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IMPACT OF VISCOSITY ON FILLING THE INJECTION MOULD CAVITY

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Abstract

The aim of this paper is to look closer at the rheological properties of plastics and their impact on technology in the plastics processing industry. The paper focuses on the influence of viscosity of the material on filling the mould cavity. Four materials were tested with the settings of process parameters with different viscosity. Using simulation software of Moldex3D, we can see the effect of change in viscosity in the material to be filled.

Key words

injection mould, CAE analysis, viscosity, CAD model

INTRODUCTION

Rheology is the science that deals with the deformation of the material to which force is applied. The term is most commonly used in the study of liquids and liquid-like materials, i.e. all materials that flow. Rheology, however, also includes the study of deformation of solids that occur for example when processing metal or moulding rubber. Two key words in the above definition are rheology deformation and strength. To learn something about the rheological properties of the material, you have to either measure the deformation resulting from the forces, or to measure the force required to achieve the observed deformation. For a linear elastic material or a Newtonian fluid, it is sufficient to have a general equation that describes how the materials react to any type of deformation. Such an equation is called a constitutive or rheological equation of state. However, for more complex materials such as molten plastic, creation of constitutive equations is much more complex task that may require the results of many types of experiments. Another aspect is the development of rheology of polymers, which shows how the rheological properties behave in the affected structure (material composition, temperature and pressure). In the case of more complex materials, a relationship can be established, which shows how the specific rheological properties such as viscosity of the treatment module affect the molecular structure, composition, temperature and pressure. The molten plastics in a fluid state are rheologically complex materials that can exhibit properties such as viscous flow and elastic recoil. General constitutive equation has been developed primarily for these materials, and the current state of knowledge of their rheological behaviour is largely based on empirical research. This fact, on the one hand, complicates the description and measurement of the rheological properties, but on the other hand, makes the plastic rheology a relatively new and interesting science (1).

RHEOLOGICAL PROPERTIES

The rheological characteristics of the material features significantly influence the shape and flow of the material. They also called flow properties. The mathematical representation is the following flow curve, which expresses the ratio of shear stress and shear rate. The flow of polymer materials during their processing is pseudoplastic and largely differs from the flow of low molecular weight liquids (2). One of the main differences between the low molecular weight fluids, which are also called Newtonian, and, high molecular compounds, which are referred to as non-Newtonian, is viscosity. The physical Oxford dictionary is defined as the viscosity value expressing the size of the internal friction in the liquid, measured as the amount of force exerted per unit area of the resistance extending flow (3). More generally, the viscosity is a material property that describes its resistance to creep. Liquid resists the movement of the layers of particles with different speeds. It is also the most common rheological measurement and the identification value, but it is a qualitatively different feature for the Newtonian and non-Newtonian fluids. Mathematically, viscosity can be defined as the ratio of shear stress and shear rate (4).

From the rheology point of view, fluids can be thus classified according to the viscosity as:

- Newtonian – liquids of low molecular weight -. To describe their rheological behaviour during shear, Newton's law is applied. The viscosity of Newtonian materials is independent of time, and speed shear deformation depends only on the temperature, pressure and molecular properties of the test substance (5).
- Non-Newtonian - high-molecular liquids, the flow of which is independent of time. Their viscosity is not constant, but depends on the strain rate. Description of their behaviour is possible using various mathematical models. The flow properties of non-Newtonian fluids are described by rheogram.
- The behaviour during the flow of non-Newtonian substances can be subdivided into:
  - Viscoplastic,
  - Dilatant.

The Newtonian fluid behaviour can be caused by several factors related to the structural reorganization of the molecules of the material as a result of the material flow. The polymeric substances and compounds are the cause of reducing the viscosity of highly anisotropic arrangement of chains (7).

FACTORS INFLUENCING THE RHEOLOGICAL PROPERTIES

- Shear stress - represents the ratio of the shear force acting on a unit area,
- Shear rate - change of shear strain versus time,
- Temperature - significantly affects viscosity,
- Pressure - affects the free volume between the particles,
- Molecular weight and structure - the arrangement of the macromolecules of the melt depends on the behaviour of the plastics,
- Additives - chemical composition of the material affects its behaviour during processing (4).

IMPORTANCE OF RHEOLOGICAL PROPERTIES IN THE SIMULATION OF INJECTION

The first injection of plastics into the mould always precedes the simulation, which should identify possible problems and shortcomings caused by the parameters selected, as well as the choice of material. The simulation parameters are important, as well as injection of the selected material, and thus on the most accurate simulation of the outputs it is necessary to select the values, including the rheological properties so as to achieve the best quality and the final shape of the product.

For the purposes of determining the rheological impact of its properties to the resulting shape of the second burst, we will compare the simulation results for four different polymeric materials used for the injection under the same conditions in the mould cavity of the same shape.

DRAFT MODEL COMPONENTS

As a model for simulation of the injection component, we proposed a flat rectangular shape, wherein the holes are rectangular. These are important to evaluate and compare the degree of filling the moulds. We constructed the model components in SolidWorks CSG method. First, we sketched a rectangle 150x46 mm in draw mode. We then pull it out to a ofmade parts can be seen in Figure 1. The finished component- was exported into the STEP format.

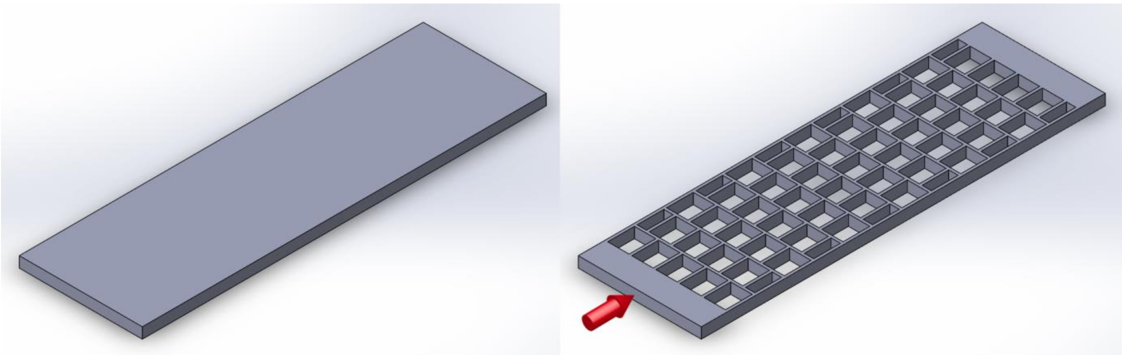

Fig. 1 *A designed 3D model part in SolidWorks*

SELECTION AND MATERIAL PARAMETERS

Table 1 Basic characteristics of selected

Material	Density [g.c^{-3}]	Modulus of elasticity [MPa]	Yield strength [MPa]	Melt temperature [°C]	Pour point [°C]
PA66 Ultramid 1003-2	1.14	3000	85	280-305	252
PC ST5201V	1.20	2400	66	280-320	163
PC XQ83619	1.32	2800	65	280-300	160
POM Ultraform E3320	1.40	2700	64	180-220	170

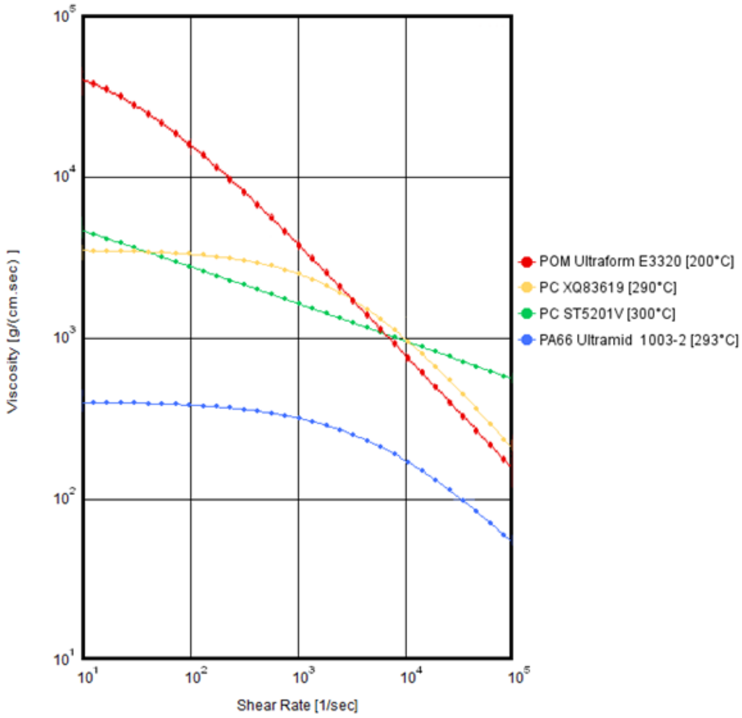

Fig. 2 *Graphical representation of the medium viscosity materials*

MACHINE SELECTION AND INJECTION PARAMETERS

The machine suitable for the production of parts- was designed based on the parameters chosen from Injection machine Engel ES 200/65. In the SolidWorks program, we found that the volume part was 8.8 cm-3, the dimensions were 150x46 mm and the height 4 mm. Comparison of these values with the values in Table 2 shows, that in the case of one-dimensional form, the machine clearly meets the specifications required for the production of the proposed part.

Table 2 Basic parameters of the selected injection moulding machine

Parameter	**Value**	**Unit**
Clamping force	650	Kn
Screw diameter	25	mm
Maximum injection volume	68	cm^3
Diameter of central ring	125	mm
ejectors	100	mm
Size of clamping plate	570x552	mm
Maximum range	430	mm
Height of mould	150	mm

SIMULATION OF INJECTION IN MOLDEX 3D ENVIRONMENT

Simulation of injection moulding to form was implemented in the environment of Moldex 3D R13.0. The Moldex 3D CAE software is designed to execute simulation of injection moulding. It offers a wide range of analyses for different processing of liquid plastics. The simulation takes place on the finite element model that can be constructed directly in the environment of Moldex-in, or we can use the model exported from any CAD software in STEP format.

First, we imported the model that we had created in SolidWorks. We then selected the appropriate solver for 3D solid model and chose the method of injection technology. After that, we chose the material and process parameters of injection. In the middle of the shorter sidewall inlet point we placed a small diameter. Finally, we ran the analysis. We repeated this process four times, which was due to the fact that the model and the parameters of the simulation were the same of each for the materials selected.

EVALUATION OF THE SIMULATION

Conditions of melt are compared at the end of the injection moulding cycle of about 4 seconds. After this period, melt solidifies under a constant pressure of 5.0 MPa, so that the extension of the injection time is not relevant. The actual injection cycle times are slightly different, the order of a hundredth of a second, as we chose the same time for all materials, in order to unify the evaluation results.

First, check the value of simulation, shear rate and shear stress.

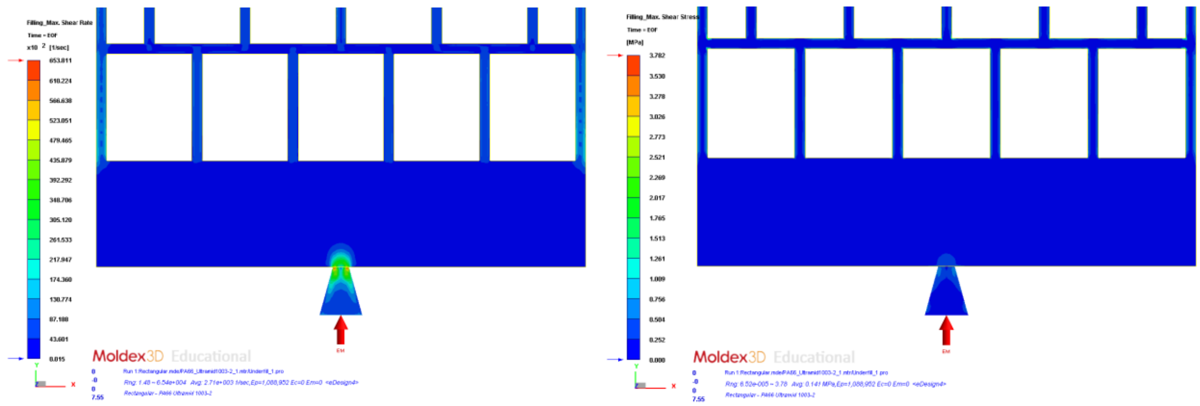

Fig. 3 *Shear rate and shear stress in the component cross section of the Ultramid10032 material*

Ultramid 1003-2 reaches the shear maximal speed 65381.1 s-1, which is on the edge of flow apertures, and sliding pressure in this place is 0.8 MPa. That makes viscidity approximately 12 Pas.

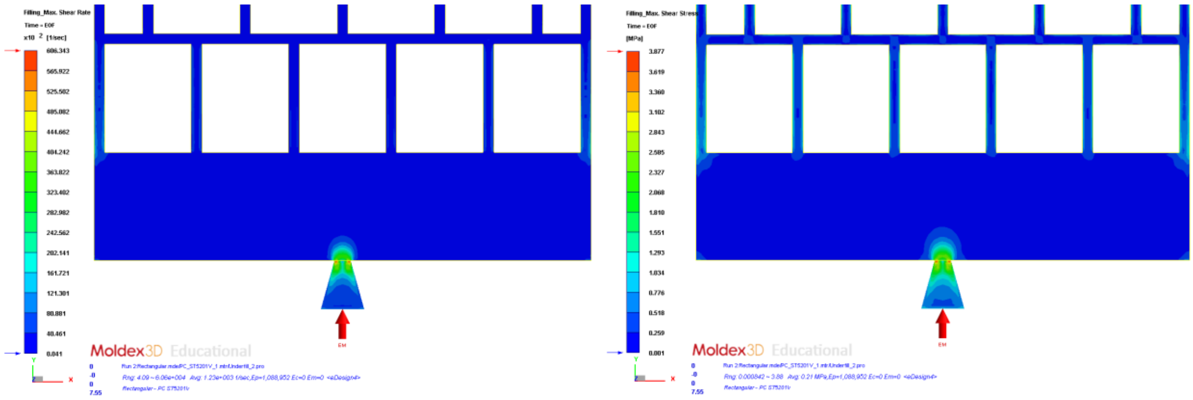

Fig. 4 *Shear rate and shear stress in the component cross section of the PC ST5201V material*

PC ST5201V reaches shear maximal speed 60634.3 s-1, which is on the edge of flow apertures, and sliding pressure in this place is 3.87 MPa. That makes viscidity approximately 64 Pas.

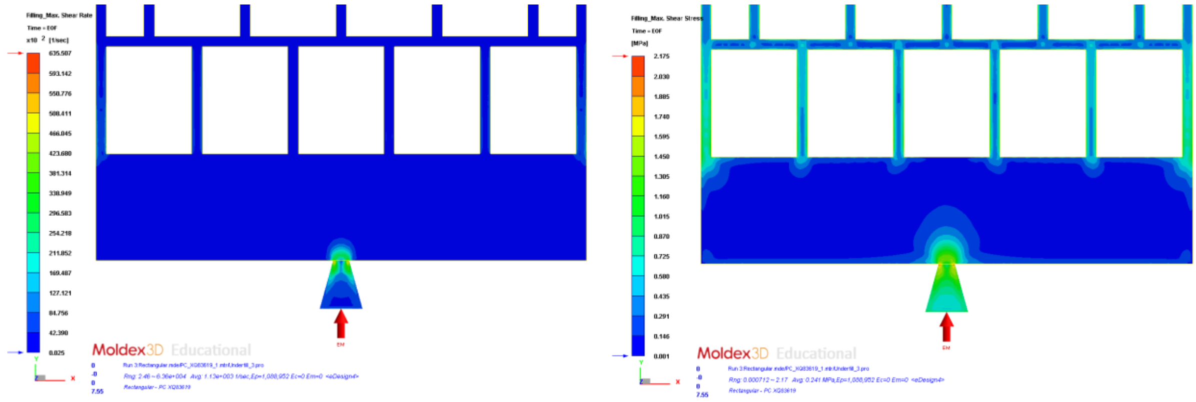

Fig. 5 *Shear rate and shear stress in the component cross section of the PC XQ83619 material*

PC XQ83619 reaches the shear maximal speed of 63550.7 s-1 which is on the edge of flow apertures, and sliding pressure in this place is 2.175 MPa. That makes viscidity approximately 34 Pas.

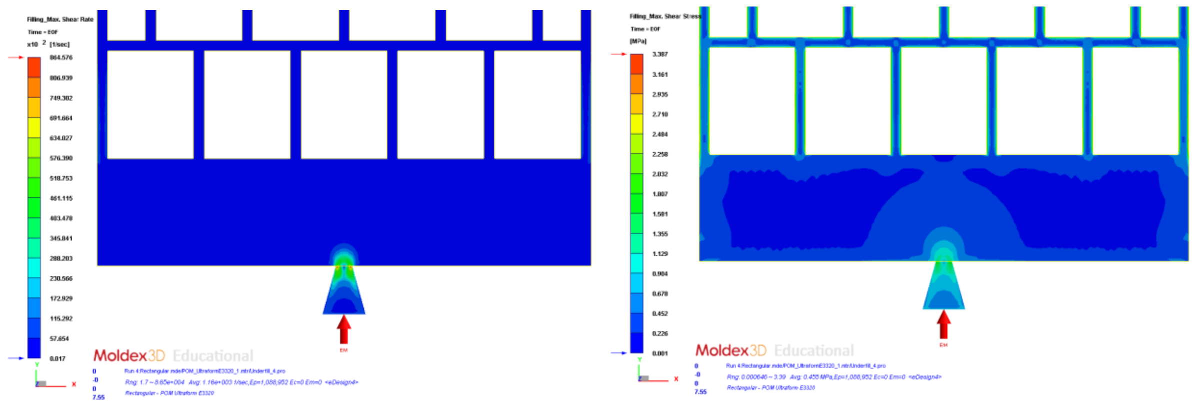

Fig. 6 *Shear rate and shear stress in the component cross section of the POM UltramidE3320 material*

POM UltramidE3320 reaches the shear maximal speed of 86457.6 s-1, which is on the edge of flow apertures, and sliding pressure in this place is 3.387 Pa. That makes viscidity approximately 39 Pas.

The biggest viscosity has material PC_ST5201V and in the selected area approximately 64 Pas. Therefore it has the highest assumption to fill the component the least, and right after is followed by material POM UltramidE3320, which has in given point viscosity 39 Pas. The PC_XQ83619 material with viscidity 34 Pas could be filled better. Out of mentioned materials in the given area, the lowest viscosity was that of plastic Ultramid 1003-2 approximately 12 Pas. Simulation of fillings revealed how the components were really filled.

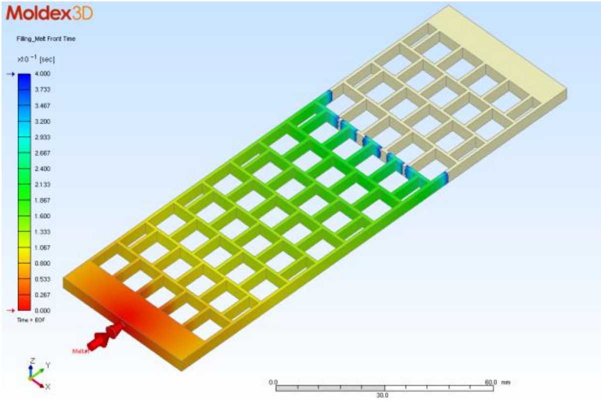

Fig. 7 *Status PA66 Ultramid 1003-2 in the mould cavity at the end of the injection cycle*

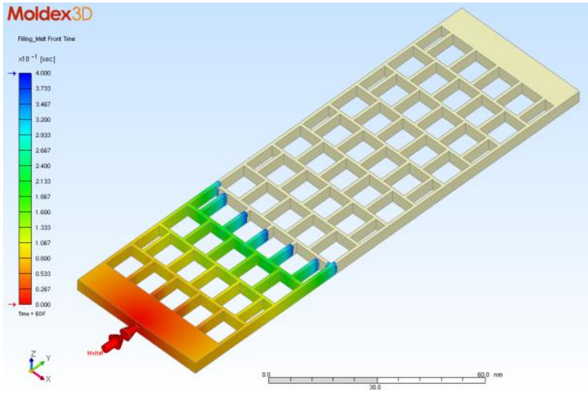

Fig. 8 *Status of the PC ST5201V melt in the mould cavity at the end of the injection cycle*

Figure 7 shows that the material filled almost 66% of the mould cavity. The four materials of the selected PA66 Ultramid 1003-2 with lowest viscosity, we can therefore expect that the mould will be filled to substantially greater extent than the other three parts. This supposition was confirmed by simulation. Figure 8 shows the state of filling the mould with ST5201V PC material, which filled approximately 30 % of the total form. Since this material has a considerably higher viscosity than Ultramid PA66 1003-2, we assumed that it fills the form in the lower range.

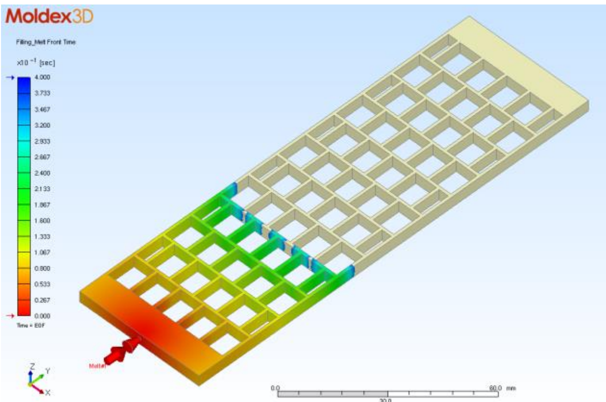

Fig. 9 *Status PC XQ83619 in the mold cavity at the end of the injection cycle*

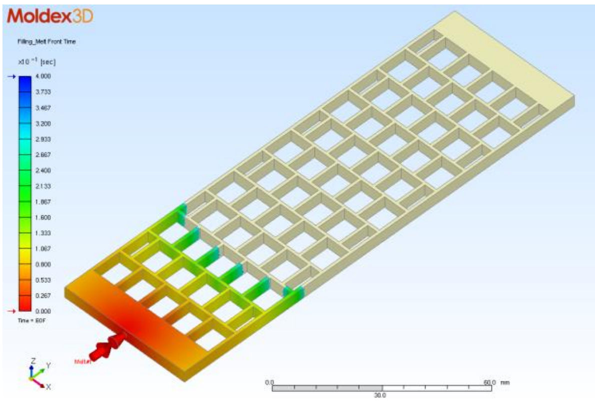

Fig. 10 *Status POM Ultraform E3320 in the mold cavity at the end of the injection cycle*

Figure 9 shows the material of XQ83619 PC that filled the mould at about 33 %; only slightly more than ST5201V PC. We could conclude that, despite the different nature of the two medium viscosity of polycarbonates, there is the minimum difference in the flow and filling. It is a more important factor than the character of viscosity value or viscosity values. The rate of filling the mould POM Ultraform E3320 is shown in Figure 10. We see the result of significantly higher viscosity compared to other materials used to fill the mould at the lowest rate, only about 23 %. Compared to PC material of XQ83619 or ST5201V PC, there is not as rapid decline as compared with those of polycarbonate and polyamide PA66, even though the different values of medium viscosity are comparable.

Simulation of filling has confirmed the assumption that component with material Ultramid 1003-2 is filled the most. Also was confirmed that materials POM UltramidE3320 and PC ST5201V fill the component the least.

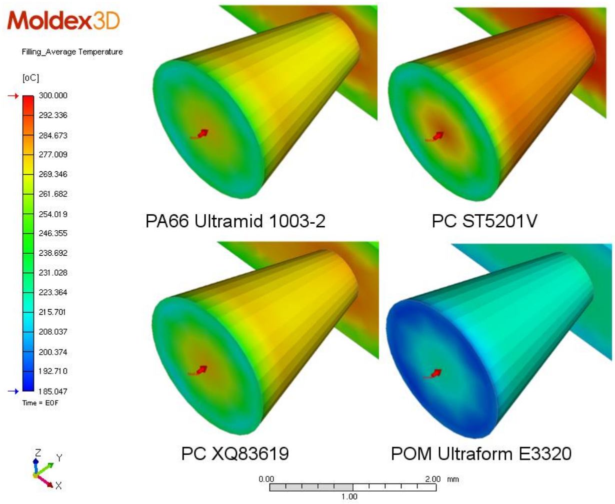

***Fig. 11** Temperatures of the inlets at the end of the injection cycle*

In Figure 11, we can see the average temperature of the inlet 4 for all the materials at the end of the injection cycle. When comparing the values as indicated in Table 1, we can conclude that, in all four cases, the material is below the melting temperature. Holding pressure is therefore not possible, and the state of filling the mould with material is finite. Comparing the preceding figures and their recovery in relation to the viscosity of each material, we can say that the viscosity, as the most important rheological property of the plastic melt during the injection moulding process, has a significant impact on the flow of material as well as the degree of filling the moulds. The complete filling of the mould was not achieved in either case; the solution could be in changing either the shape of parts and injection parameters, or selecting suitable materials with lower viscosity. We estimate that material with about half the size of medium viscosity value, such as Ultramid PA66 material 1003-2, would be able to fill up the form without changing either the form of parts or injection parameters.

CONCLUSION

Based on this simulation, we can study how the rheological properties of four different types of plastics are affected by using the same mould cavity and injection parameters of the final parts. We found that the Ultramid PA66 1003-2 material with the lowest viscosity reached the top speed of melt flow rate. When comparing XQ83619 PC and PC ST5201V, we can conclude that both the ratio of the viscosities and the degree of filling the moulds are not directly proportional; to determine their relationship would require a large number of simulations. The results of the simulations carried out, however, clearly show that the viscosity of the molten material significantly affects the final product injection and is an important parameter that should be considered when selecting the material for injection moulding.

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