A Study of Plastic Processing and Tool Design for a Polypropylene Product

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Injection moulding process needed for creation of selected polypropylene product is investigated in the paper. Material selection together with mixing ratios and their preparation for production process are shown. Influence of material composition on the quality of the product is discussed. Several parameters that the process uses are analyzed and a solution of a robust process for specified product is given. Tooling for mould cavity is investigated, modelled with Solidworks software and recommendations are given for improvement of the current and future designs. Temperature of the material and the liquefying – solidifying process of the melt is monitored and final shape errors discussed. The material required for each shot and moulding cycle is analysed and improvements implemented into design. A CAD design of mould is given and cycle time analysed. Mold flow simulation with MoldflowXpress that is found in Solidworks 2007 was also used in presented investigation.

Key words: injection moulding, 3D design, polypropylene, mould, plastic

1 Product

Selected polypropylene product is used for covering of sliding mechanism of an office chair. It is made of tree parts that slide one in another with narrow tolerances and a tap that is inserted and locked in place. The product Fig. 1 has a form of telescope and parts slide one on another as the chair is lifted up or down. Specified dimensions are H = 270 mm, A = 90 mm, B = 115 mm. The tap has a hole of Ø = 28 mm, and the three pieces have narrow tolerances that allow them to slide one in another. When they are placed on a chair their bottom and top parts are fixed and they slide with the chair shaft as it is lowered or raised. The tap is produced with the same material but on another tooling and is used in recycling process. The tap has narrow tolerances that facilitate locking with the top part after some pressure is applied.

Fig. 1 *Investigated product is a telescopic part of a chair TLS 270*

2 Material

In this investigation material polypropylene PP grade 2 is used for production of the product. The mixing ratio used in investigation is 70 % percent of primary mixture and 30 % of recycled material (Fig. 2). The primary mixture consists of 2 % of comonomer (master)., ¼ Copolymer and ¾ Homopolymer (Tipplen H-3581).

PP is very popular as a high-volume commodity plastic [1 - 9]. Higher stiffness at lower density and resistance to higher temperatures when not subjected to mechanical stress (particularly in comparison to high and low density PE (HDPE and LDPE)) are the key properties. In addition to this, PP offers good fatigue resistance, good chemical resistance, good environmental stress cracking resistance, good detergent resistance, good hardness (PP propreties Tab. 1) and contact transparency and ease of machining, together with good processibility by injection moulding and extrusion. Homopolymer PP is made by polymerising propylene in the presence of a stereospecific catalyst. In our investigation Tipplen H-3581 [9] was used, the first letter denotes the chemical nature of the polymer: H = Homopolymer, the melt flow index range of the polymer is indicated by the first two-digits in four-digit numbers, the stabiliser and modifier systems are indicated by the last two numerals of a three or four digit number. It is an internal code only.

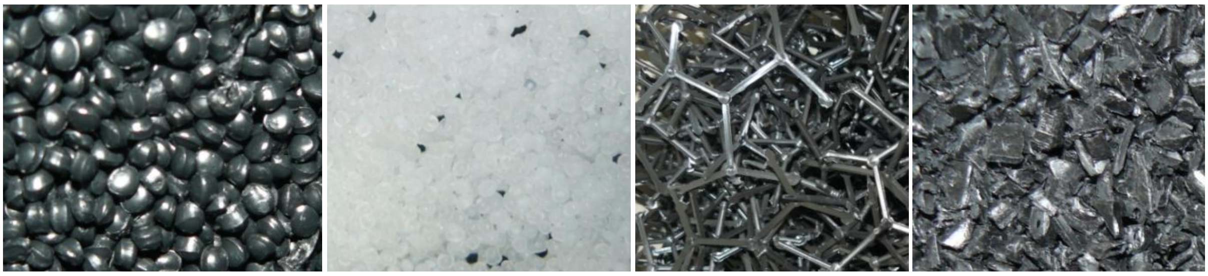

Fig. 2 *Material commoner, mixed materiel, material waste, material waste prepared to be reused*

PP Copolymer properties depend on the type and amount of comonomer. There are two basic types: random copolymer and heterophasic or block copolymer. The random polymers contain 1.5 % to 6 % by weight of ethylene or higher alkenes (such as butane - 1) in random distribution and in a single chemical phase. In our mixture 2 % of comonomer is used. PP is, like other thermoplastics, a viscoelastic material. Consequently its mechanical properties are strongly dependent on time, temperature and stress. The mechanical and thermal properties of PP are dependent on the isotacticity, the molecular weight and its distribution, crystallinity, the type and the amount of comonomer.

Tab. 1 *Unmodified PP properties* [1 - 3]

Property	PP
Flexural modulus (GPa)	1.5
Tensile strength (MPa)	33
Specific density (g/cm3) at 20 (°C)	0.88 - 0.91
Specific modulus (GPa)	1.66
HDT at 0.45 MPa. (°C)	105
Maximum continuous use temperature (°C)	100
Melting point (°C)	170 - 172
Surface hardness	RR90
Mould shrinkage (%)	1.9
Thermal expansion (x10-5)	10
Notched Izod impact strength (kJ/m) at 23 °C	0.07
Tensile elongation at rapture	20 - 600
Tensile strength (MPa)	29.3 – 38.6
Vicat softening point (°C)	154
RR = Rockwell R HDT heat deflection temperature	

3 Parameters, moulding cycle and temperature

Injection moulding machine Plastic metal Mod PM 135 is used in this investigation. Injection moulding is a cyclic process (Fig. 3) where each cycle compromises several operations feeding, melting, homogenization of polymer grains, mold closing, injection under pressure, cooling or heating the polymer inside the mold, mold opening and ejection of molded part. Control over process variables can be more precise by proper selection of barell temperature, screw speed, mold temperature, cooling or heating and injection pressure.

In Tab. 2 total cycle time and other times are presented. The times were calculated and modified until the specified product gave satisfying quality. Improvement for cycle time can be obtained in cooling time as the process will yield a good product even for 8.5 seconds; however this time was proven to be sensitive to temperature changes and therefore for a more robust process cooling time of 9.5 seconds was selected.

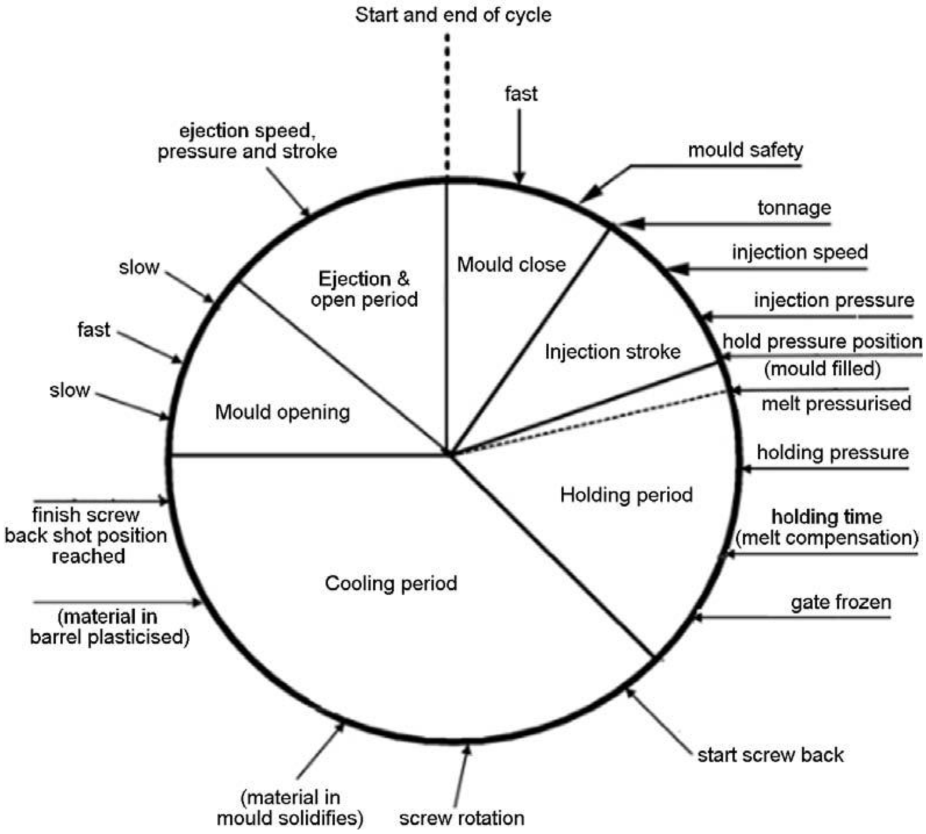

Fig. 3 *Cycle times diagram* [2]

Tab. 2 *Cycle times and pressures*

Times	Seconds	Pressures	MPa
Alarm	52.8	Clamping low	13
Recycle	0.3	Injection speed	65
Injection	2.7	Lower injection speed	55
Cooling time	9.5	Counterpressure	16
Screw delay	0.5		
Flow moulding	0.2		
Carriage retract delay	0.3		
Ejector out delay	0.4		
Ejector retract delay	0.5		
Total cycle time	14.40		

Alarm represents the setting time that activates for any failure and stops the pump for selected duration, setting time must be higher than overall cycle time. Recycle is the time necessary for ejection of moulded part. Injection represents screw rotation that starts to supply the preselected material into the mould. Cooling time is the selected time necessary for cooling of the part. Screw delay by delaying the shot volume it prevents the nozzle from drooling. Flow moulding it controls the quantity of material to be introduced in the mould. Carriage retract delay. Ejector out delay and ejector retract delay are used for part and runner ejection.

Temperature of the tooling used for specific PP material was 40 °C and the melting points used in the process were 215 °C for initial preheating then 225 °C for melting and mixing in the screw and 230 °C before entering into the die cavity. Fig. 5 presents possible errors that are results of temperature variations and errors of material mixtures. Pressure used for injection speed in the specified process was 60 Mpa Tab 2. Fig. 6 presents the tooling used in the process simulation of mold can be seen in the later chapter.

Fig. 5 *Errors caused by wrong temperature parameters*

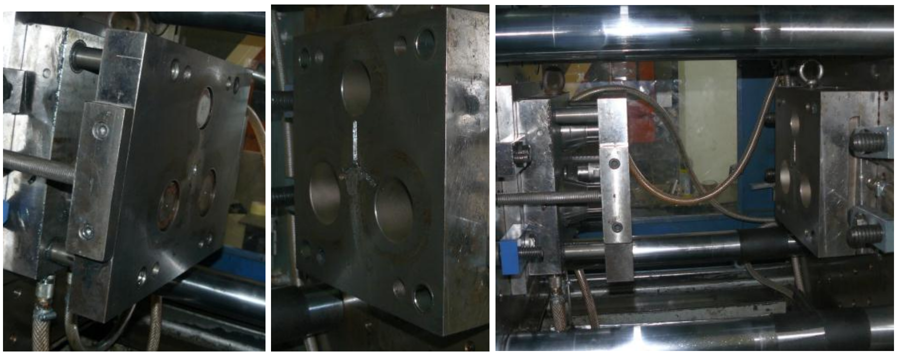

Fig. 6 *Tooling used in production process*

4 Simulation mould tool design

Simulation analysis of injection moulding is a good tool for improving the quality of plastic products and manufacturing equipment [10 - 14]. Different material compounds require specific tool parameters and simulation software allows fast investigations to be carried in order to calculate robust production processes.

Taking into account the dimension of the product and development process a 3D model of the product has been created in software Solidworks 2007. The model has been designed by taking into account real dimension of the product and his arrangement of elements, as shown in the following Fig. 7.

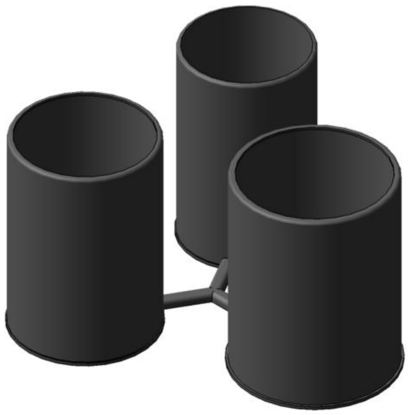

Fig. 7 *3D model of product*

As it has been stated above, the product consists of tree cylindrical elements whose assembly is in the shape of a telescopic shell with a appropriate tap. The cylindrical elements of products have been set at an angle of 120° and have been connected to a material flow channel, which should also be taken into account when planning the 3D model design. By adding specified material mixture to the model, a calculation of the necessary model mass has been done. In the process 92 gram is used however simulation gave 98 grams for specified mould therefore pressures and runners should be carefully selected because errors could occur.

After designing the 3D model of a product, a 3D model of tool has been developed with the use of the Mold design toolbox in Solidworks 2007. The first step that has been determined was the Parting lines which lie along the molded part, between the core and cavity surfaces. After specification of the parting line position the shut-off surface is defined. To cut a tooling block into two pieces, two complete surfaces are needed (a core surface and a cavity surface) without a hole that passes through the mould. Shut-off surface closes up the through hole. After determining the parting lines and shut-off surfaces, the parting surfaces are created. Parting surfaces are extruded from the parting lines and are used to separate the mold cavity from the core. After defining the parting surface, the Tooling Split tool has been used to create the core and cavity block for the tool model. External dimension of tool model haven't been greater than the parting surfaces, but in our case the parting surface is defined with parting line which is not rectangular shape (tree connected circles). Therefore it has been impossible to make the tool model with an outer prismatic shape. For this purpose, a simplification of outer shape has been done as it is shown in the Fig. 8. The aim of this paper has been creation of the core and the cavity part of tool model, therefore the external shape of tool model can be neglected.

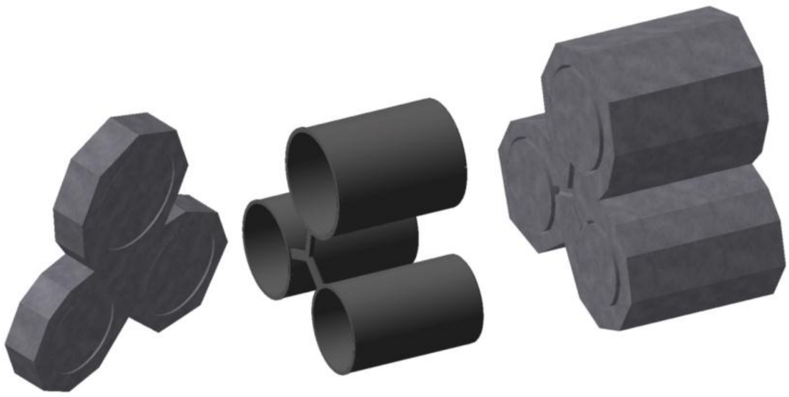

Fig. 8 *3D model of product*

5 Mold simulation with MoldflowXpress software

Mold simulation has also been made by the use of the software MoldflowXpress (Solidworks 2007). MoldflowXpress is an introductory version of Moldflow Plastics Advisers (MPA) for SolidWorks. MPA products extend the capabilities of MoldflowXpress with functionality that includes:

- Analysis of multiple injection locations
- Access to 7,500+ plastics in the Moldflow material database
- Expanded results including pressures, temperatures, weld line and air trap locations
- Simulation of flow through mold feed systems (sprues, runners and gates)
- Evaluation of mold cooling circuits to achieve uniform cooling and minimum cycle times
- Indication if a part is likely to warp or deform beyond acceptable levels

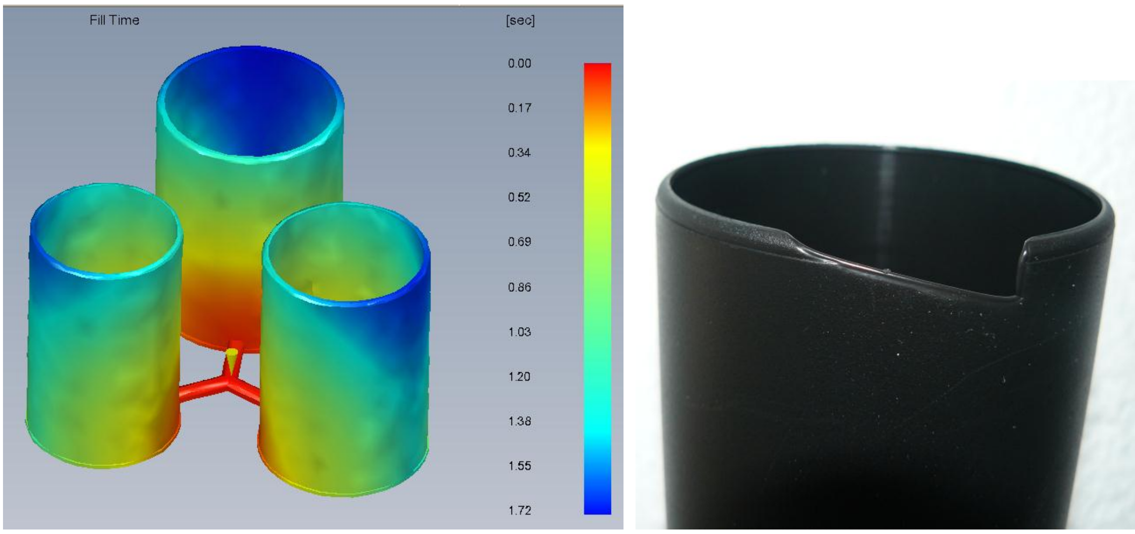

Fig. 9 *3D model of product with critical areas and an example of error that can occur because of slow filling*

Considering the real works regime and material characteristic, has been chosen material Polypropylene (PP), melt temperature 230 °C, and mold temperature 40 °C. Injection location has been chosen in the center of material flow channel, as the same in the real process. The simulation has been demonstrated that for the chosen mold material and the temperature completely filled the cavity of mold tool, without residual volume. The total time necessary for filling 98 grams into the mold was 1.72 second in simulation however in real process 2.7 was used for 92 grams at the pressure of 60 MPa in order to keep the process more robust. Results of simulated filling of the mould capacity are shown in the following Fig. 9 and it can be seen that runners are the most important part as they are filled first and the critical part where errors occur are the outer furthers parts of created cylinders.

6 Conclusion

Influential parameters for injection moulding have been presented with emphasis on cycle calculation for given product. CAD mould simulation has shown adequate results that can allow preparation of new production and give better correlation between influential process parameters. By simulation we have obtained the necessary data needed for creation of a mold design and critical points have been addressed. True experimental production has shown that simulation does not give a good enough robust process because of unpredicted parameter behaviour such as temperature variation, cooling cycle and material mixing. Several recommendations have been made in order to maintain an error free production. The CAD mould also facilitates simulations of different materials and further investigation will be concentrated on use of different material and its adaptability to given mould design. With the CAD model it is possible to create G code for milling operation where further research can be made. Several equations will be investigated such as production rates, behaviour runners, selection of optimal melt temperatures and mould temperature etc.

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