The Influence of Pressure and Temperature on the Injection Moulding of Thermoplastic Materials used for High Performance Sport Products

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In this paper it was established the influence of the processing temperature of the injection moulding on the in-mould pressures and on the characteristics of the obtained items used for high performance sport products. The processed polymers were: polypropylene (PP), polyamide 6,6(PA66), polycarbonate (PC), polyurethane (PU), polyoxymethylene (POM, polyacetal). The injection machine employed was ENGEL G/11/10/116/3 produced in 2002. For the correct temperature measurement in the injection cylinder nozzle a DYNISCO Ti422J thermocouple was used and for the determination of the cavity temperature, a thermocouple 2024T model, produced by Digitron Instrumentation Ltd. was used. The mould cavity pressure was measured with a transducer model IDA, produced by Dynisco Europe GmbH.

Keywords: injection moulding, pressure, temperature

The injection moulding processing consists in a forced flow of the polymer melt in a cold, close cavity of a desired shape permitting the solidification of material under pressure. The process is influenced by several parameters. The main factors which determine the moulding process of thermoplastic materials are: the chemical, physical and flowing properties of material related to specific injection conditions, the temperature range, the pressure range and the time necessary for moulding the product [1].

The correlation of all these parameters is often complicated, but it leads to the obtaining of moulded parts in good conditions (in respect of quality and output) [2].

The melting of thermoplastic material is realized by the thermal energy transmitted from the heated wall of plasticizing cylinder to material and by the thermal energy resulted as a frictional transformation of mechanical energy [1]. The pressure exerted by screw conveys the flowing plastic material from the cylinder chamber - through nozzle and mould runners – inside the mould to fill the cavity. The in-mould pressure reaches the maximum values at the end of screw stroke and depends on the force exerted by piston-screw, polymer viscosity and hydraulic resistance of flow path. In injection process, the following types of pressure are defined: external pressure, inner pressure, holding pressure, sealing pressure and remnant inner pressure [3,4].

Approaching the stage of filling the mould cavity with pressed plastic material, it can be considered that the mould filling is isothermally done and that the compression stage begins after the filling is completed. The filling can be analyzed either as a constant pressure–variable stream or as a variable pressure–constant stream process. Analyzing the constant pressure-filling of cavity, it is possible to determine the melt front position and the volumetric stream in a time dependency [5].

In more and more processes, the injection moulded products have to satisfy certain requirements related to their properties and dimensional stability. The conformity with such requirements is checked through analysis of properties with consideration of the source-material and the processing conditions. Also there are considered the measurement techniques which can determine the orientation of macromolecules, the residual stress, possible density alteration and other characteristic as well [6,7].

The residual stress in injection moulded products are induced by two main sources: the first is the stress induced by cooling of material flowing in mould and the second, the stress strains induced by the processing parameters, temperature and pressure. The first is caused by the viscoelastic flow of polymers during the mould filling and the others are due to different shrinkage. In absolute terms, the stress induced by temperature is higher than the stress induced by flow. However the macromolecular orientation generated by the cooling of flowing melt determines the anisotropy of mechanical, thermal and optical properties and influences the long-termed dimensional stability of the moulded products [6]. For high performance sport products, it is advisable to have low residual stress since these products are subjected to high strains and an eventual deterioration of one of the product components can put in danger the life of the sportsman.

The relations obtained through measurements on polymers which endure a flow-state processing can be used for process modelling and for obtaining new information about the shear and flow. In case of flowing materials, such real-time measurements facilitate the control of polymer state and process, as well [8].

The present study aims to analyze the variation of pressure and time needed for filling the mould cavity, both depending on the temperature of injected material, for some of technical polymers used at production of high performance sport products. The polymers used were: polypropylene (PP), polyamide 6, 6 (PA66), polycarbonate (PC), polyurethane (PU), polyoxymethylene (POM, polyacetal).

Experimental part

The polymers used for determinations are: polypropylene (grade INNOVENE 100- GB06), polyamide 6,6 (grade TECHNYL A 221), polycarbonate (grade XANTAR 18 UR), thermoplastic polyurethane elastomer (grade DESMOPAN KA 8377) and polyacetal (grade TENAC 2013 A).

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Table 1
PHYSICO-MECHANICAL CHARACTERISTICS OF ANALYZED POLYMERS

Polymer	Characteristic/Feature	Determination method	Value
PP	Melt Mass Flow Rate Melting temperature	ISO 133 (230°C /2,16 kg) ASTM D 3417	6 g/10 min 163°C
PA66	Density Melting temperature	ISO 1183 ISO 11357-1,-3	114 kg/m^3 260°C (10°C/min)
PC	Melt Volume Rate (MVR) Density	ISO 1133 ISO 1183	23,0 cm^3/10 min (300°C / 1,2 kg) 1200 kg/m^3
PU	Density Injection temperature of melt	ISO 1183 ISO 294	1180 kg/m^3 231°C
POM	Density Melt Mass Flow Rate	ASTM D 792 ASTM D 1238 (190°C/2,16 kg)	1,42 g/cm^3 (23°C) 1,70 g/10 min

Table 2
THE VARIATION OF INJECTION PARAMETERS AS A FUNCTION OF INJECTION TEMPERATURE (POLYMER PP)

Real injection temperature (°C)	220	240	260	280	300
Mould peak pressure (bars)	610	610	590	560	530
Mould cavity filling time (s)	2.1	2.1	2.1	2.1	2.1

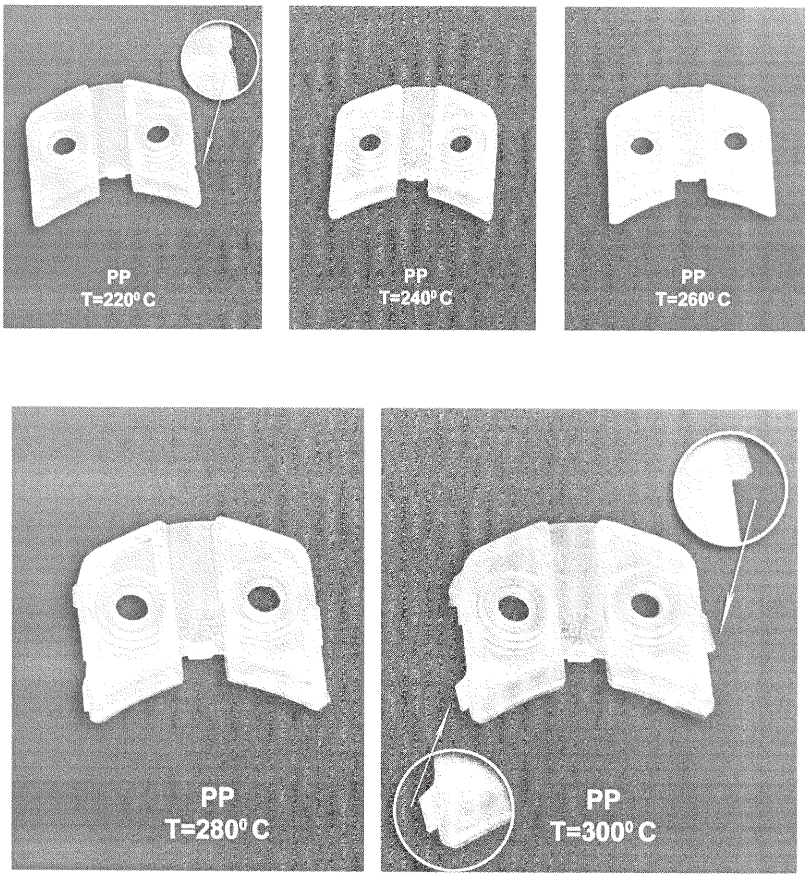

Fig.1.The influence of temperature on the quality of PP moulded parts

All these materials are used for manufacturing of high performance of sport products.

In table 1 there are presented some physical-mechanical and processing characteristics taken over from data provided by the manufacturing companies.

It was employed an injection moulding machine ENGEL, type G/11/10/116/3, year of fabrication 2002. For the correct temperature measurement in the plasticizing cylinder nozzle it was used a thermocouple (i.e., DYNISCO, type Ti422J) fit in a special port of the nozzle in order to get the real temperature within the middle of the melt flow and for the cavity determination it was used a thermocouple temperature probe (i.e., Digitron Instrumentation Ltd., model 2024T).

The mould inner pressure (cavity pressure) was determined with a transducer (i.e., supplier Dynisco Europe GmbH, model IDA). Depending on the type of material processed, different feeding time values have resulted for each material. These differences originated in the materials features: the rate of thermal transfer, shape and dimension of granules and -the last, but not the least - the melt viscosity is different for each material. There were used various temperatures for mould cavity. These values were required by the type of material processed, on one hand and by the dimensions and complexity of moulded part, on another.

For the performance of injection experiments there were generally set the temperature intervals recommended by the material producers.

Results and discussions

For injection of polypropylene the following conditions were set: injection pressure at 1600 bars, feeding time at 11.5s, mould temperature (fixed plate and moving plate) at 40°C, real temperature of the mould cavity at 35°C. The results obtained are presented in table 2.

From table 2 results that at rising the material temperature the in-mould pressure decreases, but the cavity filling time remains constant.

In respect of moulded parts quality (fig.1) it was noticed that at 220°C temperature the part is incomplete, but excess material burrs arise beginning with 280°C due to the low melt viscosity, and thermal degradation occurs at 300°C. In conclusion, the best results were obtained by injection at 240°C, and 260°C, respectively.

For injection of polyamide, the following conditions were set: injection pressure at 1200 bars, feeding time at 9 s, mould temperature (fixed plate and moving plate) at 80°C, the real temperature of mould cavity at 65°C. The experiments were realized between a range of 270 – 345°C. It was determined that the filling time of mould cavity is not temperature dependent (i.e., is not changing with temperature), as it remains constant at the value of 2.3 s. However, the in-mould pressure peak is changing significantly. In figure 2 it is presented the pressure peak variation in mould for injection of PA at different temperatures.

Figure 2 illustrates an important decrease of in-mould pressure from 800 bars to 200 bars correspondent to a rise in temperature from 270°C to 345°C. This implies that it is not technically justified to use an external pressure of 1200 bars, which leads to saving of energy and reducing the wear of machine's hydraulic system. Also, the analysis of moulded parts indicates that degradation marks are already present on the part processed at 315°C, implying that processing temperatures must not be higher than 300°C.

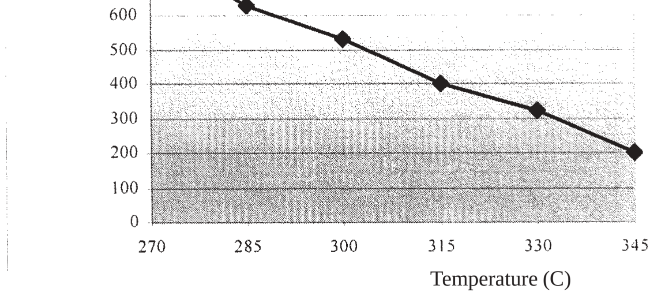

Fig.2.The pressure peak variation on PA injection at different temperatures

The polycarbonate was injection moulded in the following conditions: injection pressure at 1600 bars, feeding time at 11 s, mould temperature (fixed plate and moving plate) at 80°C, the real temperature of mould cavity at 65°C. The experiments were realized between 280 – 340°C and it was determined that the temperature of the flowing material has no influence on the time for filling the mould cavity - as it remains constant at 1.9 s, but there are modifications of the in-mould pressure. The variation of the in-mould pressure depending on the injection temperature is presented in figure 3.

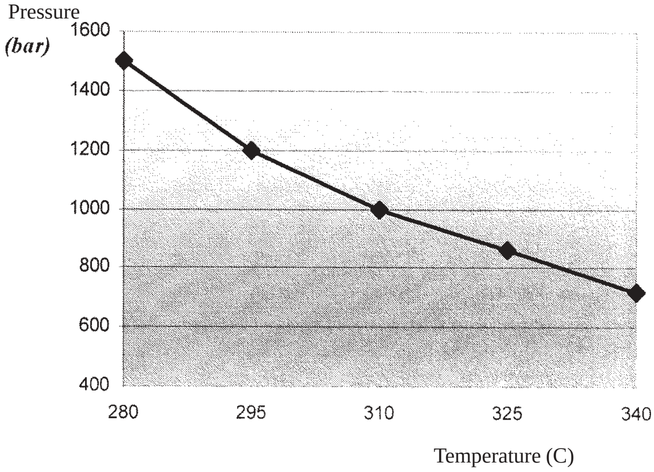

Fig.3.The pressure peak variation on PC injection at different temperatures

The same observation is valid for this material too: there is a major decrease of in-mould pressure as the temperature of injected material rises, implying that it is not justified to use an external pressure of 1600 bars. Analysing the moulded parts, there are determined the temperature limits: the temperature of 280°C is too low for part formation, but degradation of material occurs at higher temperatures than 325°C. Consequently, there is advisable to set the temperature below 325°C.

The experiments with thermoplastic polyurethane were realized in the following conditions: injection pressure at 1600 bars, feeding time at 12 s, mould temperature (fixed plate and moving plate) at 80°C, the real temperature of mould cavity at 67°C. The thermal interval considered for parts injection was 200 - 240°C. It was determined that the filling time of mould cavity is not temperature dependant, as time remains constant at 2.06 s. The temperature of flowing material influences significantly both the in-mould pressure and the part moulding. At injection temperatures of 200°C, respectively 210°C the part is incomplete, but at 240°C degradation of material occurs (fig. 4).

Since the in-mould pressure is deeply decreasing as the temperature rises (fig. 5), implying that the external pressure of 1600 bars is not necessary, the injection temperature of material can not be set at 240°C, but it can be reduced according to the results obtained for 220°C and 230°C, respectively.

At injection processing of polyacetal, the following conditions were set: injection pressure at 1900 bars, feeding time at 8 s, mould temperature (fixed plate and moving plate) at 80°C, the real temperature of mould cavity at 65°C. In table 3 it is presented the variation of the mould cavity filling time as a function of the real injection temperature.

From table 3 results that the mould filling time decreases as the temperature of material raises.

The in-mould pressure is influenced by the processing temperature. The variation of in-mould pressure as a

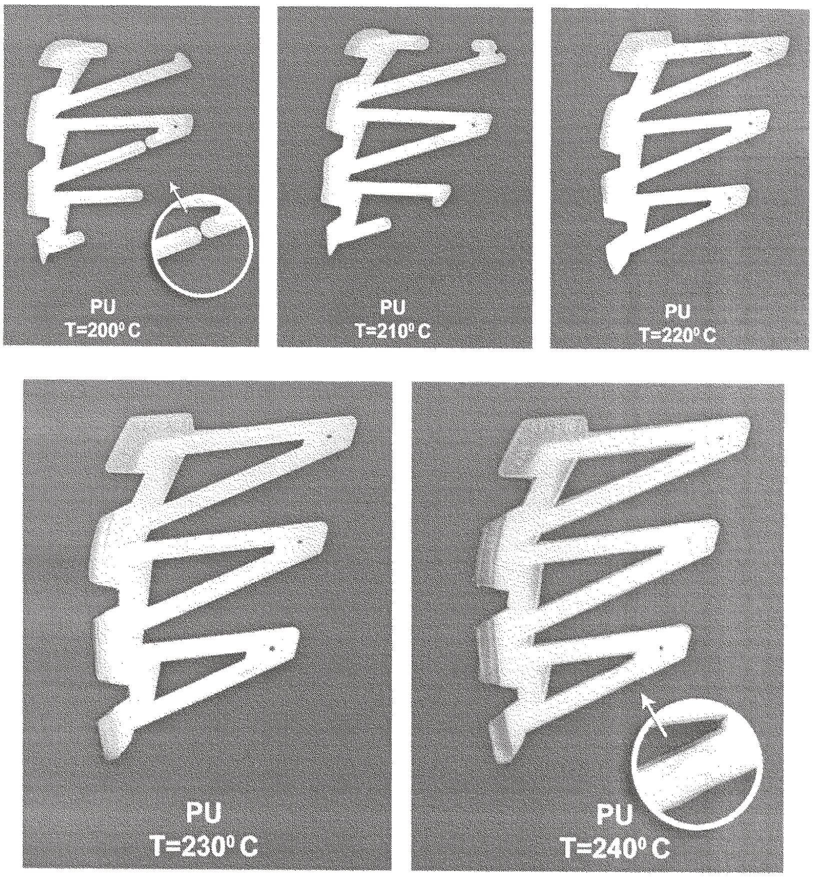

Fig.4.The appearance of PU parts injection moulded at different temperatures

Table 3

THE VARIATION OF MOULD CAVITY FILLING TIME FUNCTION OF THE INJECTION TEMPERATURE (POLYMER = POM)

Real injection temperature (°C)	180	190	200	210	220	230	240
Mould cavity filling time (s)	2.9	2.6	2.4	2.2	2.05	2.03	2.03

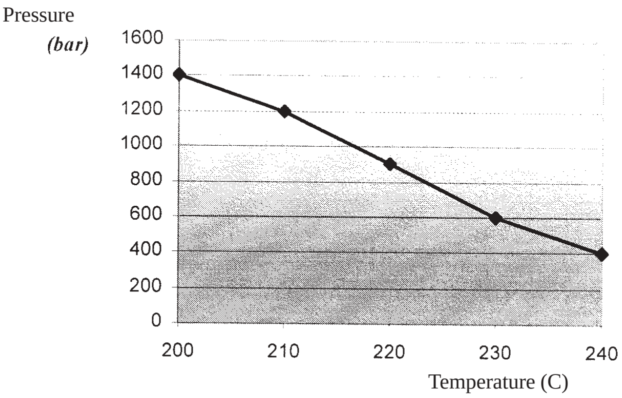

Fig.5.The pressure peak variation on PU injection at different temperatures

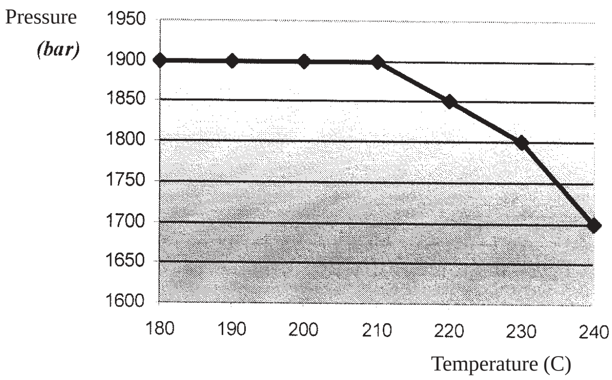

Fig.6.The pressure peak variation on POM injection at different temperatures

function of the real in-mould temperature is presented in figura 6.

From figure 6 results that the in-mould pressure decreases as the temperature increases, implying that there is not necessary to have an external pressure of 1900 bars ; this have to be correlated with the remark that no degradation of material occurs at 240°C..

From the presented data related to the tested polymers, it is noticed that the real in-mould pressure is lower than the external pressure, excepting the processing of POM at temperatures below 210°C where the cavity pressure is equal with the external pressure. This fact can be explained by the considerable decrease in viscosity of flowing-state polymer which automatically implies important pressure losses in the cylinder–screw assembly. The results obtained are compliant with the specialty literature data [9-11], which indicate important changes of melt flow rate for these polymers within the analyzed temperature ranges. In injection moulding, the polymers viscosity is one of the most important characteristics of the flowing process and this depends mainly on temperature, shear and molar mass. For the parts moulded with the chosen polymers, the results obtained are concordant with the presented information. The production of parts having qualitative characteristics and time-stable dimensions is conditioned by the processing and formation of polymers within the domain of viscoelastic deformations. All the polymers used - excepting POM – in flow-state have low viscosity and their viscosity decreases as the temperature rises, which implies increasing of pressure losses. Due to the polymer's chemical structure, the viscosity of melted POM is high, reason why the pressure losses are much lower in cylinder–screw assembly. Moreover the phenomenon of increasing the free volume of molecules was developed during the injection process, dependent on the processing temperature. This increase in free volume - according to the Williams-Landel-Ferry equation [10] - modifies the melt viscosity and additional an important decrease of the volume appears during the in mould cooling of melt due to high coefficients of contraction [3]. For this reason, in order to compensate these effects, high processing pressures were employed.

Conclusions

There were established correlations between the injection temperature, external pressure and the real cavity pressure for the following polymers: polypropylene (grade INNOVENE 100- GB06), polyamide 6,6 (grade TECHNYL A 221), polycarbonate (grade XANTAR 18 UR), thermoplastic polyurethane elastomer (grade DESMOPAN KA 8377) and polyacetal (grade TENAC 2013 A). It was employed an injection moulding machine ENGEL, type G/11/10/116/3, year of fabrication 2002. For the correct measurement of temperature in the nozzle of plasticizing cylinder it was used a thermocouple (i.e., DYNISCO, type Ti422J) and for the cavity temperature it was used a thermocouple (i.e., Digitron Instrumentation Ltd., model 2024T) . For fitting the DYNISCO thermocouple in nozzle, it was realized a port in order to get the real temperature of the flow-state polymer within the middle of the melt flow. The in-mould pressure (cavity pressure) was determined with an IDA model transducer, made by Dynisco Europe GmbH. For all the analyzed polymers, it was determined a significant decrease of material pressure inside the mould cavity as the real injection temperature increases, in condition of maintaining the external pressure at the same value. This would permit a decrease of the external pressure too, meaning energy saving and reducing of machine wear. However, over certain values of the real temperature, thermal degradation occurs affecting the characteristics of these materials used for producing of high performance sport products. For this reason, there must be established an optimum of pressure and temperature, specific for each sort of material. A study of a specific pair polymer – product allows the establishing of optimum conditions both for product properties and economical considerations

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