Rubber Product Properties Influenced by Runners Trajectory

K. Kyas, M. Stanek, J. Navratil, M. Manas, D. Manas, V. Senkerik and A. Skrobak

Abstract**—** Computational analyses are commonly used in technical industry to improve process. This paper show using computational analysis during injection molding process. Injection molding process is one of the most widespread technologies in polymer industry. There are plenty of differences between injection thermoplastic and elastomeric compound. The main aim of the paper is showing differences between types of runners on finally properties of rubber product. These received dates should be helpful for setting of injection machine and cycle in rubber injection molding process.

Keywords**—** rubber compound, cure rate, pressure sensor, temperature sensor, injection molding process, injection mold

I. Introduction

INJECTION molding is now a well-established fabrication process in environmental industry. It has more advantages in the most situations over the older processes of compression and transfer molding. These advantages comprise reduced labor cost, better dimensional control and shorter cure times for injection molding process. This process is still improved and other materials (not only thermoplastic) are used for example elastomeric compound. [1, 8, 12-22]

The injection molding process is a cyclical process, each cycle comprises several operations: feeding, melting and homogenization of polymer grains inside the plasticizing cylinder mold closing, injection under pressure of melt in mold's cavities and cooling or heating of polymer inside the mold, mold opening and ejection of molded piece. In figure 1 there is shown time influence for each parts of cycle. It is necessary to realize, that rubber injection molding cycle is several times longer than for thermoplastics. [2,4 - 38]

During injection molding process, melt is subjected to more severe processing conditions than during compression or transfer molding. Values of temperatures, pressures, and shear stresses are higher, though cure times are shorter in rubber compound. Control over process variables can be more precise. [2,3,7,15-38]

Injection molding of thermoplastic material is a process in which the hot polymer is injected into a mold cavity. Heat is removed from the polymer in the mold until it is rigid and stable enough to be ejected. Therefore the design of the part and mold are critical in ensuring the successful molding process. For the recent years, the insert molding in injection molding has been very popular. The mold insert molding process is an efficient technology for injection molding process. The insert material will have a significant effect on the filling phenomena around the insert parts. The insert materials can vary. The metal inserts are used to increase the performance of drawing heat from the cavity. On the other hand, the plastic inserts reduce the cooling effects. Different insert parts have different effects for the injection molding process. [1-15, 20-38]

Tab.1 Two cavity injection mold

Type of polymer	Family name	mold surface temperature [°C]	melt temperature [°C]
Elastomer	EPDM	150	90
	NBR	140	85
	NR	140	85
	SBR	140	85
Thermoplast	ABS	50	250
	ABS 20%	50	230
	PA6	65	250
	PC	82	299
	PE	52	220
	PP	50	230
	TPE	45	250

Process where elastomeric compound is injected has some differences. Main difference is in the temperature, mold surface temperature is higher than melt temperature. In technical industry there are plenty of materials. Differences in process setting between each type of polymers are shown in following table. Next difference is in the cycle time period. Injection molding cycle of elastomeric compound is higher for the same volume of injected material.

Kamil Kyas is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (phone: +420576035153; fax: +420576035176; e-mail: kyas@ft.utb.cz).
Jan Navrátil is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (e-mail: j1navratil@ft.utb.cz).
Michal Stanek is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (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@ft.utb.cz).
Vojtech Senkerik is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (e-mail: senkerik@ft.utb.cz).
Adam Skrobak is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (e-mail: skrobak@ft.utb.cz).

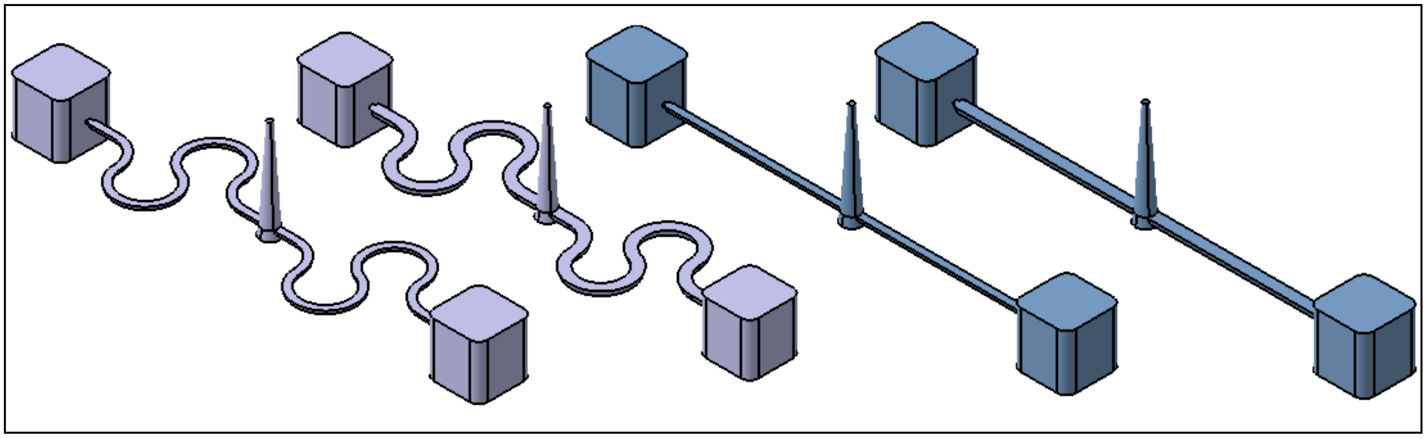

Fig.1 Examples of all trajectories

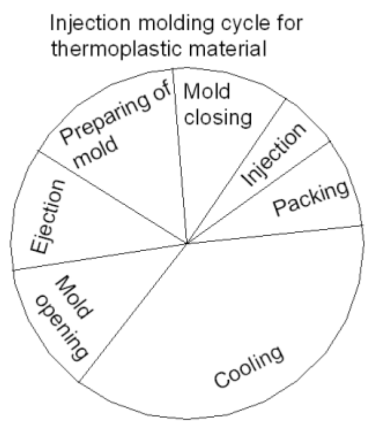

Fig.2 Thermoplastic injection molding cycle

Fig.3 Elastomeric injection molding cycle

The cycle time can be minimized by independently controlling barrel temperature, screw speed, mold temperature and injection pressure. That is the reason why the injection molding process should be improved and understood. [4,5,10]

Elastomeric injection molding offers a number of cost and quality advantages as well as design flexibilities and environmental friendliness through material cost reduction and recycling, and modification of the part quality and property. However, the technical challenges lie in proper design of the part, mold, and process as well as the selection of materials to obtain the desirable skin/core material distribution and adhesion. Improper part and mold design and material combination will result in core distribution within the cavity. Recall that the skin thickness and extent of core penetration depends on the viscosity ratio of the materials and the selection of process conditions. As a result, the development for a elastomeric injection mold and process set-up do not take longer time than that with the thermoplastic injection molding process. [12,14,19,33-35]

II. DESING OF MOLD AND PRODUCT

This paper deal with technical problem connected with injection molding process of elastomeric compound. This problem consists of design of injection mold, setting of injection mold process and its analysis.

Design, material and method co-operate together in injection molding process. This experiment is focused on observing pressure and temperature in runners and their changes.There were made two cavity injection mold for this experiment. There were used two types of runners as it is showed in Fig. 3. Type 1 which is shorter is linear and longer type 2 is curved. Mold cavity is a cube with dimension 30 x 30 x 30 mm. It is prepared for real injection molding process for the further research. Two different thicknesses of runners are used for these concrete analyses as it can be seen in Fig. 4. According to these models injection molds are prepared for testing influence of setting parameters on finally properties in real process.

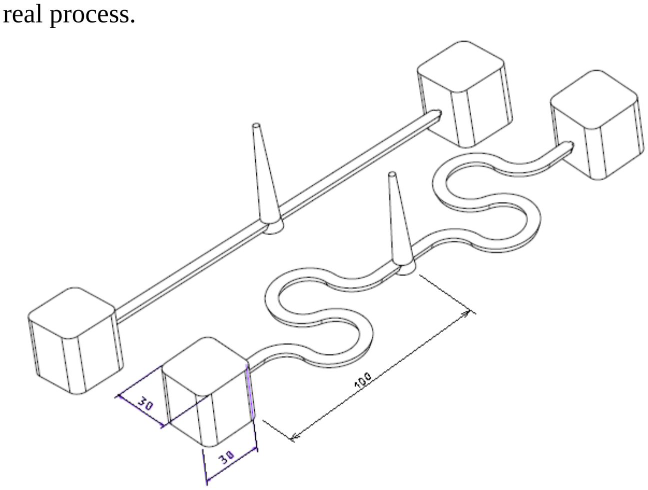

Fig.4 Dimensions of product and runners

Part with runners can be seen in Fig. For this part was designed injection mold. It is consist of four plates (two cavity plates and two clamping plates). Each plate was manufacture in 3 axis CNC machine AZK HWT C - 442. Some finish operations as drilling were handmade. Mold is prepared for further research.

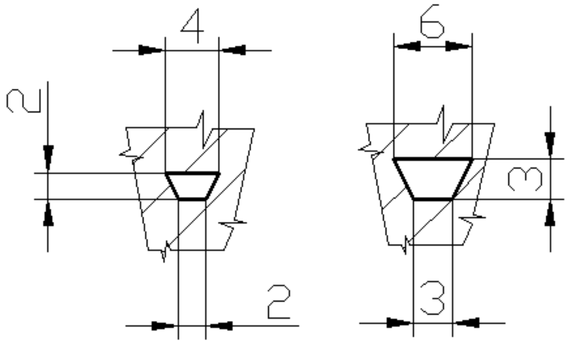

Fig.5 Section dimensions of runners

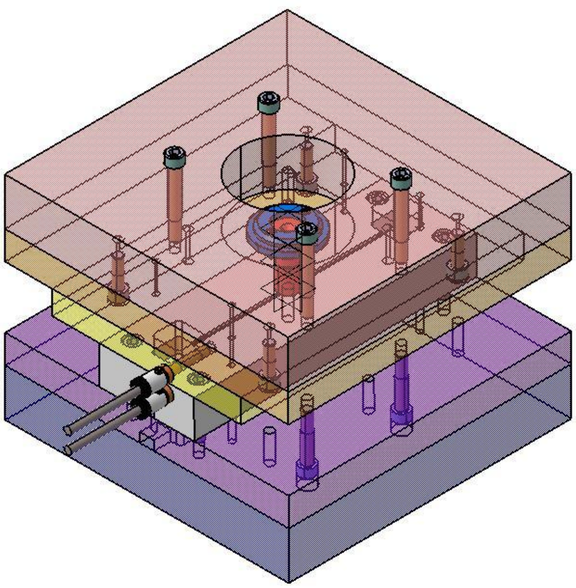

Fig.6 Model of assembled mold

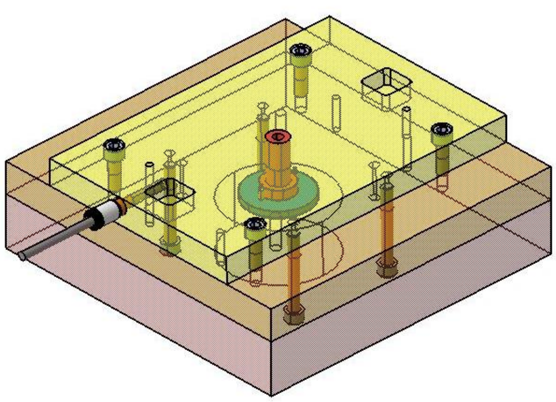

Fig.7 Model of upper part of mold

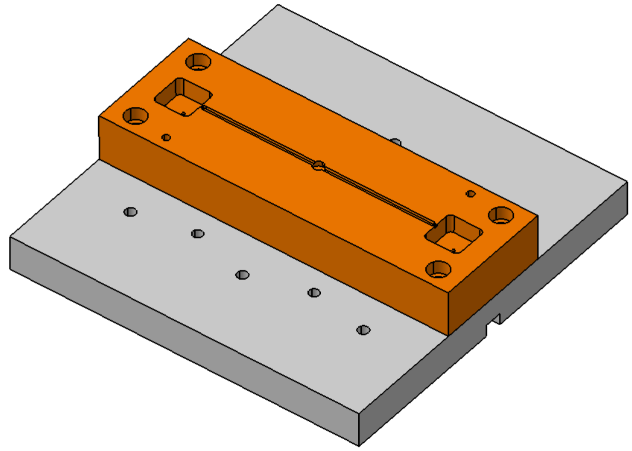

Fig.8 Universal frame with cavity plate (lower part)

III. Analysis of Injection Molding Process

These analyses of injection molding process were set for injecting on injection molding machine REP V27/Y125. It was analyzed in computational software Cadmould Rubber.

Fig.9 Injection molding machine REP V27/Y125

Tab.2 Machine parameters

Diameter of Screw	20 mm
Clamping force	57 kN
Max. volume of material	125 cm3

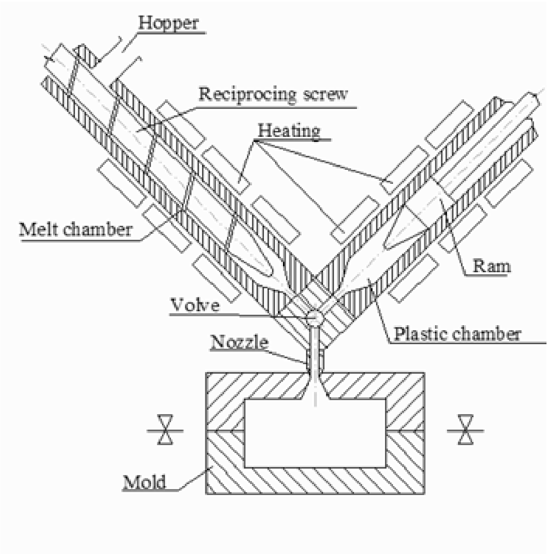

Fig.10 Schema of REP V27/Y125 machine

The complexity of today's plastic parts as well as the costs, quality and competition pressure makes maximizing every opportunity available to improving the production process a necessity rather than a choice. Injection molding is the primary process for conversion of plastic materials into components used in industrial and consumer applications, and CAE enables the simulation and analysis of this molding process. It has been available for over two decades, affording time to refine the technology.

Process simulation and analysis software like Cadmould and Moldflow use fundamental principles and scientific data unique to each material to compute the flow behaviour of the melt during the process. One of the important principles is that of Rheology, which involves the study of the flow and deformation of matter. In order to understand and control any process involving the transfer of fluids it is necessary to know how that fluid behaves under different conditions of temperature and pressure etc. The behavior of polymer melts under the influence of shear is very complex since they tend to be highly non-Newtonian; i.e. they do not obey Newton's Law of viscous flow. The viscosity of a polymer melt is therefore not constant but is highly dependent on the rate of strain. CAE programs provide a flexible and economical means of recognizing potential errors early in the design and production process. The information gained from the simulation can assist in the optimization of the process, like cutting down cycle time, or part weight. It can also support the molder in fixing certain problems, which would otherwise have to be solved by trial-and-error- methods, which consume significant amounts of time, and waste material and energy.

As it was told earlier for computational analysis Cadmould Rubber software was chosen. One of the reasons for choosing was easy receiving material data. Each compound is a mixture of rubber and additives. Each compound has different material characteristics. With help of Rheometr RPA 2000 we can measure material characteristic. First is viscosity which is used for flow analyses and second is cure curve for cure analysis.

Temperature and curing closely related together and it is important to know these values during elastomeric compound injection molding process. Software Cadmould Rubber has great advantage that it can show the temperature and percentage of crossed-links in each moment during injection molding cycle and in the individual layers of the product. It is necessary to consider how many layers use before setting analyze. With large number of layers time of computing increase rapidly on the other hand the results are more accurate.

In the two following pictures there can be seen quality of computational mesh. Mesh was checked by mesh statistic command. Mesh seems to be all right as for narrow as for wide trajectories.

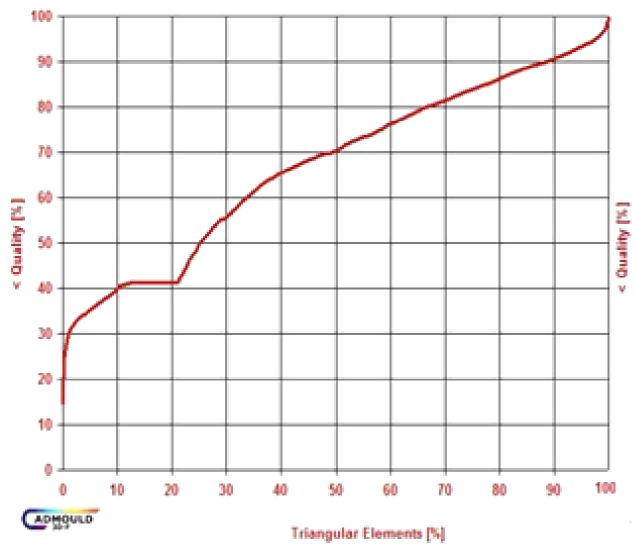

Fig.11 Mesh quality for narrows runners

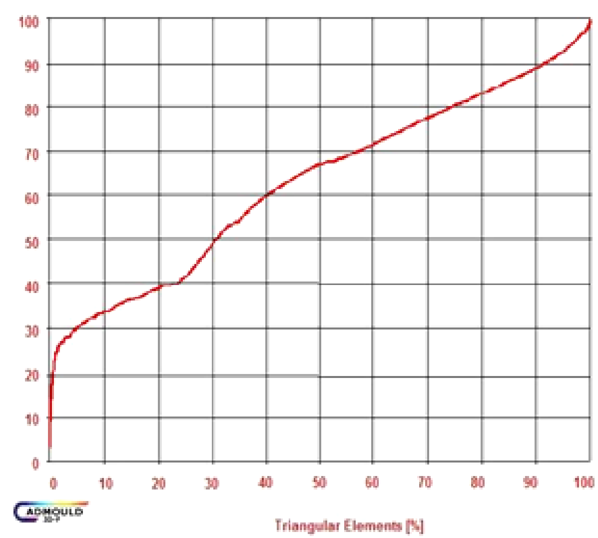

Fig.12 Mesh quality for wide runners

It is good to know how elastomeric compound behaves in each place in cavity. Sensors can be help for the better understanding of injection molding process and they are right tools to show behavior of material in the section of part.

Cadmould Rubber can render results of pressure, temperature, viscosity, shear rate and cure rate which are important for receiving final properties of elastomeric product.

Fig.13 Rheometer RPA 2000

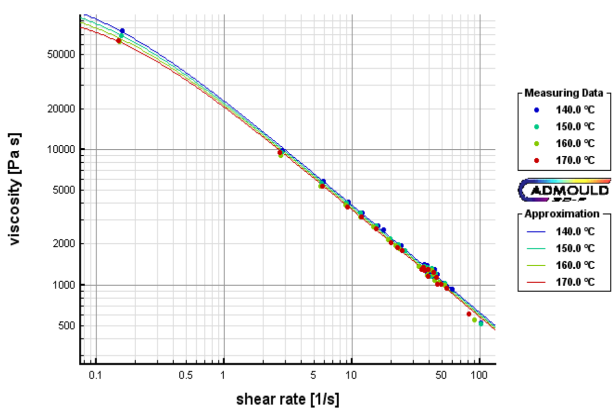

Fig.14 Viscosity vs. Shear rate

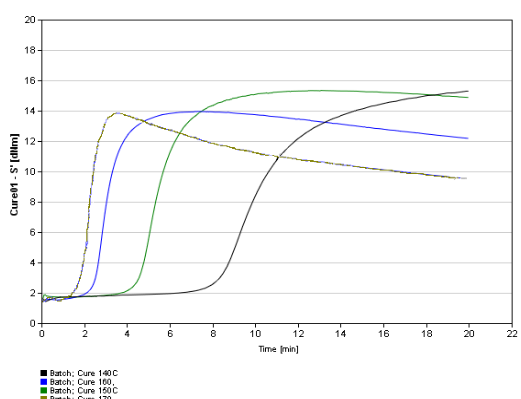

Fig.15 Cure data

IV. Setting of Injection Molding Process

Filling time depended on flow rate which was caused by a speed of moving of piston in machine. It was changed 2 mm per second to 50 mm per second as can be seen in Table 3.

After the filling a cavity pressure should be changed to holding pressure. In this case holding pressure wasn't used.

When the cavity was filled the vulcanization of material continued for 600 second. In analyses was set 200 second of post-curing at the end. All setting parameters can be seen in Table 3.

There was measured optimum of vulcanization it is time of 90% cure rate in this research and results were compared for each changing of flow rate, mold temperature and type of runners.

Cure rate was measured in the middle of cube as it can be seen in Figures 16,17,18,19,. It was the place where the material was affected by heating at the last time.

Tab.3 Process parameters

Filling time	s	*changed*
Pressure - controlled filling	[%]	99
Mass temperature	°C	100
Mold temperature	°C	*changed*
Heating	s	600
Post curing	s	200

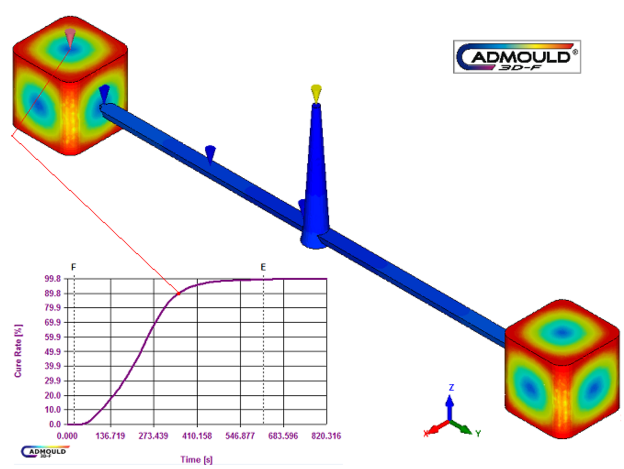

Fig.16 Straight and wide trajectory

In the cure rate graph there can be seen the time, when material is croslinked in 90%. These times were entered to bar charts bellows. This analysis were made for tree temperatures (160°C, 170°C,180°C). Each analyze takes some about 35 minutes. There was used four core computer with eight giga rams.

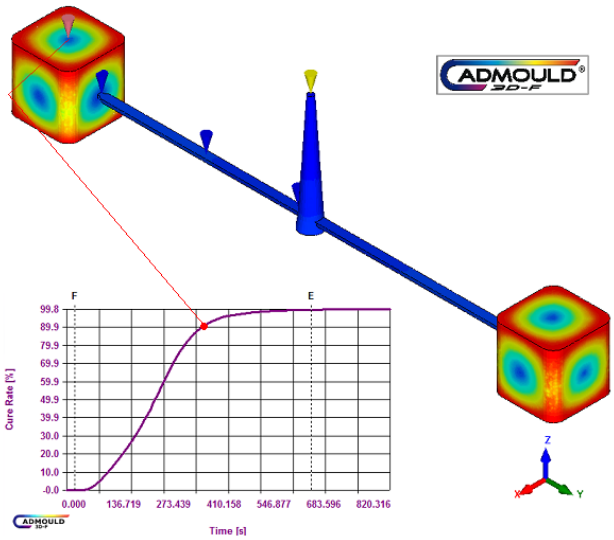

Fig.17 Straight and narrow trajectory

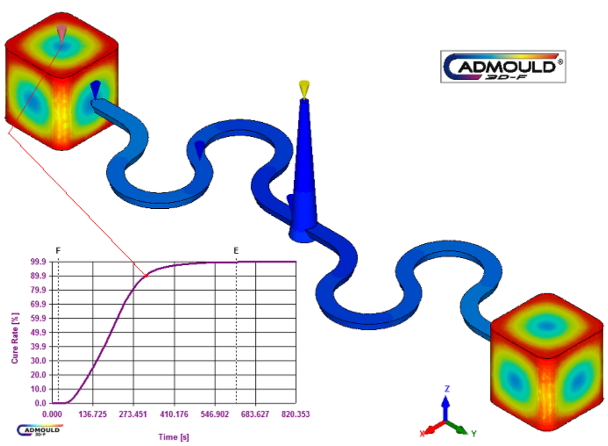

Fig.18 Curved and wide trajectory

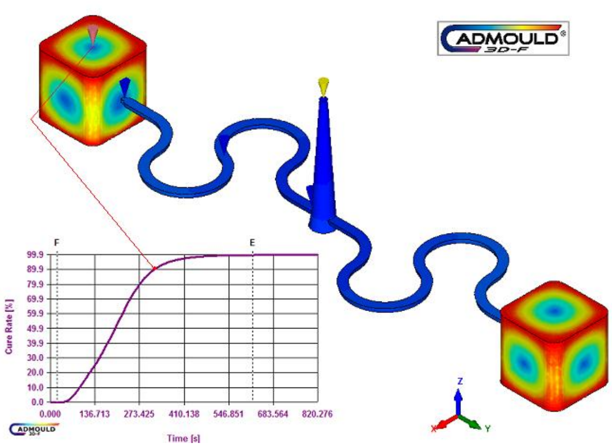

Fig.19 Curved and narrow trajectory

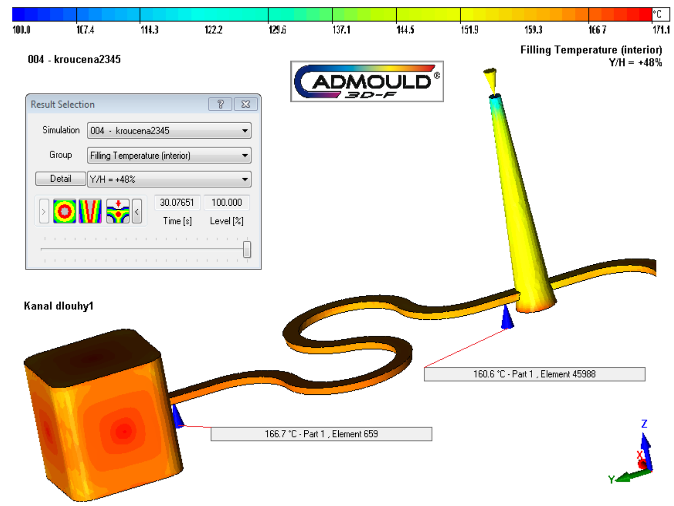

Fig.20 Receiving temperature on the cover of runner in computational analysis in Cadmould rubber software

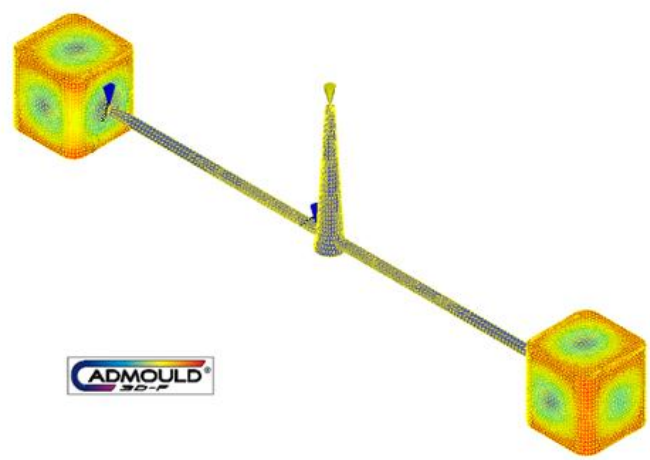

Fig.21 Sample of meshed product

V. Results

Melt is intensively heated by the wall of the mold it causes material vulcanization (cure rate).

Material is very affected by the small flow rate in the first column at chart, but the rate is too small that time for 90% cure rate is high.

The best results show second column. In this case material has small flow rate and it is intensively heated. In the rest of columns time rises. These tendencies are given by heating from mold wall and dissipation inside material.

Narrow runner has better results than wide runner in all cases. In the most cases the value is from 4 s to 8 s. As it can be seen in the figures bellow.

The shortest time is 189,9 s for curved narrow trajectory in T=180°C. For the same width in straight (shorter) channel in T=180°C value of 90% cure rate is 247,1 s. This difference is 57,2s. This difference can be seen with using small flow rate. Difference in higher flow rate is not so extensive, it is from 10 to 20 seconds. Between 160°C and 180°C difference is more than 150 seconds.

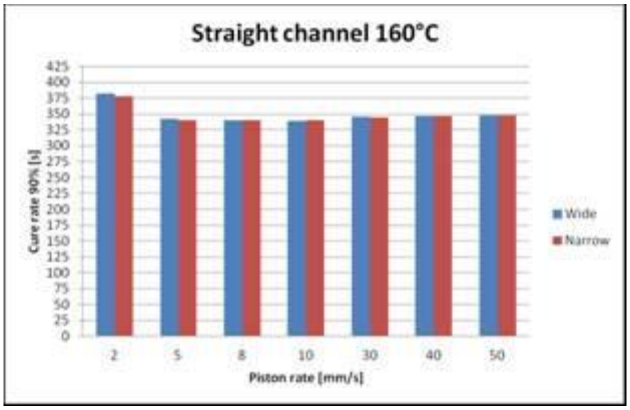

Fig.22 Results for straight channel, T=160°C

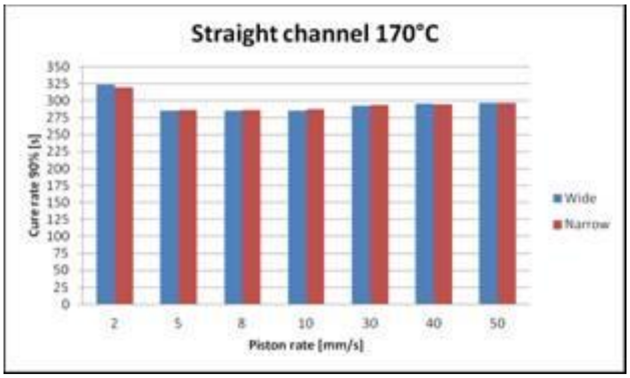

Fig.23 Results for straight channel, T=170°C

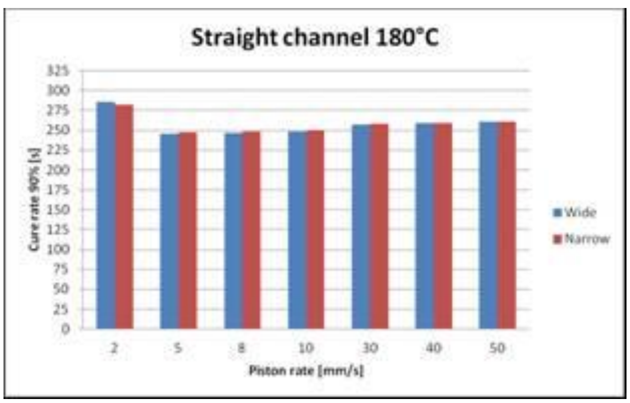

Fig.24 Results for straight channel, T=180°C

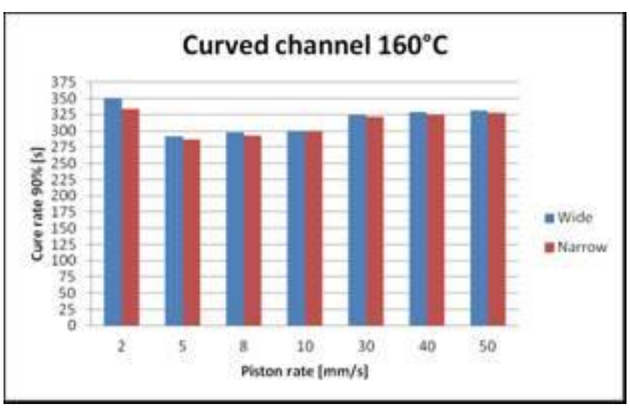

Fig.25 Results for curved channel, T=160°C

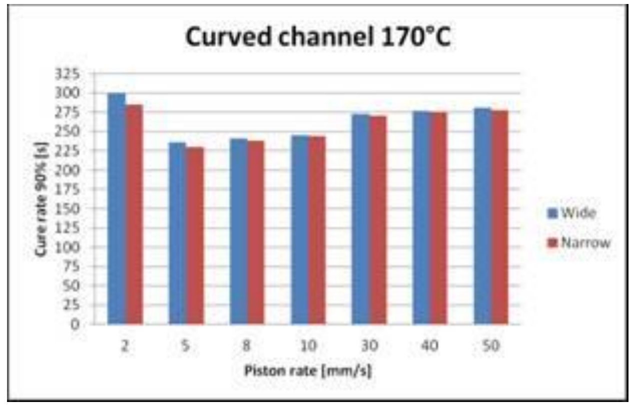

Fig.26 Results for curved channel, T=170°C

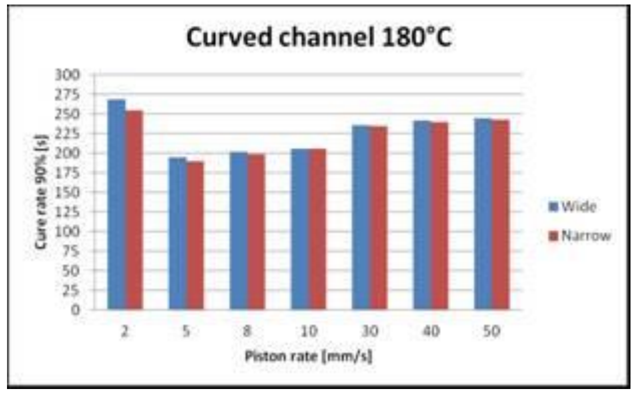

Fig.27 Results for curved channel, T=180°C

VI. Conclusion

During manufacturing and assembling there have to be kept rules which are done by producer. Mold maker have to watch out for assembling sensors to prepared hole. Hole have to be correctly drilled and polish.

Cross linking of elastomeric compound depends on temperature, pressure and time. For shorting of time of vulcanization can be achieved by changing other parameters (temperature and pressure). Pressure depends on injection flow rate and product volume. Shortening of time of vulcanization rapidly leads to save energy. This saving can be reduce by right setting parameters at the injection molding machine or right choosing of trajectory of runners (length and width) at mold and their combination. This paper showed influences on changes temperature, flow rate and trajectories. It is crucial to find right combination of mentioned parameters. Cadmould rubber software can be right tool how to save time, energy or expenses.

Many product engineers shorts injection time for shorting of cycle. There is showed that lower flow rate shorts cure time and whole cycle. Optimum of vulcanization in 90% of cure rate was achieved in the lower flow rate. Differences between width is smaller than difference between length. Time period of Injection molding process can be reduced with the right choice of length, width and setting parameters. Saving time rises with multi cavity mold.

ACKNOWLEDGMENT

This paper is supported by the internal grant of TBU in Zlin No. IGA/FT/2012/041 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.

References

[1] 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

[2] 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

[3] 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

[4] 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

[5] 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

[6] 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

[7] 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

[8] 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

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

[10] 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.

[11] 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.

[12] 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.

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

[14] 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.

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

[16] 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.

[17] 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

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

[19] M. Stanek, M. Manas, D. Manas, S. Sanda, "Plastics Parts Design Supported by Reverse Engineering and Rapid Prototyping", *Chemické listy*, Volume 103, 2009, p.88-91

[20] S. Sanda, M. Manas, D. Manas, M. Stanek, V. Senkerik Gate Effect on Quality of Injected Part", *Chemicke listy*, Volume 105, 2011, pp.301-303

[21] M. Stanek, M. Manas, D. Manas, V. Pata, S. Sanda, V. Senkerik, A. Skrobak, "How the Filler Influence the Fluidity of Polymer", *Chemicke listy*, Volume 105, 2011, pp.303-305

[22] Z. Holik, M. Danek, M. Manas, J. Cerny, "The Influence of Cross-linking Agent on Mechanical Properties of Polyamide Modified by Irradiation Cross-linking", *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Spain, 2011, pp.222-225.

[23] Z. Holik, K. Kyas, M. Krumal, J. Cerny, M. Danek, "Improvement of Polypropylene Properties", *21st International DAAAM Symposium*, 2010, Zadar, Croatia, p. 1191-1192.

[24] H. Charvatova, D. Janacova, K. Kolomaznik, "Non-Stationary Temperature Field in a Plane Plate for Symmetric and Asymmetric Problem", *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Canary Islands 2011, p.277-281

[25] D. Janacova, H. Charvatova, K. Kolomaznik, V. Vasek, P. Mokrejs, "Solving of Non-Stationary Heat Transfer in a Plane Plate", *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Canary Islands 2011, p.287-291

[26] D. Janacova, H. Charvatova, V. Vasek, K. Kolomaznik, P. Mokrejs, "Modeling of non-stationary heat field in a plane plate for assymetric problem", *in 14th WSEAS International Conference on Systems. Latest Trands on Systems*, Volume II, Rhodos, 2010.

[27] M. Stanek, D. Manas, M. Manas, J. Javorik, "Simulation of Injection Molding Process," *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, p.231-234.

[28] H. Vaskova, V. Kresalek, „Raman Spectroscopy of Epoxy Resin Crosslinking", *in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands 2011, p.357-360.

[29] 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.

[30] 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.

[31] 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.

[32] [26] 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.

[33] [27] V. Pata, D. Manas, M. Manas, M. Stanek, "Visulation of the Wear Test of Rubber Materials", *Chemicke listy*, Volume 105, 2011, pp.290-292

[34] [30] 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.

[35] [31] 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.

[36] J. Dolinay, P. Dostalek, V. Vasek, P. Vrba, "Teaching Platform for Lessons of Embedded Systems Programming*", in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.158-161.

[37] R. Prokop, N. Volkova, Z. Prokopova, "Tracking and Disturbance Attenuation for Unstable Systems: Algebraic*", in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.161-164.

[38] M. Stanek, M. Manas, T. Drga, D. Manas, "Polymer Fluidity Testing", *17th DAAAM International Symposium: Intelligent Manufacturing & Automation: Focus on Mechatronics and Robotics*, Vienna, Austria, 2006, p.395-396