the final piece is extracted [3, 4]. This process offers advantages like unique pieces with complex geometries. However, this technique tends to be slower than other shaping processes, like injection molding, and its parts can experience significant shrinkage [3, 4, 5].

Injection molding is a modern and versatile process for molding thermoplastics. It involves melting the polymer material in an injection chamber and then pouring it into a closed mold to cool and solidify the product [6]. The process offers high production speed and excellent dimensional stability for mass production. It allows for the incorporation of complex details like reinforcements and holes. However, it comes with a high initial cost, long setup times, and can result in residual stresses in the final material [5, 6].

Both processes have their advantages and disadvantages, but it is essential to understand the significant differences between each technique in order to choose the best option according to the specific needs of each desired product. This article will address the comparison between rotational molding and injection molding processes for high-density polyethylene, aiming to elucidate the influence of these techniques on its properties and characteristics resulting from each one.

Experimental

Material

In this work, high-density polyethylene HD4601U from Brasken was used. The polymer was acquired in micronized form (60 µm), specifically designed for the rotational molding. The HDPE has a melt flow index of 2.0 g/10 min, a density of 0.942 g/cm³ and a melting temperature of 129 °C.

Material Processing

Since the material was in micronized form (Fig 1), a preliminary extrusion step was required to form pellets, which were later used in the injection process. The extruder (Fig 1–a.1) used in this step was a Brabender Twin Screw Multipurpose extruder, where the material was extruded at a screw rotation speed of 180 rpm, average torque of 53 Nm, initial polymer mass temperature of 198 °C, feeding rate of 2 kg/h and pelletizer speed of 8600 rpm. The temperatures used in the six heating zones of the equipment were between 175 and 190 °C. The resulting material in pellet form can be seen in Fig 1–a.2.

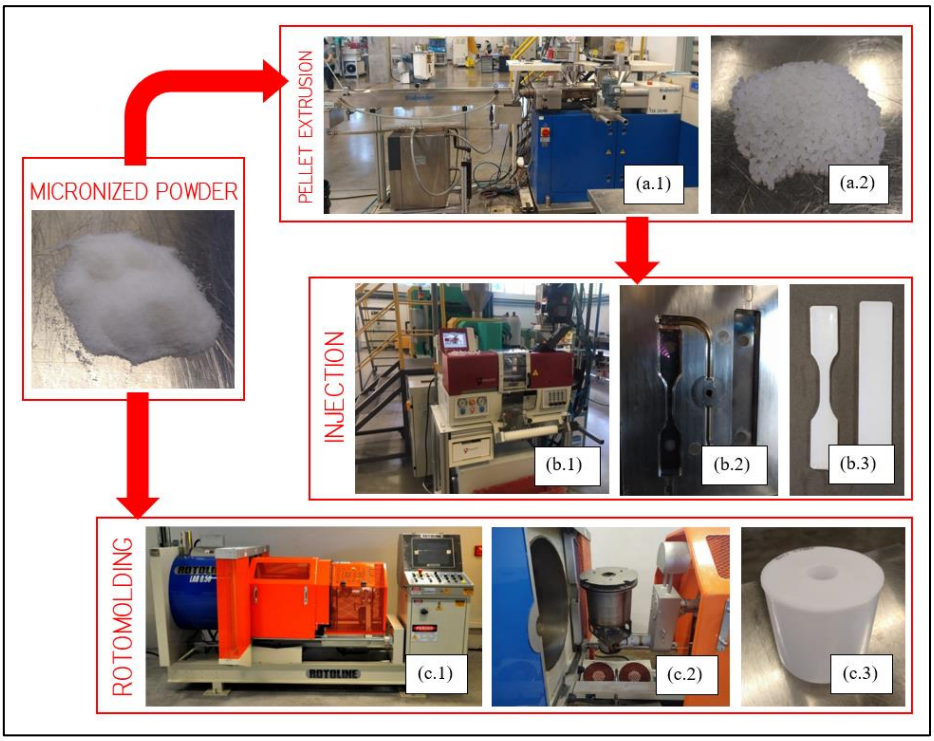

Figure 1 – Production process of HDPE samples

The injection of the test specimens was carried out using a horizontal Babyplast 10/12 injection molding machine (Fig 1–b.1). The test specimens (Fig 1–b.3) were produced in the required dimensions for subsequent testing using specific molds for each test (Fig 1–b.2). The processing conditions are presented in Table 1.

Table 1 – Injection parameters for HDPE samples

Parameters	Impact samples	Tensile samples
Temperatures (°C)		
H1 – Plasticization	190	
H2 – Nozzle	185	
H3 – Nozzle Tip	180	
Metering		
Plasticization speed (%)	60	
Metering volume (mm³)	19	14
Decompression stroke	5	

Injection and pos-injection	
Actual injection pressure (bar)	105
Injection speed (%)	20
Pos-injection pressure (bar)	80
Switch-over volume (mm³)	5
Injection time (s)	4.1
Pos-injection time (s)	6
Times	
Cooling time (s)	18
Cycle time (s)	34.1

For the production of rotomolded samples, a Rotoline LAB 0.50 rotational molding machine (Fig 1–c.1) and a circular mold with dimensions of Ø202 × 200 mm (as shown in Fig 1–c.2) were used. The heating parameters in the rotational molding process, including an oven temperature of 250 °C for 18 min, arm speeds of 4 rpm and 1 rpm, and a reversal time of 5 min. The cooling parameters consisted of an oven time of 16 min and arm speeds of 4 rpm and 1 rpm. After cooling, the vessel-shaped part was removed from the mold (Fig 1–c.3) and machined to extract the test specimens.

Physical and Thermal Characterization of Rotomolded and Injected HDPE

To evaluate the physical and thermal properties, DSC analysis was performed on HDPE samples in pellet, injected, and rotomolded forms. The samples weighing 12 ± 2.65 mg were analyzed using a TA Instruments Q200 instrument under a nitrogen atmosphere. The analysis followed a temperature program consisting of an isothermal hold at 30 °C for 2 min, a heating ramp from 30 °C to 200 °C at a rate of 10 °C/min, and an isothermal hold at 200 °C for 2 min [7].

The obtained data were plotted using the free software TA Universe Analyses, and values for the peak melting temperature (T_{peak}) and melting enthalpy (ΔH_f) were extracted from the resulting graph. The crystallinity index (X_c) was calculated using Eq. 1, where ΔH_f^0 represents the heat of fusion for a hypothetical 100% crystalline polymer (assumed to be 293 J/g) [7].

$$\boldsymbol{X_c}(\%) = \frac{\boldsymbol{\Delta H_f}}{\boldsymbol{\Delta H_f^0}} \boldsymbol{.100} \qquad (1)$$

Scanning electron microscopy (SEM) characterization was performed using a Joel JSM-6010LA microscope to assess the morphology of the processed polymer. Samples taken from the fracture region of the impact test were gold-coated and examined at an approximate magnification of X30, with a working distance (WD) of 12 mm and a voltage of 15 kV.

Mechanical Characterization of Rotomolded and Injected

To assess the mechanical properties, the injected and rotomolded specimens were tested for tensile and impact properties. The tensile test was performed by ASTM D638 standard using Type I specimens. The samples were tested on an Instron universal testing machine using 500 mm/min as displacement rate and a 5 kN load cell. The Izod impact test was conducted in accordance with ASTM D256-10. The test was performed on a Resil Impactor CEAST equipment, using a 4 J hammer for the injected samples and a 2 J hammer for the rotomolded samples. All samples in both testes were conditioned at a temperature of 23 °C and a humidity of 50% for 40 h prior to testing.

Results and Discussion

The DSC analysis results are presented in heat flow versus temperature graphs (Fig 2). It can be observed that the material processing had a slight influence on the material's melting temperature. Although, significant differences were observed in the melting enthalpy values of the rotomolded (an increase of ~20% compared to the HDPE pellets). This probably occurs due to the difference in processing temperatures of each forming method, which enables a better arrangement of the polymer chains as the processing energy increases. This also reflects in the crystallinity indices of the material,

where values of 59.76%, 49.52% and 49.28% were obtained for rotomolded, injected and pellet, respectively. This is a factor of great importance, since the HDPE applications in products probably will be limited since higher levels of crystallinity improve density, stiffness, and temperature-related properties, but reduce impact resistance and transparency [1, 5, 7].

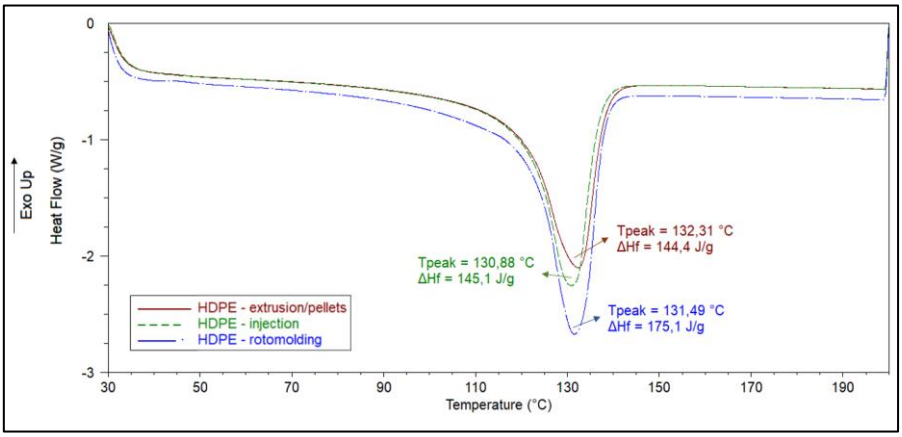

Figura 2 – DSC curves for PEAD pellet (extrusion), PEAD injection and PEAD rotomolding

The tensile test results are presented in Table 2, showcasing notable differences between the rotomolded and injected HDPE samples. The rotomolded HDPE exhibited superior modulus results compared to the injected samples, with an increase of approximately 29%. This finding aligns with the differential scanning calorimetry (DSC) analysis outcomes. Notably, no statistically significant differences were observed in terms of maximum yield stresses and yield deformation. However, the injected polymer displayed higher deformation values at rupture, reaching approximately 550% compared to the rotomolded counterpart. This disparity could be attributed to more void defects in the rotomolded HDPE, primarily due to the absence of pressure application for conformation during the process [5].

Table 2 – Results from Tensile test of HDPE samples

Sample	***Yield stress (MPa)***	***Yield strain (%)***	***Rupture stress (MPa)***	***Rupture strain (%)***	***Young's modulus (MPa)***
Rotomolding	17.97 ± 2.01	9.87 ± 0.72	10.01 ± 1.68	30.61 ± 10.71	647.87 ± 55.21
Injection	16.96 ± 1.08	10.63 ± 0.32	12.23 ± 0.51	196.48 ± 60.38	503.64 ± 41.26

In Fig 3 we can see the results for the Izod impact test (Fig 3a) and post test samples (Fig 3b). Injected samples obtained better results than rotomolded samples (about 62%). That was already expected due to the higher stiffness contents of the rotomolded samples. However, it is worth mentioning that the samples had different behaviors in their rupture. The rotomolded samples showed partial breakage (+ 90% of the total section), while injected samples showed non-breakage (less than 90%). These results can also be related to the possibility of voids in rotomolded samples.

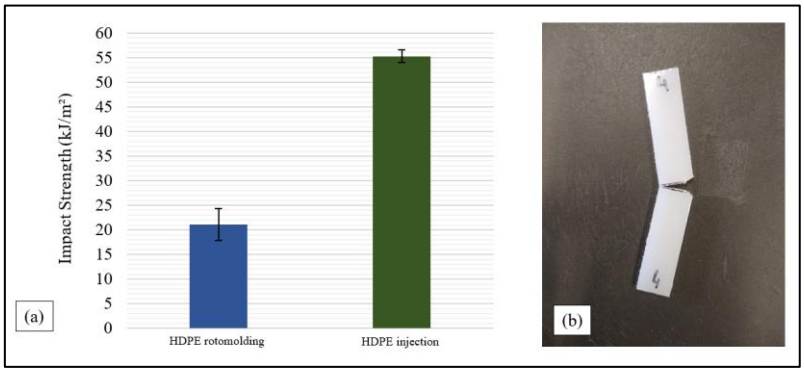

Figure 3 – Graphics from Impact test (a) and samples after test (b)

The impact-fractured samples were subjected to SEM testing, and the corresponding images are displayed in Figure 4. Fig 4a reveals the region's deformation marks (striations), indicating the impact-induced deformation, but no voids are observed. In contrast, the rotomolded sample (Fig 4b) exhibits visible void regions resulting from the processing, which might contribute to the premature fracture of the specimens. The morphology depicted in these images appears to be the primary factor responsible for the lower mechanical properties observed in the rotomolded HDPE samples.

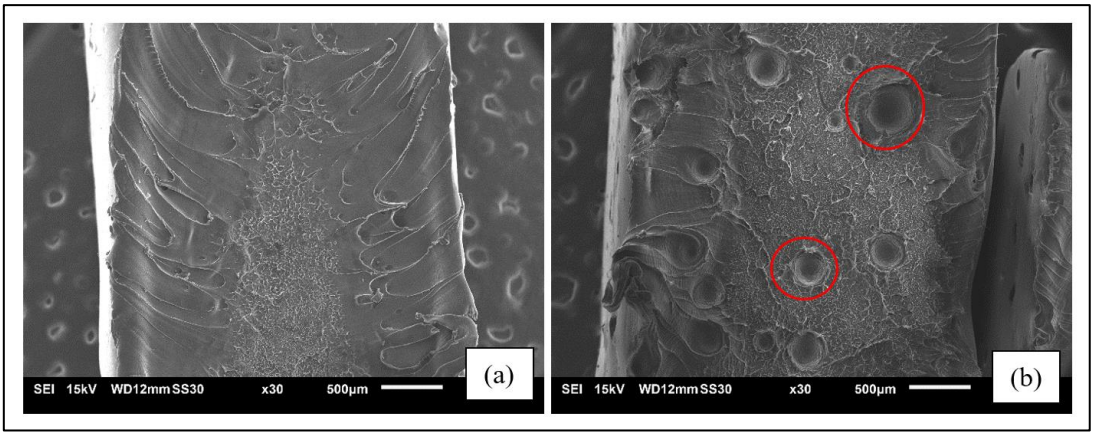

Figure 4 – SEM images from fractured impact samples: (a) injected and (b) rotomolded

Conclusion

This study compared HDPE properties obtained through rotomolding and injection molding. Both techniques had a noticeable impact on the material. Rotomolded HDPE showed higher crystallinity and melting enthalpy, while injected HDPE and pellets differed. Tensile tests indicated that rotomolded HDPE had a higher elasticity modulus, indicating increased stiffness, while injected samples were more ductile. Impact tests showed superior performance in impact resistance for injected HDPE, but void defects were observed in rotomolded samples, potentially affecting their impact performance. These findings emphasize the significant influence of the processing technique on the mechanical properties and morphology of HDPE. They provide valuable insights for selecting the appropriate molding process based on the specific requirements of the desired product.

Acknowledgments

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