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INFLUENCE OF INJECTION MOLDING PROCESS PARAMETERS ON THE MECHANICAL PROPERTIES OF POLYPROPYLENE AND POLYETHYLENE PARTS

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Abstract: *Polypropylene (PP) and high-density polyethylene (HDPE) are the most common polymers in modern industrial plastic part production. Both materials can be easily shaped through injection molding, which is one of the most widespread processing methods for polymer materials. When manufacturing parts from PP and HDPE, it is necessary to achieve the required mechanical characteristics that depend on processing parameters (melt temperature, tool temperature, cooling time, etc.). This paper presents research on the impact of tool temperature on the tensile strength of injection-molded test specimens made from PP and HDPE. Since both materials contain amorphous and crystalline phases, changes in the ratio of phases are possible depending on the tool temperature, which leads to mechanical properties (tensile strength) changes. In the experimental assessment of tensile strength for polypropylene (PP) and high-density polyethylene (HDPE) specimens, conducted at varying tool temperatures (20°C, 50°C, and 80°C), notable disparities in tensile strength values were observed. These variations were attributed to alterations in the crystalline phase content within the materials, instigated by disparate cooling rates resulting from utilizing distinct tool temperatures.*

Keywords: *Polypropylene, high-density polyethylene, injection molding, mechanical characteristics, tensile testing, tensile strength*

1. INTRODUCTION

Polymers are categorized as engineering materials due to their versatile utility alongside other materials, such as metals, ceramics, glass, and rubber. Their advantageous properties and processing capabilities have facilitated their application across various industrial sectors. Polypropylene and high-density polyethylene are among the most used materials for plastic part production through injection molding. Polypropylene, characterized by its low density and excellent high-temperature stability, enables various applications in diverse temperature conditions. Although it shares some properties with polyethylene, polypropylene exhibits greater hardness and strength, making it relatively rigid compared to polyethylene, which offers a higher degree of flexibility and elasticity [1].

In the conventional injection molding process, the polymer material is first melted and then injected into a mold under pressure, where the molded part solidifies through cooling. Subsequently, the mold is opened, and the finished part is ejected. In the context of injection molding, it is crucial to accurately define and control process parameters to ensure the production of workpieces with satisfactory mechanical characteristics. Influential parameters, such as melt temperature, tool temperature, and cooling time, must be carefully specified and monitored throughout the process [2, 3].

A frequent area of interest for numerous researchers is the analysis of the mechanical characteristics of parts obtained through injection molding using metallic tools. Rashid and colleagues, in their study [4], demonstrated that the high thermal conductivity of aluminum reduces cooling time by 30% compared to steel tools. It is well-known that accelerated cooling may lead to increased part shrinkage; however, research findings [4, 5] indicate relatively similar mechanical properties for parts molded using aluminum tools when compared to those molded in steel tools.

The crystalline structure plays a significant role in the mechanical properties of parts, in the way to enhance its tensile strength [6]. In the study by [7], the influence of heating rate on crystallinity in PP was analyzed, and it was concluded that a slower heating rate improves crystalline perfection through the reorganization of the crystal structure. Through ANOVA analysis in [8], it was determined that mold temperature, along with injection pressure, represents the most influential parameters on the mechanical characteristics of parts after injection molding. Authors in [9] demonstrated that a higher melting temperature has the potential to enhance the crystallization rate and impact strength of HDPE parts but concurrently reduces tensile and flexural strength. Conversely, in research [10], it was observed that an increase in mold temperature augments tensile and flexural resistance while decreasing impact strength.

In this study, samples from polypropylene and high-density polyethylene were produced by injection molding, aiming to analyze the influence of varying tool temperatures during the injection molding process on the mechanical properties of the materials, specifically the tensile strength.

2. EXPERIMENTAL PROCEDURE

The research presented in this paper encompasses the fabrication of test specimens from PP and HDPE, following the ISO 527/2-5A standard (Figure 1), using an injection molding machine. The study aims to determine the influence of tool temperature on the tensile properties of the materials [11].

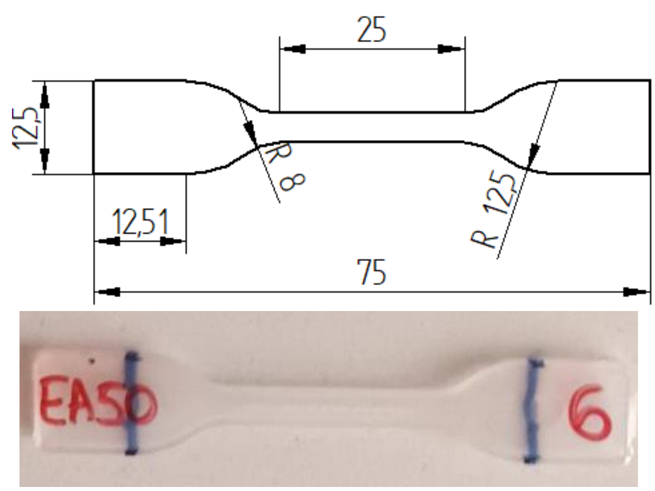

Figure 1. Test specimen according to ISO 527/2-5A standard [11] and injection molded specimen

For experimental research, an Engel Victory 50 injection molding machine was used. The injection molding process was carried out using a tool with two aluminum inserts situated in one half of the mold, while the other half of the mold remained flat (Figure 2).

The parameters used in the injection molding process are presented in Table 1. As indicated in Table 1, the specimens were produced at varying tool temperatures (20, 50, and 80°C), while the remaining parameters were optimized through an iterative process based on recommendations from the literature [12] for the specified materials and wall thickness.

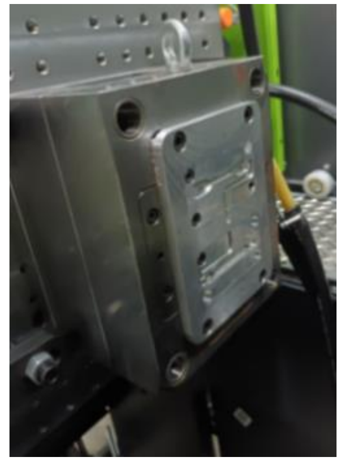

Figure 2. Injection molding tool with aluminum inserts

Table 1. The values of the parameters used in the injection molding process.

	Polypropylene	High-density polyethylene
T_a (tool temperature [̊C])	20, 50, 80	20, 50, 80
T_t (melting temperature [̊C])	190	230
t_h (cooling time [s])	30	30
p_u (first-stage pressure [bar])	800	1000

2.1 Specimens testing

A total of 18 test specimens were produced through injection molding, with three specimens from each material for every tool temperature. Tensile strength testing was conducted using an INSTRON 34SC-2 tensile testing machine (figure 3).

Throughout the tensile testing, force values were continuously recorded as a function of displacement, along with the tensile strength values for each tested specimen.

3. RESULTS AND DISCUSSION

A graphical representation of the tensile strength testing results for HDPE and PP is provided in Figure 4. The diagrams marked as EA20H, EA50H, and EA80H represent high-density polyethylene, while diagrams marked as EA20, EA50, and EA80 correspond to polypropylene characteristics. The values 20, 50, and 80 refer to the tool temperatures used in sample fabrication.

Figure 3. INSTRON 34SC-2 testing machine

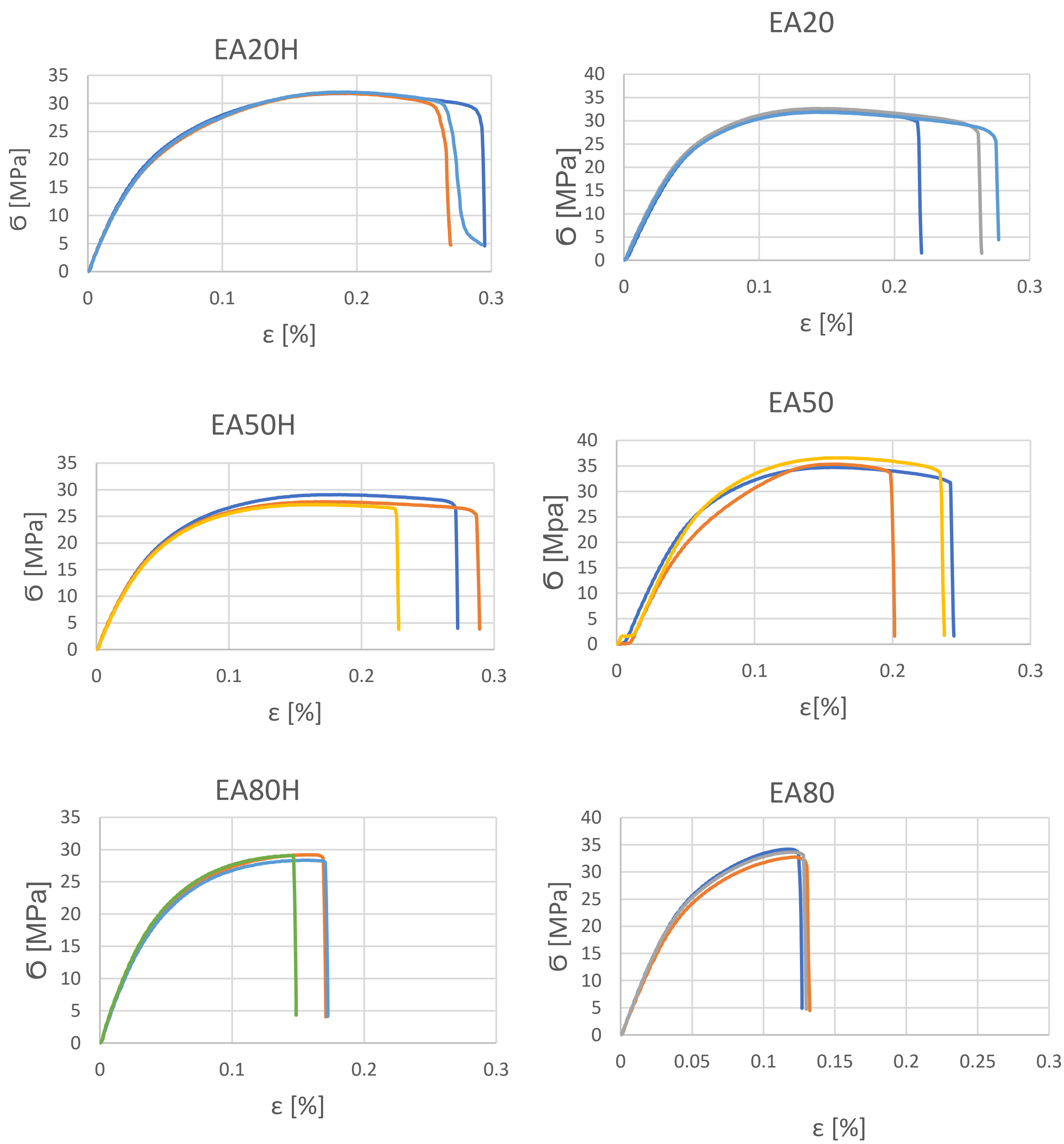

Figure 4. Tensile testing diagrams for HDPE and PP.

Table 2. The average values of tensile strength for HDPE and PP specimens

Specimen	EA20H	EA50H	EA80H	EA20	EA50	EA80
Average values of R_m[MPa]	31,86	28,01	28,88	32,32	35,53	33,51

The average tensile strength (Rm) values of the tested HDPE and PP specimens are presented in Table 2.

The higher tensile strength in polymeric materials is achieved through a higher share of the crystalline region. Crystallization represents the process of transforming the molecular structure of polymers into a specific form. A high degree of crystallization contributes to increased strength, hardness, and rigidity of the material. The degree of crystallization primarily depends on the material's molecular structure and the defined processing parameters. Mold temperature influences crystallization, as high cooling rates and low temperatures reduce material crystallinity [13]. In addition to the degree of crystallinity, the orientation of polymer chains has a significant impact on the tensile properties of materials.

During the testing of HDPE specimens, it was observed that material strength decreases as the tool temperature increases. In contrast, with PP specimens, an initial increase in tensile strength was noted as the tool temperature rose to 50°C, followed by a decrease in strength when the tool temperature reached 80°C (Table 2). This behavior in the specimens results from the formation of different material structures at different tool temperatures, primarily due to changes in crystallinity. Furthermore, the tensile strength value is also affected by residual stresses, which arise due to the varying mobility of molecules during the cooling and melting phases of the material.

Analyzing the tensile stress-strain diagrams (Figure 4), it can be concluded that the variation in tool temperature significantly impacts the achieved elongation at break and tensile strength. Notably, both materials exhibited substantial tensile strength values in accordance with the reference values specified by the manufacturers of the materials used [14, 15].

4. CONCLUSION

The significant utilization of polymeric materials across various industrial sectors arises from their favorable properties, which enable optimal performance under demanding operating conditions. When industrial components are made from polymeric materials, achieving the necessary mechanical characteristics is of paramount importance.

This research shows that the applied parameters during the injection molding process facilitate the production of high-quality workpieces. The variation in mold temperature during injection molding significantly influences the formation of the material's microstructure, thereby directly impacting the mechanical properties of the component. It has been shown that fluctuations in tool temperature affect the tensile strength value, which may be a result of combinations in crystallinity and the size of crystalline as well as residual stresses after injection molding. The materials achieved a notable tensile strength value, exhibiting substantial plastic deformation prior to fracture.

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