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A 3D Numerical and Empirical Study on the Effects of Injection Pressure and Temperature on the Quality of Produced Mold

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ABSTRACT

Plastic injection is a method in which by using an extruder plastic granules are injected in a hole with high pressure. Because of meeting the two flow fronts in this process, a welding line will be made. Along the welding line, the strength of produced part is low; therefore, the position of welding line and its clarity are very important. In this paper, analysis has been done with Fluent and Mold Flow softwares. In addition, verification of these analysis have been done with practical experiments in order to study the effect of injection pressure and temperature on the welding line and its clarity. The materials used in these experiments are ABS and PP. Results show that applying different injection pressures and temperatures affects the strength of the produced part. It is worth noting that both considered polymers are sensitive to pressure at high temperatures. For instance, pressure increase from 45 MPa to 65 MPa at 210 °C results in 35% and 45% reduction in plastic region, respectively. Temperature increase from 170 °C to 210 °C reduces the modulus of elasticity by about 16%. For the ABS polymer, the plastic region increases 13% at the injection pressure of 55 MPa and 65% at the injection pressure of 65 MPa. Temperature increase from 190 °C to 230 °C reduces the elastic modulus by 8%.

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1. INTRODUCTION

There are several parameters in the injection molding process that strongly influence the quality of the achieved product. Among these parameters, injection pressure, melt temperature, location of injection andso on can be pointed out. Injection molded products occasionally have some defects like blister, flow trace, flash knit line formation, change in color, etc. One of the routines faced by a designer when designing quality into a part is the process of cavity balancing. This entails controlling the plastic flow in the filling phase such that the melt front reaches the boundaries of the mold at the same time [1-3].

Effects of injection material on the contact interface form and situation has been studied by Crisan et al. [4]. Park and Dang [5] investigated the injection procedure with conformal cooling channels. Complex molds of variable thicknesses are claimed to be produced more with cooling channels.

Dotta et al. [6] studied the characteristics and behavior of the alumina obtained by low-pressure injection. They found that the surface friction coefficient and its specific wear coefficient are strongly sensitive to the injecting mold velocity.

Sardarian et al. [7] studied the influence of injection pressure and temperature on the properties of alumina mold. They found that increase in injection temperature and pressure leads to the formation of voids which impairs the properties of molded parts. Ronkay et al. [8] investigated effects of injection temperature on the porosity of produced mold. They found relationships between mold temperature and porosity. Jiang et al. [9] studied effects of the mold temperature in the injection molding on the mechanical properties of isotactic polypropylene (PP). They found that the modulus increases with increasing mold temperature.

In the present study the mold filling of ABS and PP is simulated both by the MOLDFLOW and FLUENT.

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Effect of injection pressure and temperature is evaluated on the final quality of the produced material. In this regard, a three-dimensional study is presented for the effect of injection pressure and temperature on the mold filling time and knit line formation. As the numerical model is validated by the experimental works (Sec. 4), considering the effective parameters by the introduced softwares may be considerably time and cost saving.

Fluent is proved to be more precise compared to conventional softwares that are employed by other researchers for the same computation costs. In the experimental work, the estimated location for the knit line as well as the mold filling time in the modeling is verified and the produced materials are evaluated through some empirical tests like tensile tests.

2. MATERIALS METHOD

2. 1. Numerical Simulation The numerical simulation of the injection process in this study is accomplished by applying both FLUENT and MOLDFLOW softwares.

FLUENT is a general-purpose CFD software ideally suited for incompressible and mildly compressible flows. FLUENT capability in handling injection mold filling problems is proved to be excellent [6, 10]. Extensively employed in injection molding applications, MOLDFLOW can effectively detect the defections caused during the injection procedure.
In the present study in the other hand FLUENT is a popular software for modeling and simulation of fluid flows. Void formation as well as vortex flows can be simulated precisely in this software. Since formation of voids is an important defect in the injection molding both FLUENT and MOLDFLOW are employed in the present study.

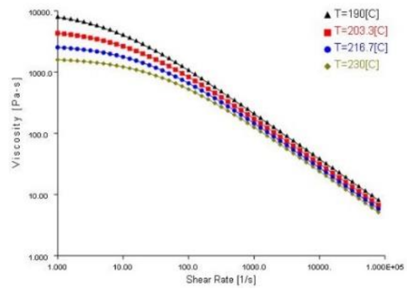
In the present study a three-dimensional mold filling of ABS and PP is studied. In the simulation procedure by FLUENT, the VOF Method and viscosity cross model is used for the melt front tracking. The numerical simulation is performed by FLUENT 14. Modeling and meshing are performed by using Gambit 2.3 software. Navier–Stokes equations are solved by finite volume method and SIMPLE segregated algorithm and implicit method is applied for time discretization. The Cross Model is applied for considering viscosity variations in the FLUENT software.

In the simulation procedure by MOLDFLOW 2015, the defined polymer is "PPliwo60" made by Fraunhofer institute representing PP. UMG ABS PS-507 made by UMG ABS ltd is selected to simulate the ABS polymer. The injection passages in the software are hot and cold. In the present simulation, the latter type is considered. There are three types of passage geometries available in the MOLDFLOW: annulus, round and conic. The annulus type is considered to be consistent with the accomplished experiment. Cold type gates of quadrangular geometry are considered. The cooling system is exerted similar to that of empirical procedure. Viscosity-shear rate curves of different temperatures are demonstrated both for ABS and PP in Figure 1.

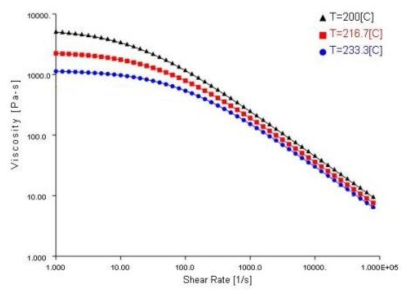
2. 2. The Mold Geometry The model is created by using CATIA software and then imported to the GAMBIT environment to generate total 327,627 elements for simulation. The injection passages are meshed by using tetrahedral elements; while the total mold is meshed by hexahedral elements. The model geometry is shown in Figure 2. The meshed geometry (Figure 3) is then sent to FLUENT for simulation and evaluation of the injection procedure. Pressure inlet boundary condition is applied at the flow inlet and the outlet boundary condition is considered as pressure outlet. Mold is considered as wall and the convection thermal boundary condition is considered on the walls.

2. 3. Experimental Work Fabrication of the sample: In this research in order to fabricate samples a Chinese plastic injection machine (HXF88) made of HAIXING with injection volume capacity of 140 grams and clamp tonnage of 88 tones. A view of the injection machine is shown in Figure 4.

Mentioned temperatures have been chosen based on the temperature range of polymers. In order to keep the mold temperature fixed intervals have been considered within producing the samples. By considering intervals mold temperature will get to the environment temperature and stables. The other parameters are shown in the Table 1.



(a)



(b)

Figure 1. Variation of viscosity against shear rate for a) PP, b) ABS

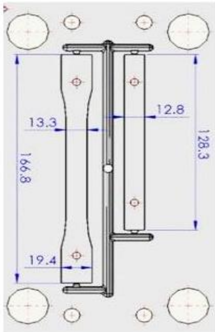


Figure 2. The mold geometry (dimensions, mm)

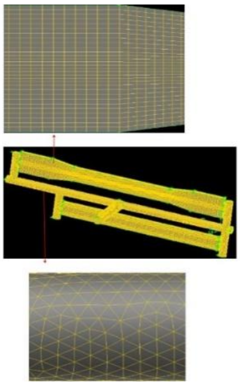


Figure 3. The mold geometry which is meshed by Gambit

Figure 4. plastic injection machine

Figure 5 shows a sample of molding part. The other injection parameters are considered as fixed values. Three samples of different pressures, before executing tensile tests, are demonstrated in Figure 6.

2. 4. Experiment Method Using tensile test some parameters can be obtained including: plastic range and ultimate strength. Test was loaded with strain rate of 2 mm/min. In order to measure the force on the sample, a load cell was used, and in order to increase the accuracy of movement and strain an extensometer was used in addition to the movement of machine itself. The experiments were done with a Chinese machine made by Times Company, and a 3-tone Load Cell. This test will be done in a continuous cycle which results the engineering stress-strain. Tensile machine and extensometer are shown in Figure 7.

TABLE 1. Injection parameters

Injection pressure (M Pa)	Melt temperature (°C)	Mold temperature (°C)	Cooling time (sec)	Injection time (sec)	Injection speed (mm/s)
45-55-65	210	30	15	2	15

Figure 5. sample of molding part

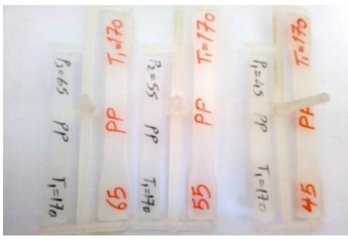


Figure 6 .different pressures, before executing tensile tests in produced samples

Figure 7. Tensile test machine and extensometer

2. 5. Validation of the Numerical Model The location of weld line is compared between the both numerical models and what is experienced in the experiment. Results are shown in Figure 8. As can be observed in this figure, the exact location of the weld line obtained by the numerical models is consistent with what is observed in the performed experiment.

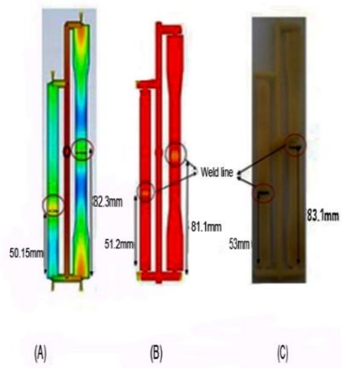


Figure 8. Weld line location (comparison between numerical models and the experiment) A)Result of Mold Flow, B) Result of FLUENT, C) Result of the performed experiment

3. RESULT AND DISCUSSION

The mold filling process as well as the temperature distribution within the mold is comprehensively investigated simultaneously by the two softwares. Filling times in different injection conditions are calculated and compared with the accomplished experiments.

Mold filling time and the temperature distribution of ABS melt front obtained from Mold Flow is demonstrated in Figure 9. The mold filling contours in two different times, obtained by FLUENT, are also demonstrated in Figure 10.

3.1. Effects of Injection Temperature and Pressure for the Weld-lined Sample of PP

At 170°C as the lowest considered temperature range of PP, viscosity has its maximum value; therefore, the flow shear rate is low. This is due to the fact that for non-Newtonian fluids the shear rate directly corresponds to temperature and pressure while has the inverse relation with viscosity. As explained before, the mold production with PP is performed with three injection pressure of 45, 55 and 65 MPa. The weld line for the three produced molds are located at the center as shown in Figure 11. The tensile test was performed for the samples until fracture. The fracture locations for the samples are shown in Figure 11. The fracture line for those samples produced by the injection pressure of 45 MPa and 55 MPa coincide with the weld line while for the sample obtained by the injection pressure of 65 MPa the fracture does not occurs at the weld line. This issue may be due to vortices that are formed in high shear rates and low viscosities. The vortex formation, and consequently void creation at 65 MPa is observed in the numerical simulation in the FLUENT software (Figures 12 and 13). Void formation, because of the stress concentration, accelerates fracture [11]. The fracture phenomenon at locations other than the weld lines can directly correspond to melt flows strike and vortex formations. Shear rate increases as the cross section decreases. It has been observed in the numerical results that sample fracture and void formation occurs in the locations where the cross section is small. One of the outstanding issues regarding the sample with the injection pressure of 65 MPa is the significant deformation caused as a result of fracture, while a negligible deformation is observed for the other two samples.

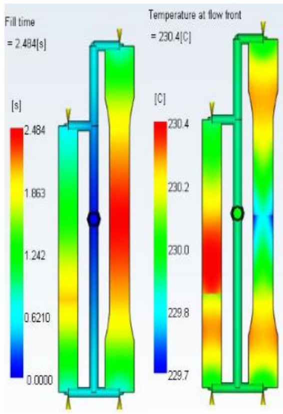


Figure 9. a) mold filling time of ABS, b) temperature distribution of ABS melt front (Results of Mold Flow)

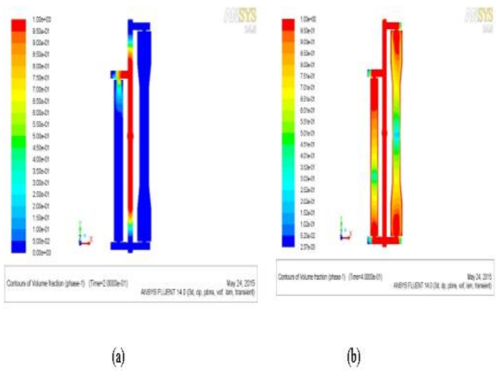


Figure 10. a) Filling the mold in (a) 0.2 and (b) in 0.4 seconds in temperature of 190 and pressure of 65

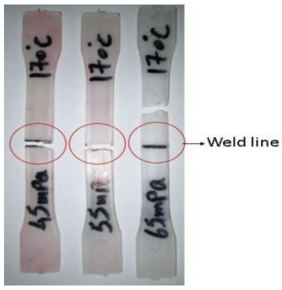


Figure 11. Weld line and fracture line locations for the PP samples produced by different injection pressures at 170°C

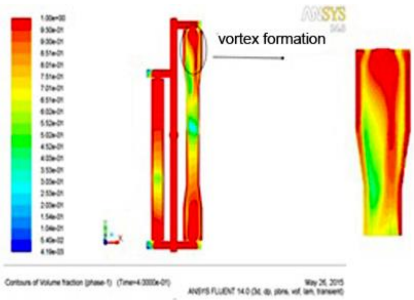


Figure 12. Formation of vortex in PP melt at injection pressure of 65 MPa and injection temperature of 170°C

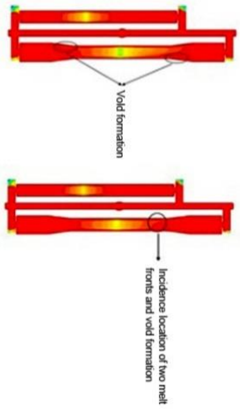


Figure 13. vortex and void formation for the injection temperature of 170°C and injection pressure of 65 MPa

It can be obtained from Figure 14, The ultimate strength in temperature of 170°C is more compared with the ultimate strength in temperature of 190 and 210, which can be related to the molecular mass of polymers. If the molecular mass increases, the entanglement of chains and viscosity will increase [10, 12, 13] that finally causes reduction in cutting rate. Three other samples are produced by similar injection pressures as before (45, 55, 65 MPa) but with injection temperature of 190°C. As can be found from Figure 15, the fracture line approximately coincides with the weld line and there is no

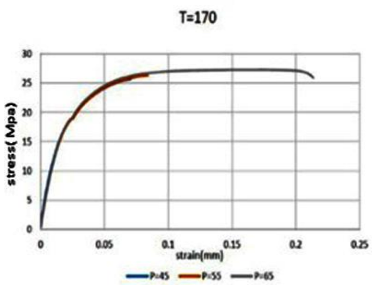


Figure 14. stress- strain diagram for PP at 170ºC in different pressures

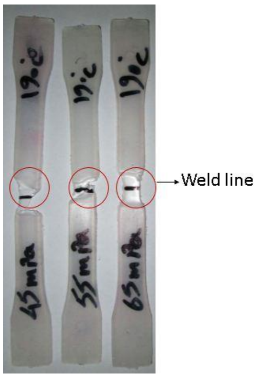


Figure 15. Weld line and fracture locations for the PP samples produced by different injection pressures at 190ºC

specific difference in the fracture location between the three samples although considerable deformation is observed in comparison with the previous samples (those injected by 170°C). Similar to what mentioned before, increase in the injection pressure results in a little increase in deformation during fracture in the present injection temperature.

Because of molecular volume in this temperature, the ultimate strength reduces in an ignorable state. In this temperature, if the molecular volume and entanglement of chains reduce, the strength will experience reduction of 1.1% compared to temperature of 170°C

At this stage, three samples are produced in injection temperature of 210°C at different injection pressures of 45, 55 and 65 MPa. Results of the tensile test are shown in Figure 16.

The fracture location shifts above the weld line for the sample with injection pressure of 45 MPa while for the other two samples, fracture occurred at the weld line. The shear rate increased by temperature and pressure increment. Although the maximum shear rate is experienced in samples with injection pressure of 55 and 65 MPa, fracture is not located at the weld line for the 45MPa sample.

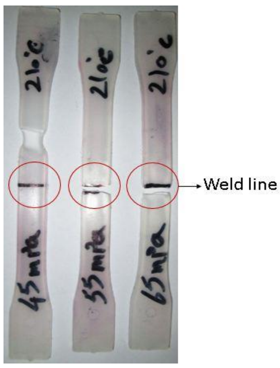


Figure 16. Weld line and fracture locations for the PP samples produced by different injection pressures at 210°C

This issue is due to the fact that vortex and void formation take place in specific shear rate and viscosity. In the present study for the injection temperature of 170°C and injection pressure of 65 MPa as well as injection temperature of 210°C and pressure of 45 MPa, vortex and void formation have occurred. At 210°C, pressure increase results in significant deformation decrease. As can be seen in the figure, there is maximum deformation in the fracture location of the sample produced by 45MPa injection pressure. The approximate amount of deformation in the latter sample is respectively 35% and 45% greater than those in 55MPa and 65MPa samples.

The ultimate strength at temperature of 210°C shows 3.7% increase with respect to that at 190°C, and 4.8% increase with respect to injection temperature of 170°C (Figure 17). It should be noted that temperature increase from 170°C to 210°C decreases the modulus of elasticity by 16%.

3.2. Impact of temperature and injection pressure on ABS in samples with welding line At the injection temperature of 190ºC, if the pressure increases, the ultimate strength of samples decreases in a way that in the pressure of 45 MPa, the ultimate strength increases 7.3 % compared to ultimate strength in the pressure of 55 MPa and it increases 6.6 % compared to its amount in the pressure of 65 MPa. At the injection temperature of 190°C, there is no plastic deformation in samples (Figure 18). At the injection temperature of 210°C, if the pressure increases from 45 to 55 MPa, there will be 4.2% of increase in the ultimate strength. There is not any noticeable difference in the ultimate strength of 55 MPa compared to its amount in the pressure of 65 MPa. There is a little plastic deformation in the samples in the pressures of 55 and 65 MPa. In the pressure of 45 MPa the amount of plastic deformation can be considered as zero, which is shown in the Figure 19.

At the temperature of 230°C, the ultimate strength of samples in all pressures is equal, but if the pressure increases, there will be some differences in the plastic deformation of them, as if pressure increases plastic deformation decreases. In the pressure of 45 MPa there is an increase of 13% in the amount of deformation compared to pressure of 55 MPa and an increase of 65.2% compared to pressure of 65 MPa (Figure 20). Modulus of elasticity is 8% reduced at injection temperature of 230°C in comparison with the previous injection temperature. As shown in Figure 21, fracture position locatesabove?? the welding line. In the numerical model of FLUENT, there isn't any noticeable reason for this fracture, while in analyzing the prediction of quality in the numerical model of MOLDFLOW, positions of fracture are determined as intersection of high quality and average quality.

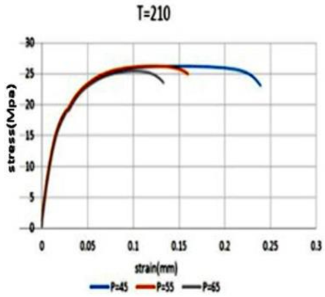


Figure 17. stress- strain diagram for PP at 210ºC in different pressures

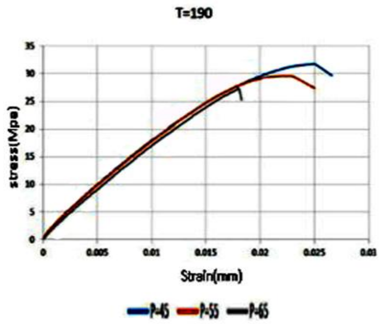


Figure 18. Stress- strain of ABS polymer in the temperature of 190 centigrade and in pressures of 45 and 55 and 65 MPa

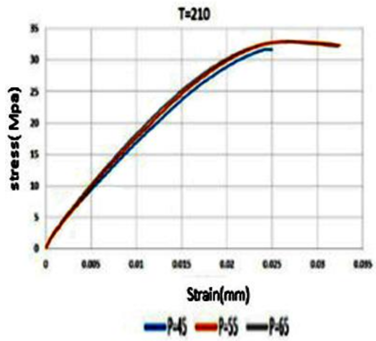


Figure 19. stress- strain diagram of ABS polymer in the temperature of 210 centigrade and pressures of 45 and 55 and 65 MPa

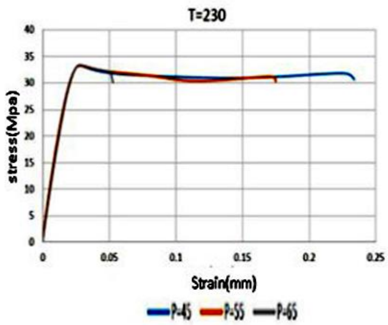


Figure 20. stress-strain diagram of ABS polymer in the temperature of 230 centigrade and in pressures of 45 and 55 and 65 MPa

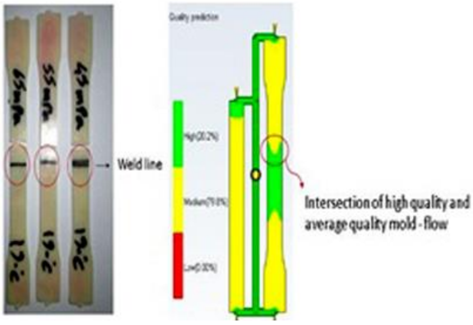


Figure 21. numerical and experimental sample of ABS polymer an the position of fracture in samples

4. CONCULSION

In the present study, mold filling process is simulated by couple of popular softwares (FLUENT and MOLD FLOW). Results of the simulation were employed for justification of the phenomena which were faced to during the experimental works. Different samples of ABS and PP were produced by exerting different injection pressures and temperatures to study the effects of the injection operating conditions on the quality of the produced samples. For each of experimental cases, an analysis of equal condition was accomplished in FLUENT as well as MOLDFLOW software. Results show that increasing the injection pressure reduces the clarity of the welding line which in turn leads to increment of the sample strength. Location of rupture for the sample of different conditions is comprehensively discussed. It has been demonstrated that vortex formation as well as weld line thickness significantly affect strength of the produced sample. It is worth noting that both considered polymers are sensitive to pressure at high temperatures. For instance, pressure increase from 45 MPa to 65 MPa at 210°C results in 35% and 45% reduction in plastic region, respectively. Temperature increase from 170°C to 210°C reduces the modulus of elasticity by about 16%. For the ABS polymer, the plastic region increases 13% at the injection pressure of 55 MPa and 65% at the injection pressure of 65 MPa. Temperature increase from 190°C to 230°C reduces the elasticity modulus by 8%.

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Weld Line

چکیده

تزریق پلاستیکی روشی است که در آن به وسیله یک اکسترودر گرانول پلاستیک را در یک حفره با فشار تزریق می‌کنند در این فرآیند بر اثر به هم رسیدن جبهه موج سیال، خط جوش ایجاد می‌شود در راستای خط جوش استحکام قطعه کم، و از این رو موقعیت خط جوش و همچنین وضوح آن حائز اهمیت است. در این پروژه به بررسی پارامترهای موثر بر پر شدن قالب‌های تزریق از جمله دمای تزریق، فشار تزریق و تأثیر آن‌ها بر استحکام قطعه پرداخته شده است. شبیه سازی و تحلیل جریان یک نمونه قالب تزریق با استفاده از نرم افزار فلوئنت و مولد فلو انجام شده و نتایج تحلیل با نتایج آزمایشگاهی مقایسه و سازگاری مناسبی بین نتایج مشاهده شده است. در کار آزمایشگاهی نمونههای تست کشش و ضربه برای دو پلی-مر ABS-PP- در سه دما و فشار مختلف قالب‌گیری شده است. نتایج نشان می‌دهد که اعمال دماها و فشارهای مختلف تزریق بر استحکام نمونه تولید شده تاثیر دارد. نکته حائز اهمیت در هر دو پلی‌مر یاد شده تبعیت تغییر شکل پلاستیک در دماهای بالا نسبت به فشار است به طوری که با افزایش فشار در پلی‌مر PP در دمای 210 سانتی‌گراد از 45 MPa به 55 و 65، ناحیه پلاستیک به ترتیب 35٪ و 45٪ کاهش پیدا کرده است . همچنین، افزایش دما از 170 به 210 درجه سانتی-گراد باعث کاهش 16٪ مدول الاستیسیته شده است. در پلی‌مر ABS نیز 13٪ افزایش ناحیه پلاستیک نسبت به فشار 55MPa و 65٪ نسبت به فشار 65 MPaدیده شده است. همچنین، افزایش دما از 190 به 230 درجه سانتی‌گراد باعث کاهش 8٪ مدول الاستیسیته گردیده است.

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