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Investigation of Mechanical and Dimensional Features in Unfilled Polyketone Polymer

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Abstract: High performance engineering polymers are widely used in automotive sector today. For this reason, the mechanical and dimensional of one of these polymer materials after injection molding under different process conditions (melt temperature, injection pressure and gate type) will be investigated. In order to examine the mentioned properties of these polymers, a series of plastic injection experiments were carried out based on the Taguchi Experimental design (L_9). In the experiments, tensile strength, percentage elongation and shrinkage values were obtained by using the parameters of mold temperature, injection pressure and type runner gate. At the end of the study, time and cost savings were achieved by performing the least number of experiments according to the Taguchi experimental design. In addition, the problems encountered in the use of polymer materials in the literature and industry have been tried to be removed. Moreover, some solutions will be provided on mechanical and the quality problems in plastic injection molding.

Keywords: Polymers, Plastic injection molding, Mechanical properties, Dimensional properties, Taguchi design

Introduction

In our today, the need for the use of high-performance engineering plastics in plastic injection method is increasing rapidly. In the plastic injection molding method, advanced polymers are used extensively in the automotive and aviation industries (Ezdeşir et al., 2006). Basic injection process parameters such as temperature, pressure, injection speed and cooling time are used in shaping high performance engineering polymers (Akyüz, 2006). Plastic products shaped with these parameters are expected to exhibit high strength, better quality and high performance according to their usage areas. Plastic injection process parameters play an important role in the quality of the plastic product after injection (Beaumont et al., 2002). High performance engineering polymers include Polyphenylene Sulfide (PPS), Polysulfone (PSU), Polyphenylensulfone (PPSU), Polyamide-imide (PAI), Polybenzimidazoles (PBI), Polyetheretherketone (PEEK), Polyketone (PK) and Liquid Crystal Polymer (LCP).) can be ranked as important. High performance engineering polymers have properties such as high tensile, compression and creep strength, ability to work at high temperatures and under load, resistance to chemicals and radiations, flame resistance and insulation properties, and safe operation at extreme humidity and temperatures. These polymers have started to find wide usage areas in the aerospace industry, automotive industry, nuclear power plants, steam turbines and medicine (Akkurt, 2007).

In particular, polymers such as PK attract attention due to their properties. Some researchers investigated the mechanical, thermal, rheological and volumetric shrinkage (dimensional) properties of engineering polymers using different plastic injection process conditions (Arıcıoğlu et al., 2000) & (Kurt, 2011). A group of

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researchers investigated the mechanical properties of plastics produced with glass fiber reinforced Polypropylene (PP) and Nylon 6 (PA6) polymer materials (Güllü et al., 2001). The tensile strength and part geometry properties of Ultimate High Molecular Weight Polyethylene polymer (UWHDPE) were investigated by another group of researchers using the Taguchi method. In the study, it was stated that the cross-section without weld lines had significant effects on the tensile strength. It has also been stated that the Taguchi method is very effective in selecting the most suitable mechanical properties of the polymer material (Kuo & Jeng, 2010). In a similar study, researchers studied on estimating the mechanical properties of 25% recycled PE and 75% original polymer mixture with the best process parameters. Researchers also examined the effect of recycling plastic additive on mechanical properties and flow index. At the end of the study, it was stated that the addition of recycled plastic contributed to the mechanical properties and reduced the production cost (Mehat & Kamaruddin, 2011). In another similar study, the mechanical and thermal properties of PP and ABS (Acrylonitrile Butadiene Styrene) recycling polymers were investigated. For this purpose, tensile test, heat deformation test were carried out. As a result, 30% improvement in thermal properties and 50% improvement in mechanical properties of recycled polymer materials has been achieved (Şen et al., 2020).

After the injection molding of polymer materials, due to different cooling rates and thermal gradients, volumetric contraction and distortion occur in polymer materials. Some researchers investigated the effects of plastic injection parameters, which cause volumetric shrinkage and warping, on different polymers with the Taguchi method and experimental methods (Çakır & Güldaş, 2001), (Iyer & Ramani, 2002), (Jansen et al., 1998). In addition to these studies, optimization of process parameters based on Taguchi method on both volumetric shrinkage and warping was performed (Liao et al., 2004), (Öktem & Erzincanlı, 2012), (Öktem et al., 2007). An optimum cooling system is very important to more decrease the volumetric shrinkage in the injection process of polymer materials. If the cooling system is well designed, high part geometry and quality surface can be achieved (Wang, et al., 1996) & (Yıldırım, 2011). In addition to these, cold and hot runners are preferred according to the flow distance and the filling volume of the part cavity during the injection of polymer materials. Researchers have stated that the reason why hot runners are more preferred is higher plastic part quality, injection of advanced engineering polymers and lower cost (Öztürk & Özkan, 2015) & (Demirer, et al., 2007).

In this study, a series of experiments were carried out using Taguchi L_9 design to evaluate the mechanical and dimensional properties of high performance engineering polymers of un-filled PK in plastic injection molding. During the current study, the effects of melt temperature, pressure and runner gate type as initial parameters on tensile strength, elongation (%) and shrinkage and were investigated. Upon the literature surveying, it has been seen that very serious and comprehensive works have not been carried out on high-performance engineering polymers. Therefore, it was decided to conduct this current study. Moreover, tensile strength values had changed from 58.55 to 63.60 MPa unfilled PK polymer. The lowest percentage elongation was obtained in 9.12 (%) whilst the highest percentage elongation was found as 9.86 (%). The best shrinkage value was calculated in 1.864 (%). It can be observed that this material is a ductile polymer due to some properties.

Experimental Study

Design of Experiments

In this study, using four different injection parameters of polymer material (Polyketone-PK), a total of 9 experiments were performed on a plastic injection machine according to the three-level L_9 Taguchi orthogonal design (Minitab Software, 2007). In the experiments, tensile strength, elongation (%) and shrinkage of the injected samples were determined by using injection parameters such as melt temperature, injection pressure and gate runner type (Table 1). Gate runners are divided into three types: T is single gate; C is double gate and D is direct gate over the plastic sample.

Table 1. Design of experiments (L_9 Taguchi) for PK polymer

Parameters	Melt temperature (°C)	Injection pressure (Bar)	Gate type (C-T-D)
	250	80	1
	260	100	2
	270	120	3

Materials and Method

In this study, plastic molds were designed and manufactured for the injection process of three different polymer materials on a plastic injection machine (TMC 60). The plastic samples were injected by using three injection parameters based on the Taguchi L_9 design given in Table 1. The samples of tensile rod and shrinkage bar were injected for polymer of PK as shown in Figure 2. In plastic injection experiments, three runner gates were utilized by changing them. Injection machine was adjusted in values of clamping force is 600 kN, injection speed is 45 mm/s, injection time 2 s, packing time is 5 s, cooling time is 10 s, mold open-close time is 5 s and total cycle time is 22 s.

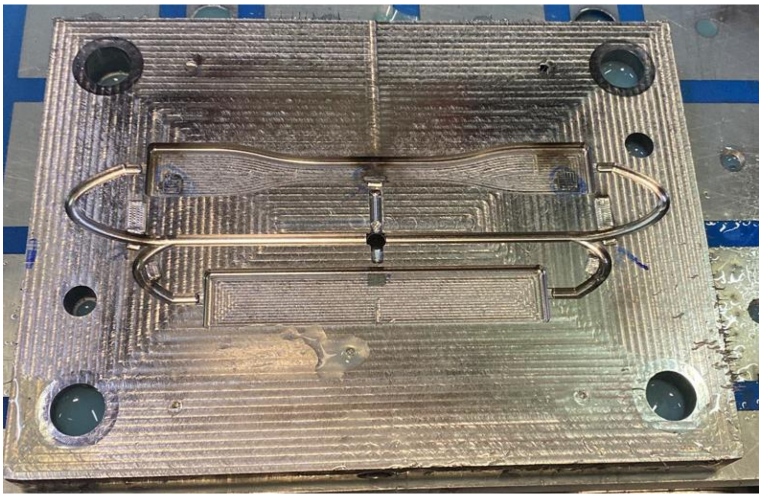

Figure 1. The finished of plastic molds for plastic sample

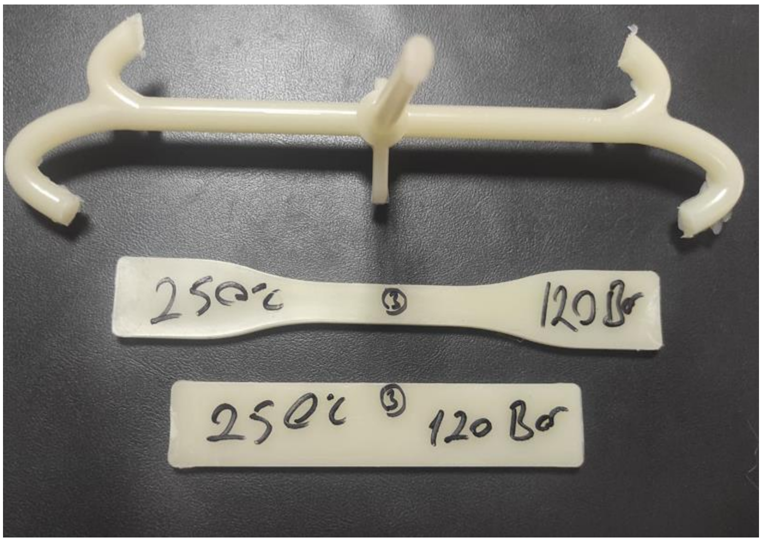

Figure 2. The tensile rod and rectangular samples of PK Polymer

Measurement of Mechanical and Dimensional Properties

In this study, the general properties of high performance engineering polymers are tried to found by means of tensile strength and dimensional measurement. For this purpose, firstly, 9 tensile rod samples were conducted in MACRONA model instrument. According to International standards (ASTM D-638, 2010) & (ASTM D-1238, 2001), the test speed is 100 mm/min in tests as shown in Figure 3. Tensile strength values were measured at yield point during the tests. From these tests, it was obtained the values of tensile strength (MPa) and elongation (%).

Figure 3. The tensile tests of polymers

Secondly, the values of shrinkage in ASTM D-955 were calculated by measuring the dimensions of mold and plastic samples in length direction for PK polymer with a digital caliper in Figure 4. The instrument is made by Mitutoyo with accuracy of 0.01mm. The measurements were performed at least three times. All of shrinkage measurements were conducted after the first 48 hours out of the mold.

Figure 4. The measurement length of PK sample in longitudinal direction

Results and Discussion

In this section, all the results related to the mechanical and dimensional properties obtained from the tests carried out on plastic samples are examined and evaluated. Table 2 shows the results of tensile strength, elongation (%) and shrinkage in longitudinal (X-direction) of plastic samples.

Table 2. Experimental results for unfilled PK polymer

Polymers	Tensile Strength (MPa)	Elongation at yield (%)	Shrinkage (Longitudinal) (%)
Polyketone	62.58	9.17	2.136
	61.29	9.27	2.318
	60.20	9.86	1.864
	58.55	9.58	1.927
	59.47	9.26	2.018
	61.83	9.33	2.364
	61.32	9.38	2.291
	60.92	9.74	1.936
	63.60	9.12	2.109

From Table 2, it can be observed that the tensile strength values obtained as a result of the tensile test applied to un-filled PK polymer vary according to the plastic injection conditions. The highest tensile strength values were found for the injection parameters where the plastic melt is given from a double gate (C). In addition, each of the tensile strength values was obtained from plastic injection parameters such as pressure of 120 and temperature of 270 ºC. The highest tensile strength is 63.60 MPa, while the lowest is 58.55 MPa. These values obtained are very close to the values given by the literature and manufacturers.

In Table 2, it is also seen that the elongation (%) values are changed from 9.86 to 9.12 %. The lowest percentage elongation is calculated in the injection condition with double gate (C). This situation can be explained by the weaker bond structure of the PK polymer compared to other polymers in literature at the morphological level (Campo, 2008). Additionally, since the melt is filled from two directions, it will create weld line formed at the middle point, and this has caused PK sample to have a high percent elongation value.

As seen in Table 2, the volumetric shrinkage values in the direction of flow rate vary between 1.864 and 2.318 for PK polymer. The reason for this can be explained by the higher melt flow index of the PK polymer and its morphological structure of the polymer. On the other hand, semi-crystalline polymer materials have more than high shrinkage value amorphous (Beaumont, 2002).

Conclusions

In this study, the mechanical and dimensional properties of a high-performance engineering polymer were investigated by experiments performed under three different injection conditions. In light of results and evaluations obtained from these experiments, the conclusions can be summarized as follows:

- The unfilled Polyketone is a high performance engineering polymer, it is also semi-crystalline polymer which requires a shorter molding cycle and higher melts and mold temperatures.
- The elongation (%) values appropriated that this polymer is high mechanical properties.
- The high elongation values have showed a ductile of PK polymer. This is why can be explained by the weaker bond structure of the PK polymer compared to other polymers (Campo, 2008).
- Additionally, the fact that the flow is from both sides it will create weld line formed at the middle point has led to an increase in the percent elongation values.
- Shrinkage values of PK polymer are higher than other high-performance engineering polymer because PK polymer is a semi-crystalline material. This is because its bond structure is weak.7
- Among three injection parameters, the best is runner gate type on the mechanical and dimensional properties.
- This study enabled the production of plastic products within the desired criteria as a result of the application of injection parameters on a high-performance polymer.

Recommendations

In future trends, the pressure of cavity in mold can be measured with piezo electric-sensors with PPS, PPSU, PEEK, PEI. Thus, the values of pressure can be obtained in real conditions.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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