How Surface Roughness of Mold Cavity Influence the Material Flow

M. Stanek, D. Manas, M. Manas and V. Senkerik

***Abstract*—** Delivery of polymer melts into the mold cavity is the most important stage of the injection molding process. This paper shows the influence of cavity surface roughness, polymer material (with different flow properties) and technological parameters on the flow length of polymers into mold cavity. Application of the measurement results may have significant influence on the production of shaping parts of the injection molds especially in changing the so far used processes and substituting them by less costly production processes which might increase the competitiveness of the tool producers and shorten the time between product plan and its implementation. Because the finishing operations of machining are very time and money consuming leading to high costs of the tool production. Six types of thermoplastic polymers with different flow properties were tested in this paper.

***Keywords*—** injection molding, mold, polymer, roughness, surface, fluidity.

I. Introduction

INJECTION molding is one of the most extended polymer processing technologies. It enables the manufacture of final products, which do not require any further operations. The tools used for their production – the injection molds – are very complicated assemblies that are made using several technologies and materials. Working of shaping cavities is the major problem involving not only the cavity of the mold itself, giving the shape and dimensions of the future product, but also the flow pathway (runners) leading the polymer melt to the separate cavities. The runner may be very complex and in most cases takes up to 40% volume of the product itself (cavity). In practice, high quality of runner surface is still very often required. Hence surface polishing for perfect conditions for melt flow is demanded. The stated finishing operations are very time and money consuming leading to high costs of the tool production. The fluidity of all polymers during injection molding cycle is affected by many parameters (mold design, melt temperature, mold temperature, injection rate, pressures, etc.) and by the flow properties of polymers. Results of the experiments carried out with selected types of polymer materials proved a minimal influence of surface roughness of the runners on the polymer melt flow. This considers excluding (if the conditions allow it) the very complex and expensive finishing operations from the technological process as the influence of the surface roughness on the flow characteristics does not seem to play as important role as was previously thought. A plastic nucleus is formed by this way of laminar flow, which enables the compression of the melt in the mold and consecutive creeping. A constant flowing rate given by the axial movement of the screw is chosen for most of the flows.

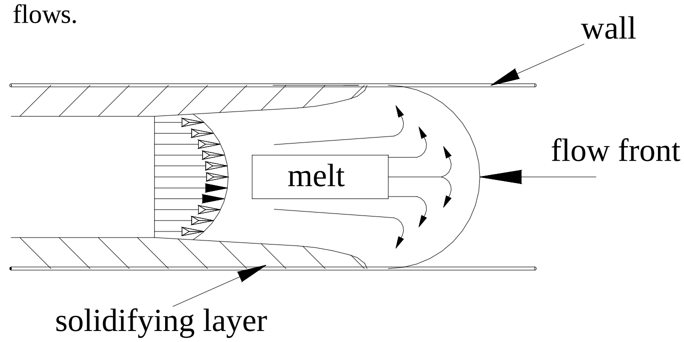


Fig. 1 Fountain flow

During filling the mold cavity the plastic material does not slide along the steel mold surface but it is rolled over. This type of laminar flow is usually described as a “fountain flow” (Fig.1).

II. Injection molding

The testing samples were prepared by injection molding technology (injection molding cycle is shown on Fig. 2). The injection mold for was designed for the easiest possible manipulation both with the mold itself and during injection molding process while changing the testing plates, size of the mold gate, pressure and temperature sensors inside the cavity, etc. The cavity space of the mold is generated by the female mold part, called cavity, and a male mold part, called the core. It is necessary to fill the mold cavity fully during the injection molding process. The ability of cavity filling could be affected by the polymer properties and the properties of cavity walls.

This paper is supported by the internal grant of TBU in Zlin No. IGA/FT/2014/016 funded from the resources of specific university research and by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089.

Michal Stanek is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (phone: +420576035153; fax: +420576035176; e-mail: stanek@ft.utb.cz).

David Manas is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (e-mail: dmanas@ft.utb.cz).

Miroslav Manas is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (e-mail: manas@fai.utb.cz).

Vojtech Senkerik is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (e-mail: vsenkerik@ft.utb.cz).

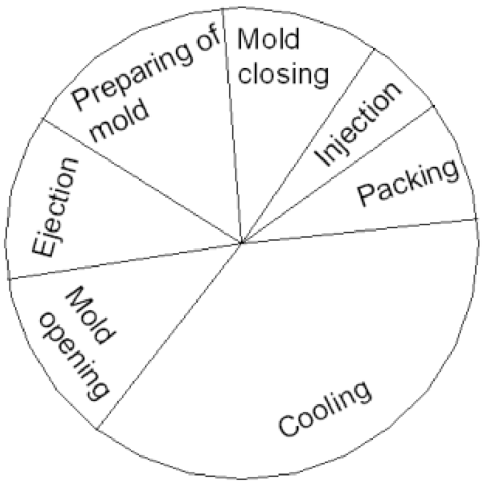


Fig. 2 Injection molding cycle

A.Testing plates

The shaping part of the injection mold is composed of right and left side. The most important parts of the injection mold concerning the measurements are: testing plate, cavity plate and a special sprue puller insert. There is possible to use pressure and temperature sensors in the mold cavity for the values progress evaluation.

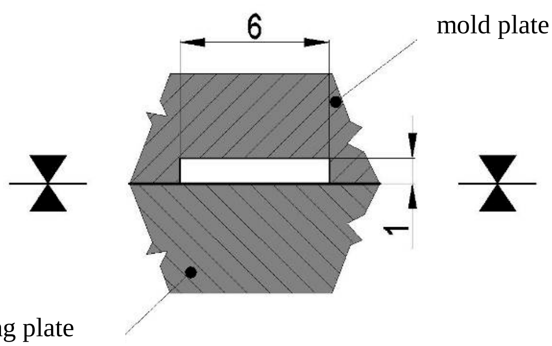
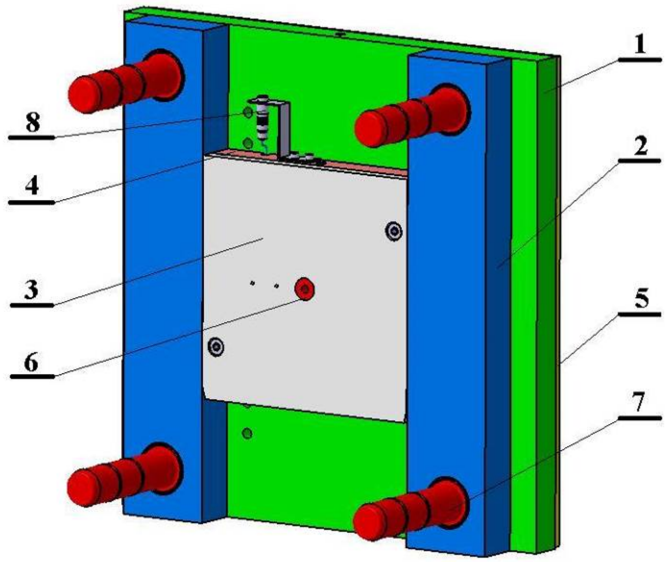


Fig. 3 Cross section of mold cavity

The cavity (Fig. 4) of testing injection mold for is in a shape of a spiral (Fig. 5) with the maximum possible length of 2000 mm and dimensions of channel cross-section: 6x1 mm. The cavity is created when the injection mold is closed, i.e. when shaping plate seals the testing plate in the parting plane of the mold. The mold cavity is cooling by flowing oil from tempering unit. [2]

a)



b)

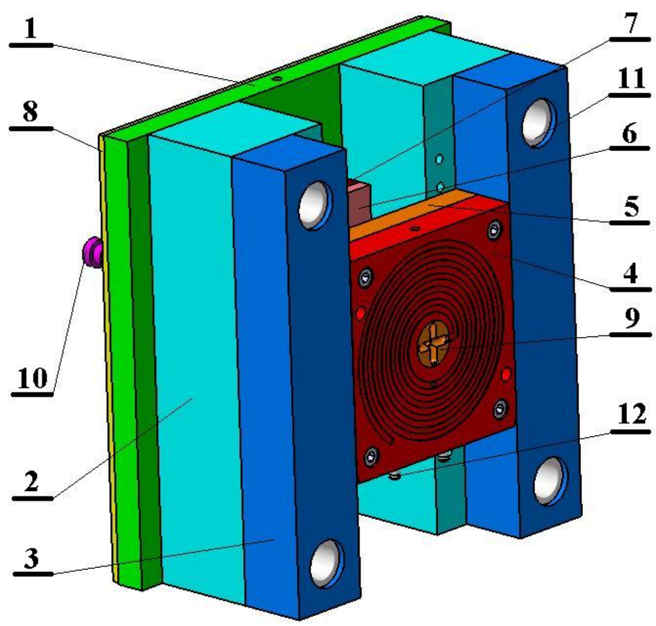


Fig. 4 Injection mold

a) Left side of injection mold (ejection side)
1 – clamping plate, 2, 3 – spacer plate, 4 – cavity plate, 5 – plate, 6,7 – ejector plates, 8 – insulating plate, 9 – sprue puller insert, 10 – ejector rod, 11 – guide bush,12 – hose nipple

b) Right side of injection mold (sprue side)
1 – clamping plate, 2 – spacer plate, 3 – testing plate, 4 – plate, 5 – insulating plate, 6 – sprue bushing, 7 – guide pillar, 8 – connector of pressure sensor

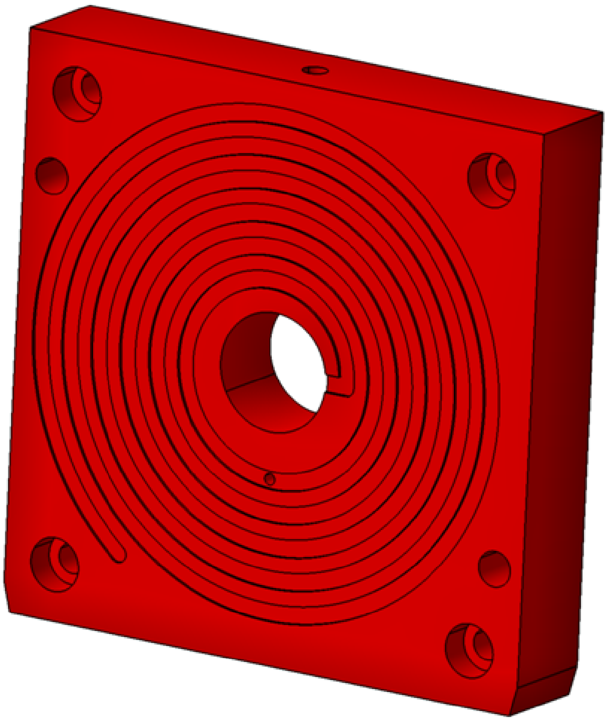


Fig. 5 Cavity plate – shaping plate

Fig. 6 Testing sample – spiral

Testing Injection mold can operate with 5 easy exchangeable testing plates (Fig. 7) with different surface roughness.

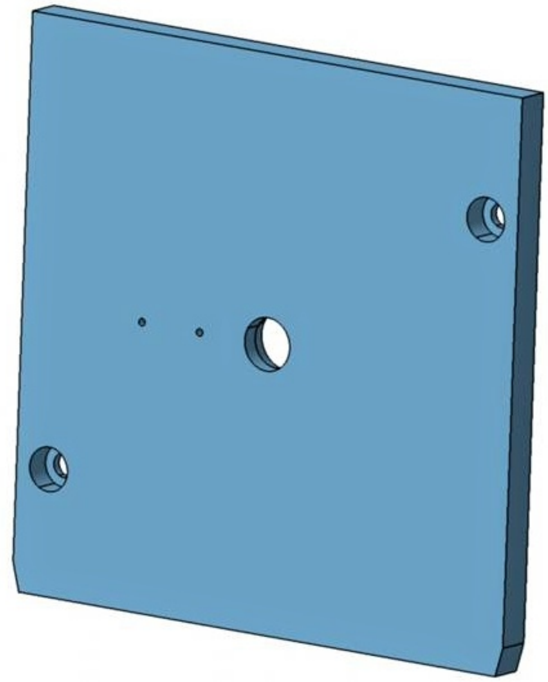
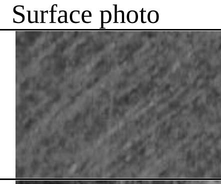
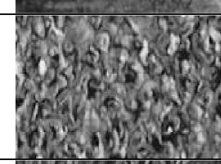
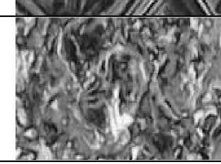


Fig. 7 Cavity plate – testing plate

The surface of the plates was machined by four different technologies, which are most commonly used to work down the cavities of molds and runners in industrial production. These technologies are polishing, grinding, milling and two types of electro-spark machining – fine and rough design (Table 1).

Table 1 Surfaces of testing plates

Plate surface	Surface photo
Polished plate (R_a = 0,102μm)	
Grinded plate (R_a = 0,172μm)	
Electro – spark machined plate with a fine design (R_a = 4,055μm)	
Milled plate (R_a = 4,499μm)	
Electro – spark machined plate with a rough design (R_a = 9,566μm)	

The testing plates are made from tool steel (DIN 1.2325) whose are used for simple and fast changing the surface of the mold cavity. [7]

Injection molding machine ARBURG Allrounder 420C 1000 – 350 with oil tempering unit Regloplas 150 smart were used for testing samples production.

B. Sprue puller insert

Special sprue puller insert enables the exchange of differently sized gates. Size of the gate could be 1, 2, 4 or 6 mm.

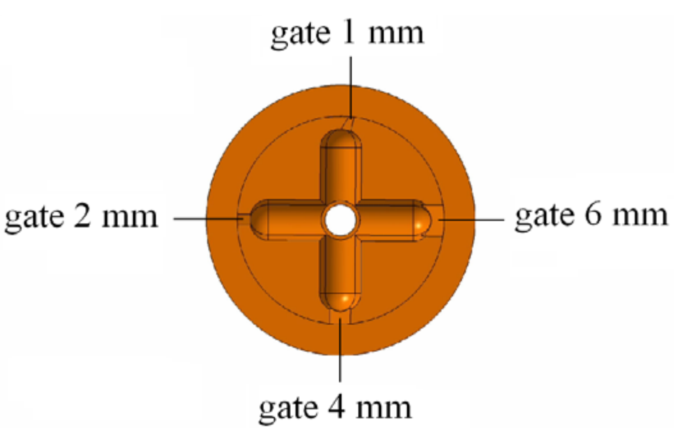


Fig. 7 Sprue puller insert

C. Testing injection mold

The testing injection mold is inserted into a universal frame which was designed for use with many different injection molds that fit the size of the frame. This makes the change of the separate injection molds easier, because the frame remains clamped to the injection molding machine and only the shaping and ejection parts of the molds are changed. Attaching right and left sides of the frame to fixed and moving plates of the injection molding machine is done using four adjustable clamps on each side. [16, 17]

III. TESTED POLYMERS

Six types of thermoplastic polymers with different flow properties (MFI - Melt Flow Index) were tested:

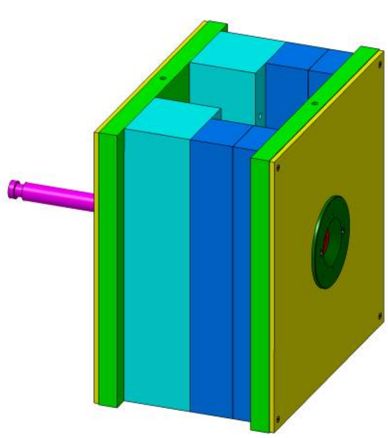
- polypropylen (PP) Mosten GB 003, MFI = 3,3
- polyethylen (LDPE) Bralen VA 20-60, MFI = 20
- termoplastic polyurethan (TPU) Ellastolan C 78 A, MFI = 6,1
- akrylonitril-butadien-styren (ABS) Polylac PA 757, MFI = 2,4
- polypropylen filled by 20% of chalk Taboren PH 89 T20, MFI = 14,4
- polypropylen filled by 10% of chalk Keltan TP 7603, MFI = 16,9

Measurement of Melt Flow Index has been done on extrusion rheometer Kayeness LMI D4003. The principle of measurement consists in polymer melt preparation and its extrusion. The values of melt temperature and load of ram are defined in standard. Extruded samples are weighted in defined time intervals after their cooling. The Melt Flow Index is calculated from samples weight and from the time interval of extrusion.

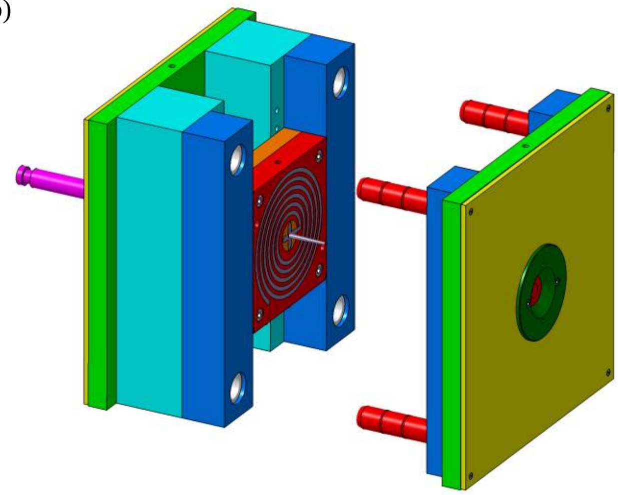
Fig. 8 Melt flow indexer Dynisco Kayeness LMI D4003

IV. INJECTION MOLDING OF TESTING SAMPLES

a)



b)



c)

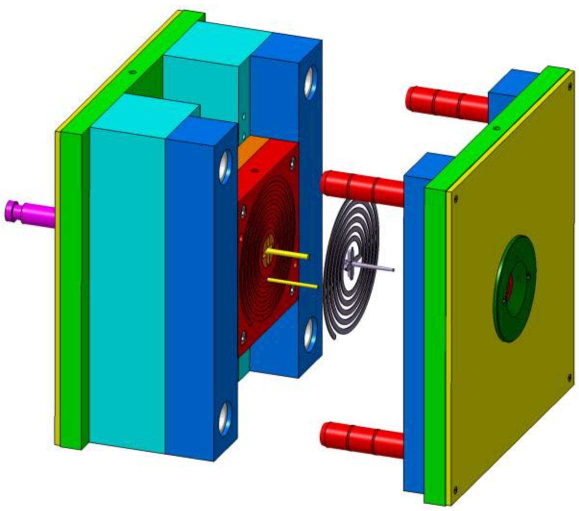


Fig. 9 Injection molding cycle
a) closing the mold, injection of the melt, packing, cooling,
b) opening the mold, c) ejection of the testing sample

Injection molding machine ARBURG Allrounder 420C with oil tempering unit Regloplas 150 smart were used for testing samples production.

Fig. 10 Injection molding machine ARBURG Allrounder 420C

V. Injection molding process simulation

A simulation of the injection molding process in SW Autodesk Moldflow Insight 2013 was carried out for comparison with the reality.

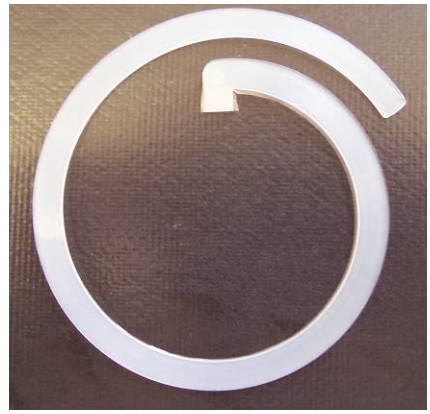


Fig. 11 Flow length – real sample

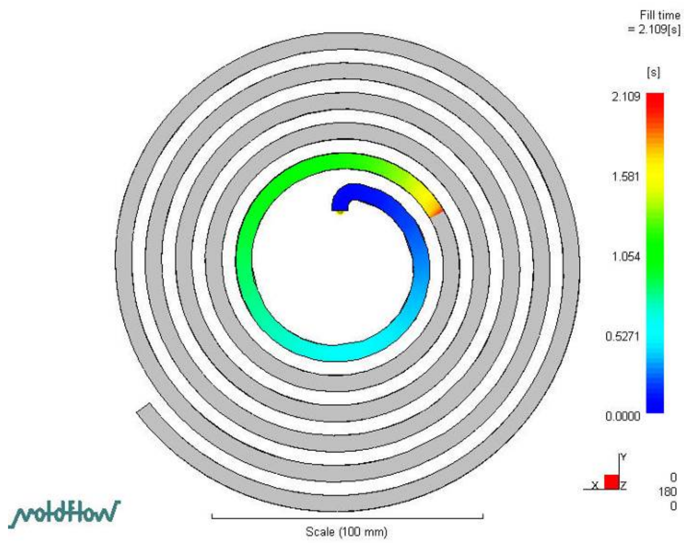


Fig. 12 Flow length – simulation

The same conditions were set as during the actual injection molding process. The flow length in the mold cavity of the polymeric material was observed. The comparison was done using only the polished plate, because the SW Autodesk Moldflow Insight does not enable to alter the quality of the surface cavity. The results from both real injection molding process and simulation prove congruent; see Fig. 10 and Fig. 11.

VI. RESULTS

The filling of mold cavity depends on material properties, technological conditions and surface quality. The lower is the viscosity of polymer (measured by Melt Flow Index) the better cavity filling has been achieved (Fig. 12 and Fig. 13).

Rising injection rate and filling pressure have a result in better in mold cavity filling (Fig. 15) Above mentioned results of polymer melt behaviour during mold filling were expected. New and very important result rises from experiments which analyzed the influence of surface quality on injection mold filling. It could be generally said that the surface quality of flow pathway significantly affect flow of polymer melt. It was found that better quality of wall surface worsened the flow condition the length of injected sample spiral was shorter. This finding could have very important effect for tools producers. There is not necessary to use high precision cutting operation and it would be possible to exclude some very costly final operation as for example grinding or polishing.

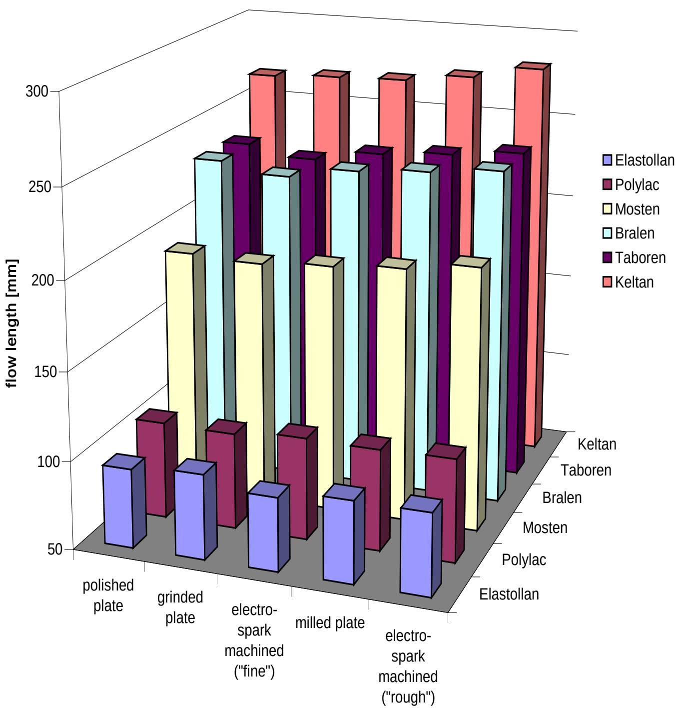


Fig. 12 Influence of flow length on surface quality and type of polymer (injection pressure 8 MPa)

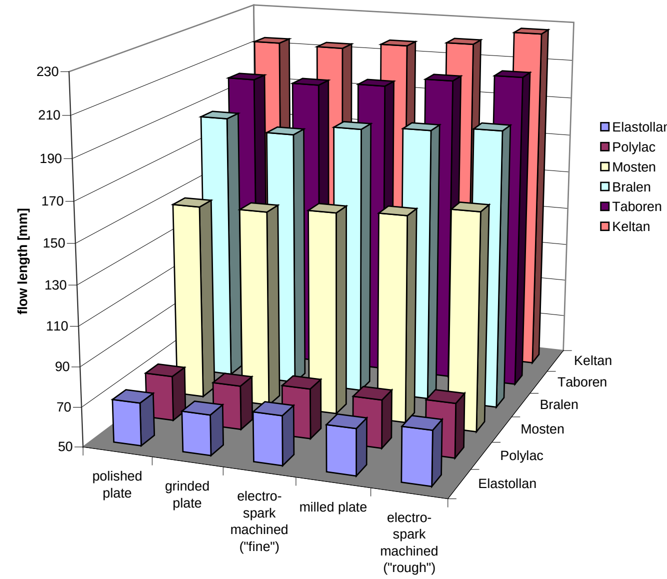


Fig. 13 Influence flow length on surface quality and type of polymer (injection pressure 6 MPa)

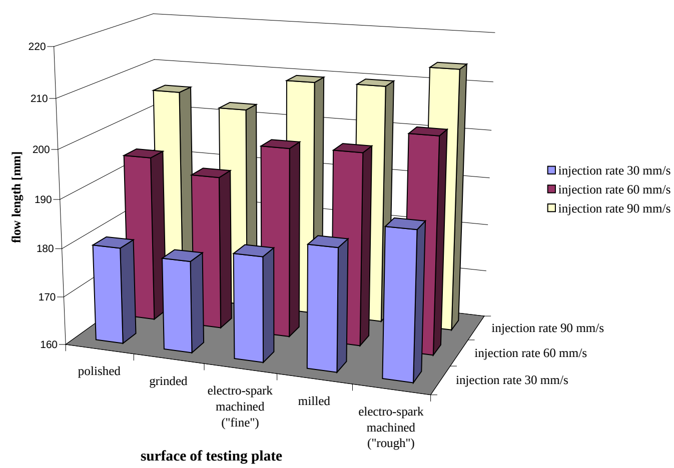


Fig. 14 Influence of flow length on surface quality and injection rate (Taboren, gate 6 mm, injection pressure 6 MPa)

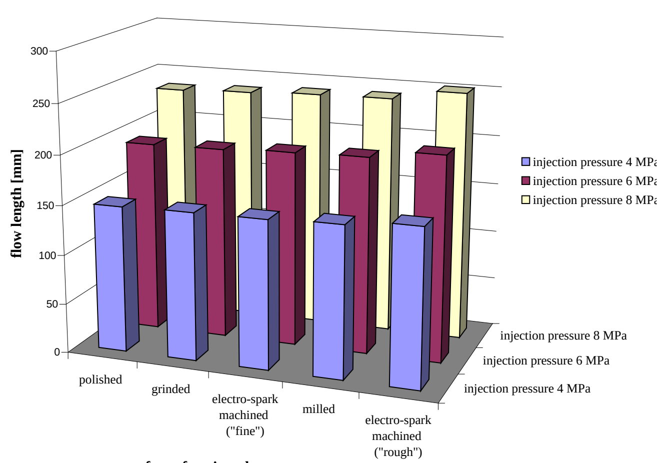


Fig. 15 Influence of flow length on surface quality and injection pressure (Keltan, gate 6 mm, injection rate 30 mm.s^{-1})

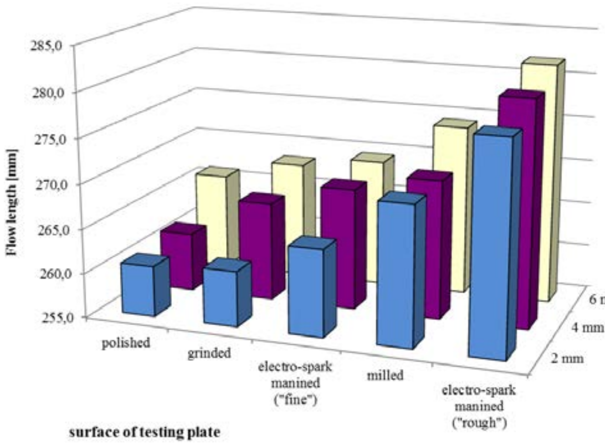


Fig. 12 Influence of flow length on surface quality and gate size (Keltan, injection pressure 8 MPa, injection rate 90 mm.s^{-1})

Table 2. Increase of flow length in percentage against the polished plate for selected materials

	polished plate	grinded plate	electro-spark machined ("fine")	milled plate	electro-spark machined ("rough")
Mosten	-	+0,4%	+2,3%	+3,5%	+7,0%
Taboren	-	-0,2%	+0,6%	+3,1%	+5,2%

VII. Statistical evaluation of the measured data

The final statistical evaluation of the measured data was done by SW STATISTICA 7. The aim of the statistical evaluation was to determine the influence of separate parameters on filling the mould cavity by all materials. Due to the influence of more factors (some independent variables) on the change of the observed feature (dependent variables), multiple regression was chosen for the description. The result of the regressive analysis is the regressive model used to predict the value of dependent variable at a given value of independent variable.

The dependent variable is the flow length. We observe the influence of five independent variables (injecting pressure, injecting rate, size of the gate, surface roughness of the testing plates and Melt Flow Index of the materials) on the flow length.

To find out the impact of the factors on flow length, the dispersion analysis was carried out. The analysis was done separately for every material group (thermoplastics, thermoplastic elastomers and elastomers) The resulting p-values are stated in Table 3. The values under $p<0,05$ are statistically relevant.

Table 3 P-values of observed factors

factor	p-value
injecting rate	0,000001
injecting pressure	0,000000
size of gate	0,000000
surface roughness of testing plate	0,291675
melt flow index	0,000000

The following regressive models were found out using the multiple regression.

$R^2 = 0,943915$

$$y_t = 0,025286X_1 + 0,692656X_2 - 0,041169X_3 - 0,003387X_4 + 0,351107X_5 + \varepsilon_i$$

where: y_t – flow length
X_1 – injection rate
X_2 – injection pressure
X_3 – size of gate
X_4 – surface roughness of testing plate
X_5 – melt flow index
ε_i – incidental values

VIII. Conclusion

This research looked into the influence of technological parameters on filling of the injection mold cavity and the flow length respectively. The differences in flow lengths at the testing cavity plates with different surface roughness were very small, rather higher in case of rougher surfaces testing plates of the mold.

The measurement shows that surface roughness of the injection mold cavity or runners have no substantial influence on the length of flow. This can be directly put into practice. It also suggests that final working and machining (e.g. grinding and polishing) of some parts of the mold, especially the flowing pathways, are not necessary.

Acknowledgment

This paper is supported by the internal grant of TBU in Zlin No. IGA/FT/2014/016 funded from the resources of specific university research and by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.

REFERENCES

[1] D. Manas, M. Hribova, M. Manas, M. Ovsik, M. Stanek, D. Samek, “The effect of beta irradiation on morfology and micro hardness of polypropylene thin layers“, 2012, *Thin Solid Films*, Volume 530, pp. 49-52. ISSN 0040-6090.

[2] M. Stanek, D. Manas, M. Manas, O. Suba, “Optimization of Injection Molding Process“, *International Journal of Mathematics and Computers in Simulation*, Volume 5, Issue 5, 2011, p. 413-421

[3] M. Stanek, D. Manas, M. Manas, J. Javorik, “Simulation of Injection Molding Process by Cadmould Rubber“, *International Journal of Mathematics and Computers in Simulation*, Volume 5, Issue 5, 2011, p. 422-429

[4] D. Manas, M. Manas, M. Stanek, S. Sanda, V. Pata, “Thermal Effects on Steels at Different Methods of Separation“, 2011, *Chemicke listy*, Volume 105, Issue 17, pp. S713-S715

[5] M. Manas, D. Manas, M. Stanek, S. Sanda, V. Pata, “Improvement of Mechanical Properties of the TPE by Irradiation“, 2011, *Chemicke listy*, Volume 105, Issue 17, pp. S828-S829

[6] J. Javorik, J., M. Stanek, “The Shape Optimization of the Pneumatic Valve Diaphragms“, International *Journal of Mathematics and Computers in Simulation*, Volume 5, Issue 4, 2011, p. 361-369

[7] Stanek, M, Manas, M., Manas, D., Sanda, S., “Influence of Surface Roughness on Fluidity of Thermoplastics Materials”, *Chemicke listy*, Volume 103, 2009, pp.91-95

[8] Manas, D., Stanek, M., Manas, M., Pata V., Javorik, J., “Influence of Mechanical Properties on Wear of Heavily Stressed Rubber Parts”, *KGK – Kautschuk Gummi Kunststoffe*, 62. Jahrgang, 2009, p.240-245

[9] Stanek, M., Manas, M., Manas, D., Sanda, S., “Influence of Surface Roughness on Fluidity of Thermoplastics Materials”, *Chemicke listy*, Volume 103, 2009, p.91-95

[10] Stanek, M., Manas, M., Manas, D., “Mold Cavity Roughness vs. Flow of Polymer”, *Novel Trends in Rheology III*, AIP, 2009, pp.75-85

[11] J. Javorik, M. Stanek, “The Numerical Simulation of the Rubber Diaphragm Behavior,” *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Spain, 2011, pp. 117-120.

[12] J. Javorik, D. Manas, “The Specimen Optimization for the Equibiaxial Test of Elastomers,” *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Spain, 2011, pp. 121-124.

[13] M. Stanek, D. Manas, M. Manas, O. Suba, “Optimization of Injection Molding Process by MPX,” *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, p.212-216.

[14] M. Manas, M. Stanek, D. Manas, M. Danek, Z. Holik, “Modification of polyamides properties by irradiation”, *Chemické listy*, Volume 103, 2009, p.24-26.

[15] D. Manas, M. Manas, M. Stanek, M. Zaludek, S. Sanda, J. Javorik, V. Pata, “Wear of Multipurpose Tire Treads” *Chemické listy*, Volume 103, 2009, p.72-74.

[16] S. Sanda, M. Manas, M. Stanek, D. Manas, L. “Rozkosny, Injection Mold Cooling System by DMLS”, *Chemicke listy*, Volume 103, 2009, p.140-142.

[17] M. Stanek, M. Manas, T. Drga, D. Manas, “Testing Injection Molds for Polymer Fluidity Evaluation”, *17th DAAAM International Symposium: Intelligent Manufacturing* & *Automation: Focus on Mechatronics and Robotics*, Vienna, Austria, 2006, p.397-398.

[18] M. Stanek, M. Manas, D. Manas, S. Sanda, “Influence of Surface Roughness on Fluidity of Thermoplastics Materials, *Chemické listy*, Volume 103, 2009, p.91-95

[19] M. Manas, M. Stanek, D. Manas, M. Danek, Z. Holik, ”Modification of polyamides properties by irradiation”, *Chemické listy*, Volume 103, 2009, p.24-28

[20] Manas, D., Stanek, M., Manas, M., Pata V., Javorik, J., “Influence of Mechanical Properties on Wear of Heavily Stressed Rubber Parts”, *KGK – Kautschuk Gummi Kunststoffe*, 62. Jahrgang, 2009, p.240-245.

[21] J. Javorik, D. Manas, “The Specimen Optimization for the Equibiaxial Test of Elastomers,*” in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Spain, 2011, pp. 121-124.

[22] M. Stanek, D. Manas, M. Manas, J. Javorik, “Simulation of Injection Molding Process by Cadmould Rubber“, *International Journal of Mathematics and Computers in Simulation*, Volume 5, Issue 5, 2011, p. 422-429.

[23] V. Pata, D. Manas, M. Manas, M. Stanek, “Visulation of the Wear Test of Rubber Materials”, *Chemicke listy*, Volume 105, 2011, pp.290-292.

[24] M. Adamek, M. Matysek, P. Neumann, “Modeling of the Microflow Senzor”, i*n Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.137-140.

[25] M. Stanek, D. Manas, M. Manas, O. Suba, “Optimization of Injection Molding Process by MPX,” *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, p.212-216.

[26] Manas, M.; Manas, D.; Stanek, M.; Mizera, A.; Ovsik, M. Modification of polymer properties by irradiation properties of thermoplastic elastomer after radiation cross-linking. *Asian Journal of Chemistry*, 2013, Volume 25, Issue 9, s. 5124-5128. ISSN 09707077.

[27] Ovsik, M., Manas, D., Manas, M., Stanek, M., Kyas, K., Bednarik, M., Mizera, A. “Microhardness of HDPE influenced by Beta Irradiation“, *International Journal of Mathematics and Computers in Simulation*, Volume 6, Issue 6, 2012, p. 566-574, ISSN 1998-0159.

[28] T. Sysala, O. Vrzal, “A Real Models Laboratory and an Elevator Model Controlled through Programmable Controller (PLC)”, *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Canary Islands, 2011, p.365-368.

[29] Stanek, M., Manas, M., Manas, D., “Mold Cavity Roughness vs. Flow of Polymer”, *Novel Trends in Rheology III*, AIP, 2009, pp.75-85.

[30] F. Hruska, “Project of Control System of Thermal Comfort*”, in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.96-100.

[31] O. Suba, L. Sykorova, S. Sanda, M. Stanek “Modelling of Thermal Stresses in Printed Circuit Boards*”, in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.173-175.

[32] O. Suba, L. Sykorova, S. Sanda, M. Stanek, “Stress – State Modelling of Injection-molded Cylindrical Bosses Reinforced with Short Fibres*”, in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.177-179.

[33] T. Sysala, O. Vrzal, “A Real Models Laboratory and an Elevator Model Controlled through Programmable Controller (PLC)*”, in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.365-368.

[34] V. Pata, D. Manas, M. Manas, M. Stanek, “Visulation of the Wear Test of Rubber Materials”, *Chemicke listy*, Volume 105, 2011, pp.290-292

[35] L. Pekar, R. Matusu, P. Dostalek, J. Dolinay, “The Nyquist criterion for LTI Time-Delay Systems*”, in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.80-83.

[36] L. Pekar, R. Prokop, “Analysis of a Simple Quasipolynomial of Degree One*”, in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.86-89.

[37] M. Stanek, M. Manas, D. Manas, “Mold Cavity Roughness vs. Flow of Polymer”, Novel Trends in Rheology III, AIP, 2009, pp.75-85.

[38] K. Kyas, M. Stanek, J. Navratil, M. Manas, D. Manas, V. Senkerik, A. Skrobak, “Rubber product properties influenced by runners trajectory”, International Journal of Mathematics and Computers in Simulation 7 (1) , pp. 1-8.

[39] J. Cerny, D. Manas, Z. Holik, M. Ovsik, M. Bednarik, A. Mizera, M. Stanek, M. Manas, “Wear of heavy industry tires”, International Journal of Mathematics and Computers in Simulation 7 (1) , pp. 9-16

[40] J. Cerny, D. Manas, Z. Holik, M. Ovsik, M. Bednarik, A. Mizera, M. Manas, M. Stanek, “Methods of design of ergonomics parts”, International Journal of Mathematics and Computers in Simulation 7 (1), pp. 17-24

[41] M. Stanek, D. Manas, M. Manas, J. Navratil, K. Kyas, V. Senkerik, A. Skrobak, “Comparison of different rapid prototyping methods”, International Journal of Mathematics and Computers in Simulation 6 (6), pp. 550-557

[42] K. Kyas, J. Cerny, M. Stanek, M. Manas, D. Manas, V. Senkerik, A. Skrobak, “Measuring of temperature and pressure in injection mold”, International Journal of Mathematics and Computers in Simulation 6 (6), pp. 600-607