ANALYSIS OF PROCESS OF THE MOLD CAVITY FILLING OF THE LIGHTWEIGHT PROFILE FROM MATERIAL PE TIPPELIN 7100S BY THE TECHNOLOGY OF PLASTIC EXTRUSION

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The presented paper deals with the examination of the mold cavity filling process for the production of lightweight plastic profiles from material PE TIPELIN 7100S applying the technology of extrusion into the mold. The principle of the extrusion technology and the carrying out of the experiments are determined in the introductory parts. The following parts focus on the analysis and evaluation of the mold cavity filling process for the production of lightweight profiles from from material PE TIPELIN 7100S with orientation on the influence of the mold temperature on the mold cavity filling time and status.

KEYWORDS

extrusion, filling process, mold temperature, filling time

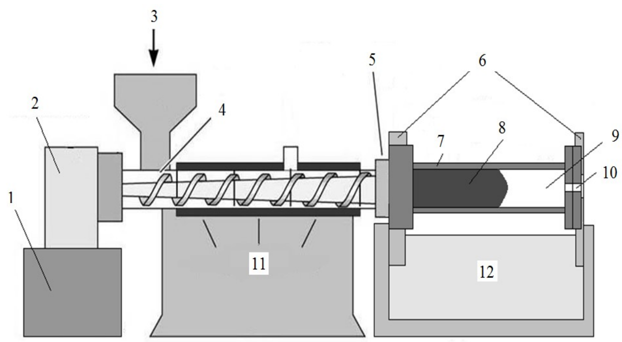
1 INTRODUCTION

The extrusion technology ranks among the machining technologies of plastic matters which are applied in production of diverse types of profiles, plates, foils, etc. Currently, various methods of production of lightweight plastic products are used by means of which considerable material saving can be gained. Lightening of the plastic products is usually achieved by application of the core, formation of the cavity inside the molded piece or by generating of pores inside the molded piece. [Pasko 2015]

The existing knowledge has proved the extrusion technology to rank among the first technologies of production of plastic profiles. The process involves the interacting technological parameters which influence the quality and properties of the final product. [Osswald 2008] The task of planning and of methodology is to bring the particular values of the technological parameters into the actual conditions of the technological process of extrusion. In majority of cases the technological parameters are interactive. The respective technological process can be analysed right by the performance of experiments. The computer simulation of the technological processes allows performing of the experiments off the real object. The advantage of the computer simulation rests in not interfering into the actual production process. Owing to the computer simulation a possibility of gaining a simple access to reliable and comprehensible responses and information exists. The aim of production of the lightweight profile is to decrease the usage of material, to shorten the production time, and to increase the productivity. Up to this point the production equipment A.R.T. has produced the profiles not lightened by the mold technology. [Kulik 2013, Bielousova 2012]

2 SPECIFICATION OF THE EXTRUSION PRODUCTION MACHINE AND PLAN OF THE EXPERIMENT

The attention in the submitted article is paid to the development of the technology node (the mold) of the extrusion machine for production of lightweight profiles made PE TIPELIN 7100S. The changes of the structure of the technology node were performed with the mold of the extrusion production machine for the option of production of lightweight plastic profile. The extrusion production machine A.R.T. serves for production of the plastic profiles by the mold technology. [Dobransky 2007] The respective extrusion machine is as to structure designed in the same way as the single-screw one. The screw drive includes an electric motor and a gear unit. The material is melted in the cylinder of the screw by means of electric resistance spirals. The screw extrudes the molten material into the mold fixed on the rotating carousel. The carousel disposes of the capacity for fixation of 12 molds. The rotation of the carousel is performed by the electric motor through the pinion towards the toothed wheel. The equipment disposes of a technological tank with water as a cooling medium. When the mold is filled with the melt, the carousel with the fixed mold rotate by means of the drive and the mold sinks into the cooling medium in which solidification of the material inside the mold is performed. After cooling the mold is rotated again by the carousel and the material is taken out of the mold. The arrangement of the molds on the carousel is even so that the first mold can be filled with the melt, the other assures cooling of the melt inside the cooling medium, the product is taken out of the third one and the rest of the molds are placed on the carousel and are air-cooled or do not participate in the process. The equipment is designed to assure taking the products out of the mold in direction opposite to the mold filling with the mold position being off the extrusion head during filling. Taking the products out of the mold is performed manually or by air pressure.



1 – motor, 2 – gear unit, 3 – input material, 4 – screw, 5 – extrusion head, 6 – carousel, 7 – mold, 8 – extruded material, 9 – mold cavity, 10 – vent, 11 – heating, 12 – cooling

Figure 1. Scheme of extruder

Polyethylene TIPELIN 7100S is the bimodal high-density polyethylene copolymer with 1 butene or comonomer determined for extrusion of plates and profiles required to possess extensive strength, very good corrosion resistance under tension, and good resistance against creep stress. It is recommended for production of plates and profiles for technical purposes. [Brestovic 2015, Krsak 2014]

Table 1. Properties of polyethylene TIPELIN 7100S

Characteristic stress [MPa]	25
Relative elongation at characteristic stress [%]	13
Tensile strength in rupture [MPa]	32
Modulus of elasticity in bend [MPa]	1350
Unnotched impact resistance Izod (notch impact, 23 °C) [kJ/m^2]	18
Unnotched impact resistance Izod (notch impact, -20 °C) [kJ/m^2]	6
Shore A hardness	63

3 CHARACTERISTIC OF THE MONITORED FACTORS

The most significant factors of the technology of extrusion into the mold influencing the process of the mold cavity filling are the following:

- *speed of filling:* speed of the mold cavity filling depends on the rotation speed and on type of the screw,
- *filling pressure:* depends on type of the screw and on diameter of extrusion head,
- *mold temperature:* the mold temperature influences time of filling, mold cavity pressure as well as the state of mold cavity filling. On the basis of the mentioned factors the monitoring was oriented towards time of filling, mold cavity pressure, and the state of mold cavity filling under observance of the identical technological conditions in case of which only mold temperature was changed. Dependences of the individual factors on mold temperature were specified.

4 STRUCTURE DESIGN OF THE LIGHTWEIGHT PROFILE AND OF THE MOLD

4.1 Structure Design of the Lightweight Profile

The mold design for production of the lightweight profile by the core application was preceded by the structure design of the lightweight plastic profile and of its cavity. The external shape and dimensions of the lightweight plastic profile must be identical with the shape and dimensions of the standard profile (section of □63 mm and length of 545 mm). The thickness of the lightweight profile wall of at least 6 mm was proposed and designed was the shape of the plastic profile cavity with section of □51 mm and length of 516 mm. Fig. 2 shows the scheme of the designed lightweight profile.

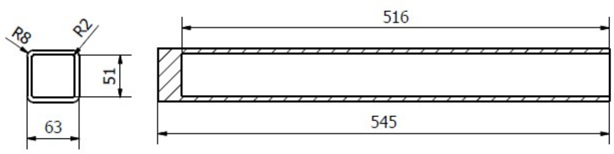


Figure 2. Scheme of the designed lightweight profile

4.2 Design of the Mold for Lightweight Profile Production

The shape of the mold cavity must correspond to the shape of the produced lightweight profile. In proposing the mold cavity dimensions the material shrinkage had to be taken into consideration, too. The value of shrinkage for the applied materials is of 3%. Fig. 3 shows the scheme of the mold cavity shape for production of the lightweight plastic profile.

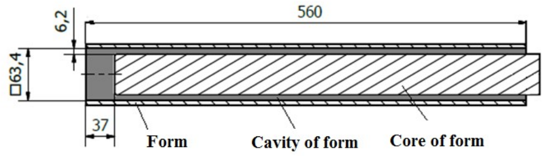


Figure 3. Scheme of the mold cavity shape for production of the lightweight plastic profile

Fig. 4 shows the scheme of the designed mold system for production of the lightweight profiles with the open cavity. A detail of the part in the point of vent location is shown. The vents allow gases to be exhausted out of the mold cavity.

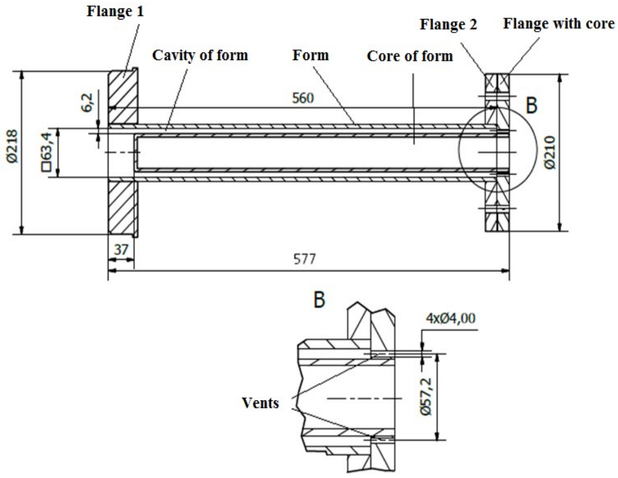


Figure 4. Scheme of the designed mold system for production of the lightweight profile

5 SIMULATION AND ANALYSIS OF THE PROCESS OF THE MOLD CAVITY FILLING OF THE LIGHTWEIGHT PROFILE, MATERIAL PE TIPELIN 7100S

Simulation software Plastic Advisor represents the module of system Pro/Engineer Wildfire allowing performance of computer simulation of the process of the mold cavity filling. Simulation of the mold cavity filling for production of the lightweight profiles with the application of material PE TIPELIN 7100S were realized with the technological parameters presented in Table 2.

Table 2. Input technological parameters for the computer simulation

Mold temperature [°C]	Melt temperature [°C]	Max. pressure of the cavity filling [MPa]
20	190	2
30		
40		
50		
60		
70		

Figures 5, 6, and 7 shows the computer simulation result of the mold cavity filling for the production of the lightweight profile with the application of material PE TIPELIN 7100S at mold temperatures of 20°C, of 30°C and of 40°C. Figures 8, 9 and 10 show the results of the computer simulation of the mold cavity filling for the production of the lightweight profile with the application of material PE TIPELIN 7100S at mold temperature of 50°C.

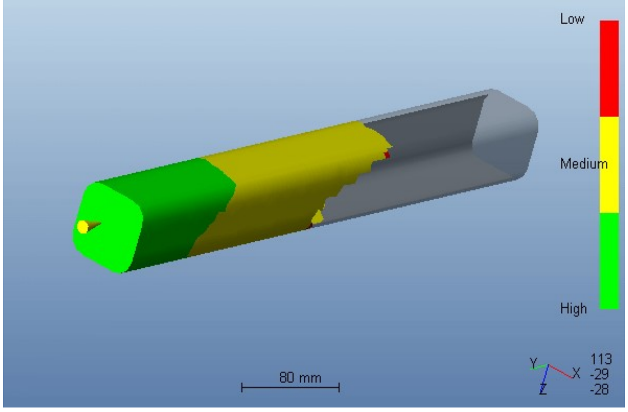


Figure 5. State of the mold cavity filling – T_f = 20°C

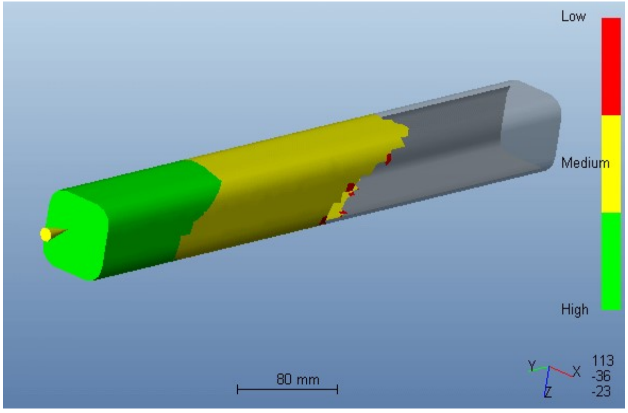


Figure 6. State of the mold cavity filling – T_f = 30°C

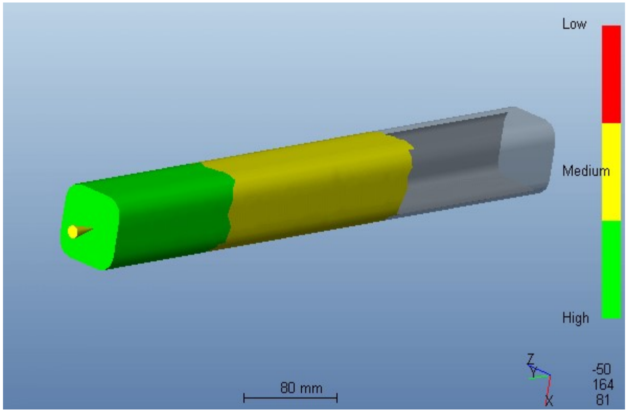


Figure 7. State of the mold cavity filling – T_f = 40°C

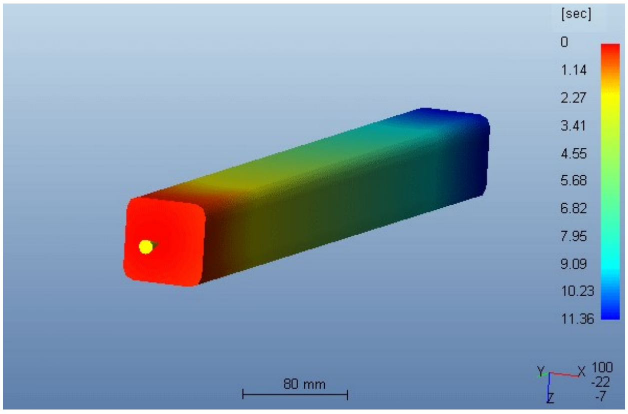


Figure 8. Time of filling – T_f = 50°C, t = 11,36s

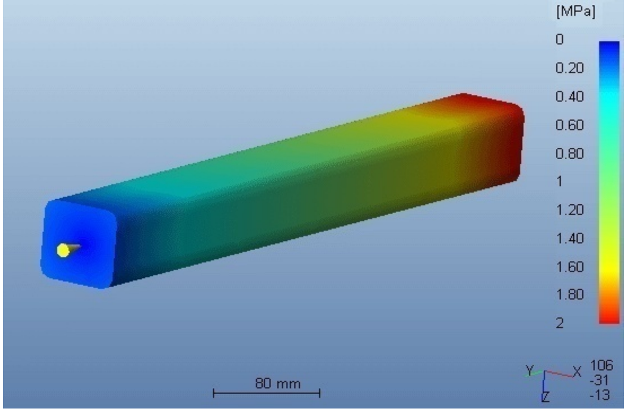


Figure 9. Pressures in the mold cavity – T_f = 50°C, p_{max} = 2 MPa

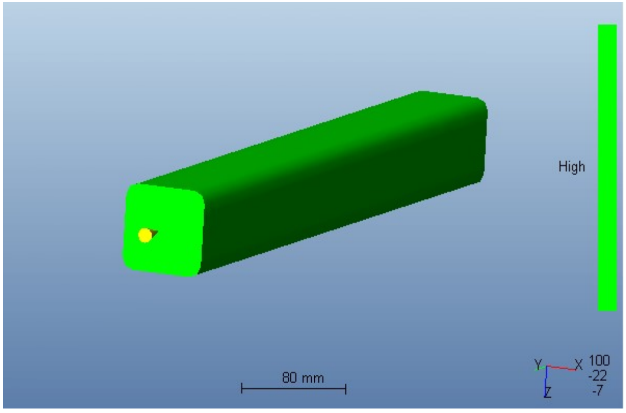


Figure 10. State of the mold cavity filling – T_f = 50°C

Table 3 shows the values of time of filling and of maximal pressure in the mold cavity in dependence on the mold temperature during mold cavity filling for the production of the lightweight profile with the application of material PE TIPELIN 7100S. Table 3 presents also the state of the mold cavity filling in dependence on the mold temperature. According to the given facts it can be assumed that at mold temperature ranging from 20°C up to 40°C the mold cavity is not completely filled with the melt. When mold temperature exceeding 50°C is reached, the simulation result presents the fact that the mold cavity is completely filled.

Table 3. Computer simulation results

Mold temperature [°C]	Time of filling [s]	Max. pressure in the mold cavity [MPa]	State of the mold cavity filling
20	-	-	unfilled
30	-	-	unfilled
40	-	-	unfilled
50	11,36	2	filled
60	10,35	2	filled
70	9,94	2	filled

Fig. 11 shows graphic development of dependence of mold cavity filling time on the mold temperature during the mold cavity filling for the production of the lightweight profile with the application of material PE TIPELIN 7100S. At mold temperature ranging from 20°C up to 40°C the mold cavity is not filled therefore the graphic dependence of these mold temperature values cannot be produced. Fig. 12 shows graphic dependence of maximal pressure in the mold cavity on the mold temperature during the mold cavity filling for production of the lightweight profile with the application of material PE TIPELIN 7100S. At mold temperature ranging from 20°C up to 40°C the mold cavity is not filled therefore the graphic dependence of these mold temperature values cannot be produced.

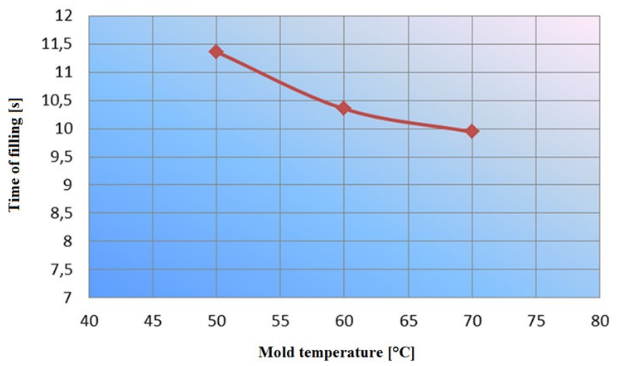


Figure 11. Mold temperature dependence on time of filling according to the computer simulation results

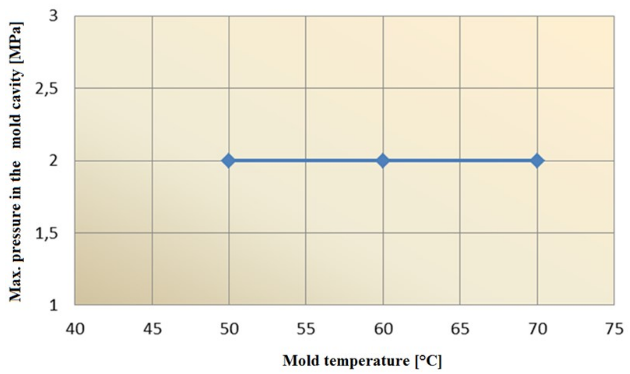


Figure 12. Mold temperature dependence on maximal pressure in the mold cavity according to the computer simulation results

6 REALIZATION OF DESIGN

Fig. 13 shows the interpretation of the real produced mold for the production of lightweight plastic profiles.

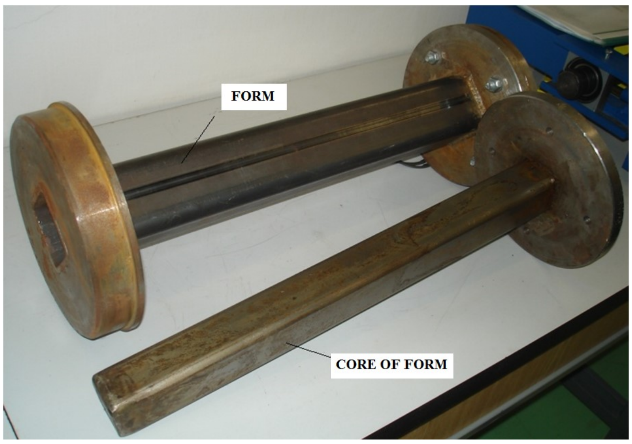


Figure 13. Produced mold for production of the lightweight plastic profiles

7 REALIZATION AND ANALYSIS OF THE MOLD CAVITY FILLING PROCESS WITH THE APPLICATION OF MATERIAL PE TIPELIN 7100S

Filling of the mold cavity for production of lightweight profiles with the application of material PE TIPELIN 7100S at mold temperature ranging from 20°C up to 70°C was realized under actual conditions. Table 4 presents the results of the experimental study of actual process of the mold cavity filling for the production of the lightweight profile with the application of material PE TIPELIN 7100S. Fig. 14 shows dependence of time of filling of the mold cavity for the production of the lightweight profiles with the application of material PE TIPELIN 7100S on the mold temperature.

Table 4. Results of the experiment

Mold temperature [°C]	Time of filling [s]	State of the mold cavity filling
20	-	unfilled
30	-	unfilled
40	-	unfilled
50	20,5	filled
60	19,9	filled
70	19,4	filled

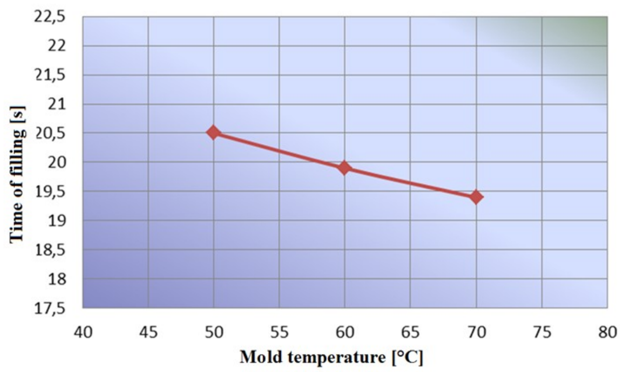


Figure 14. Dependence of the mold temperature on time of filling

The results of the experimental study of the mold cavity filling process for the production of the lightweight profiles with the application of material PE TIPELIN 7100S have proved that at temperatures of 20 °C, 30 °C and 40 °C the mold cavity is not completely filled. The complete mold cavity filling can be observed at temperature of 50°C or at higher temperature. The shortest time of 19.4s of the mold cavity filling can be reached at mold temperature of 70°C. The realization of this experiment under actual conditions proved the result of the computer simulation of the mold cavity filling for the production of the lightweight profiles with the application of material PE TIPELIN 7100S concerning the fact that the mold cavity is completely filled at mold temperature of over 50°C. In production of the lightweight profiles with the application of material PE TIPELIN 7100S the mold must be heated minimally to temperature of over 50°C to assure the complete mold cavity filling.

8 CONCLUSIONS

The computer simulation results have proved that time of filling of the mold cavity for the production of lightweight profiles with the application of material PE TIPELIN 7100S decreases with the increasing temperature. On the basis of the achieved results it can be concluded that in filling of the mold cavities for the production of the standard profiles maximal pressure in the mold cavity slightly decreases with the increasing mold temperature. In filling of the mold cavity for the production of the lightweight plastic profile with the application of material PE TIPELIN 7100S at mold temperatures of 20 °C, 30 °C and 40 °C the mold cavity is not completely filled. Complete filling of the mold cavity can be observed at mold temperature of 50°C and at higher temperatures. In other cases the complete filling of the mold cavity can be observed at 20°C and at higher temperatures. The results of the experimental study performed in actual production process have proved that time of the cavity filling of respective molds shortens in dependence on increasing mold temperature. Verification of the results acquired through the computer simulation and actual process has proved the fact that in actual production process time of the mold cavity filling is longer. It is mainly caused by the character of the mold cavity surface, by the external influence of environment, by the material quality, and by the production machine.

Knowledge of dependence of filling state of the mold cavity on the mold temperature represents in terms of technological practice significant aspect influencing prevention of occurrence of defects.

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