Measuring of Temperature and Pressure in Injection Mold

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

Abstract— Injection molding is one of the most widespread technologies in polymer process. This technology has enough advantages in rubber industry too. This article compare results from temperature/pressure sensors in real process with flow analyses in computational software. These received dates should be helpful and advantageous for the polymeric industry, especially rubber industry. The product's production cycle can be shorted with right setting of process. Using sensors and flow analyze can be good way for right process setting.

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).
Jakub Cerny is with the Tomas Bata University in Zlin, nam. T. G. Masaryka 5555, 76001 Zlin, Czech Republic (e-mail: j1cerny@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).

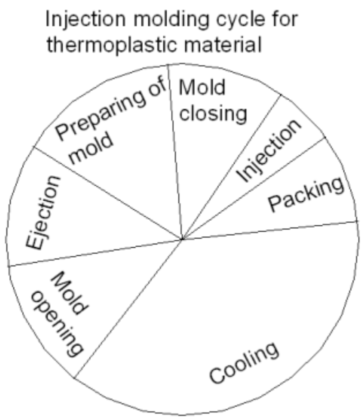

Fig.1 Thermoplastic injection molding cycle

Fig.2 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. Design of Mold

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 was used long type of runners as it is showed in Fig. 3. This type is curved and its length is 200 mm. Mold cavity is a cube with dimension 30 x 30 x 30 mm. It is prepared for testing influence of setting parameters on finally properties for the further research.

Part with runners can be seen in Fig. For this part was designed injection mold. After designing injection mold was manufactured. Each plate was manufacture in 3 axis CNC machine AZK HWT C - 442. Finish operations as drilling holes for sensors were handmade.

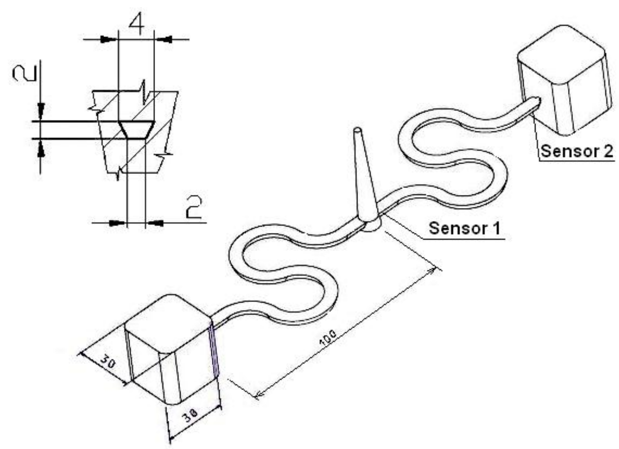

Fig.3 Injected product

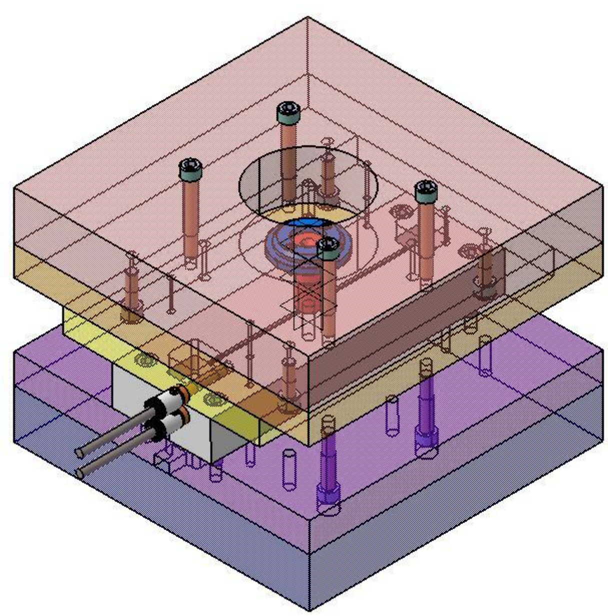

Fig.4 Model of assembled mold

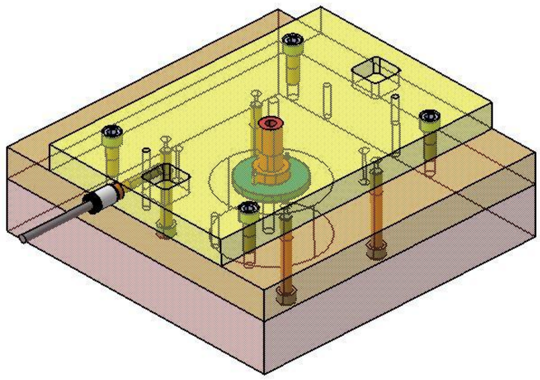

Fig.5 Model of upper part of mold

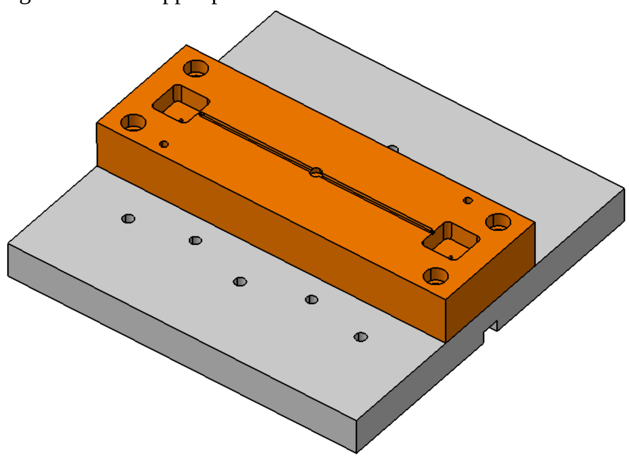

Fig.6 Universal frame with cavity plate (lower part)

Fig.7 CNC machine AZK HWT C - 442

Fig.8 Manufactured cavity plate

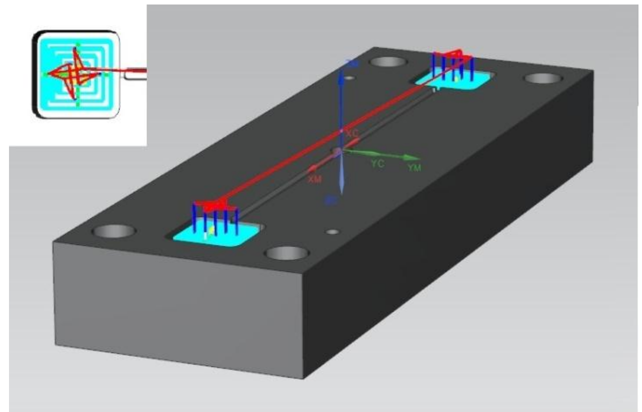

Fig.9 Roughness manufacturing of cavity

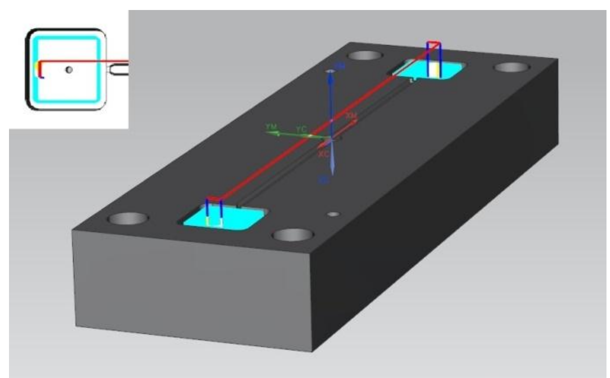

Fig.10 Finishing of cavity

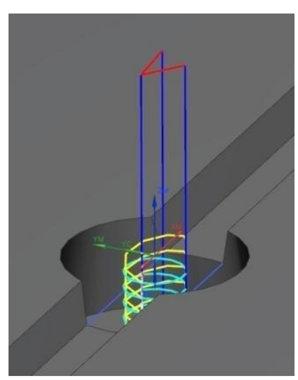

Fig.11 Example of drilling

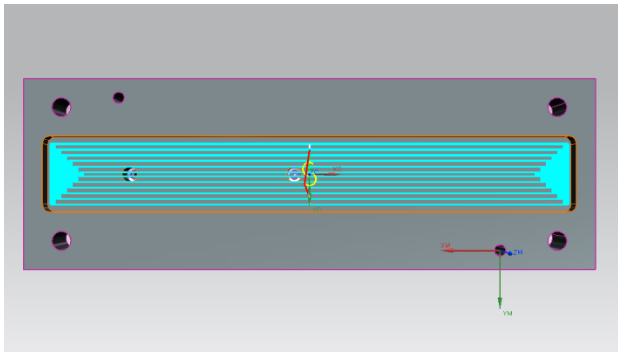

Fig.12 Roughening space for sensors

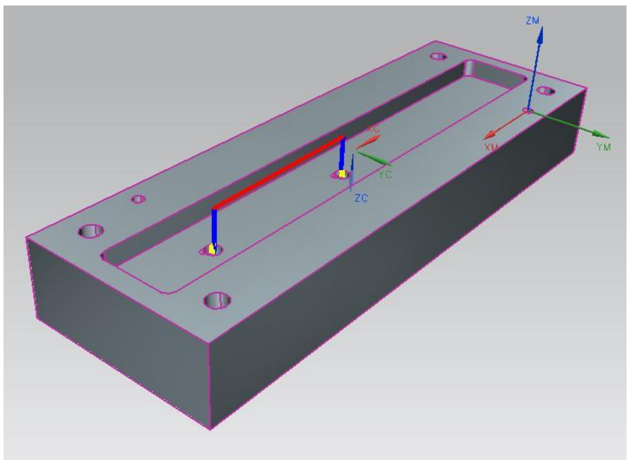

Fig.13 Drilling holes for sensors

This mentioned injection mold is supplied with two temperature/pressure sensors in begin and in the end of the runner as it can be seen in figure. There are dimensions and size comparing with safety match in the Fig.16. Measuring range of these sensors can be seen in the following table.

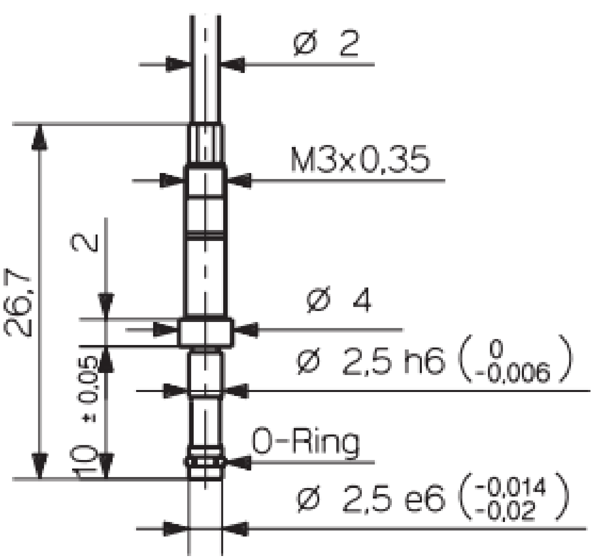

Fig.14 Dimension of sensor

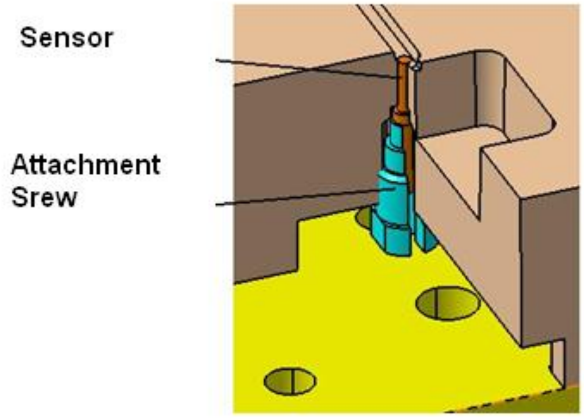

Fig.15 Attached sensor in runner

Fig.16 Comparing with safety match

Tab.2 Two cavity injection mold

Measuring range	bar	0 - 2000
Overload	bar	2500
Sensitivity	pC/bar	-6.5
Melt temperature	°C	<450
Tooling temperature	°C	0 - 200
Temperature connector	°C	0 - 200

There can be seen assembly of two cavity mold with sensors in the figure 4. It consists of upper and lower parts which are divided by split line. Runners are situated to lower part and there are pressure/temperature sensors too. These sensors are connected with computers. In special software can be worked with measured dates.

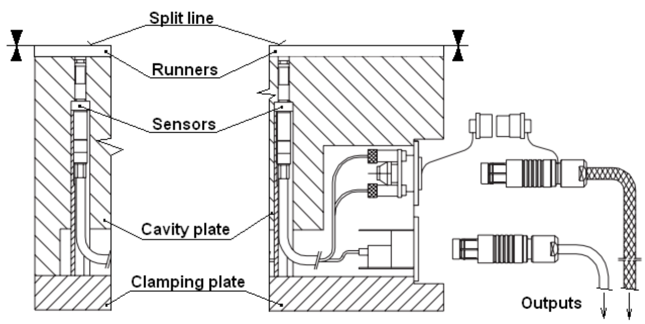

Fig.17 Situation sensors in mold

Fig.18 Injection molding machine REP V27/Y125

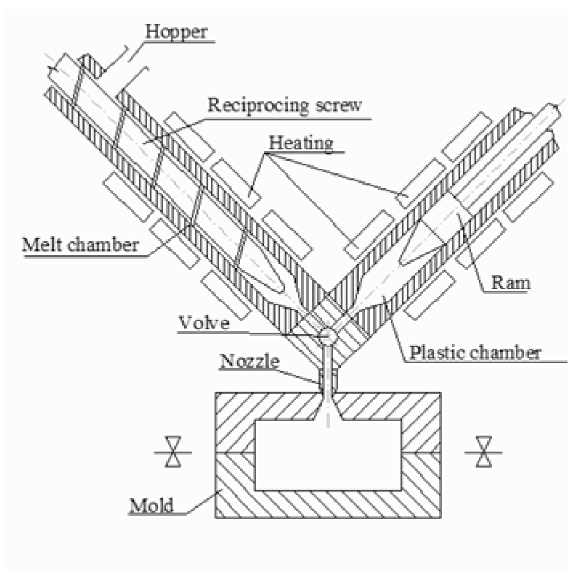

Fig.19 Schema of REP V27/Y125 machine

III. Setting of Injection Molding Process

Injection molding process was realized on vertical injection molding machine REP V27/Y125.

Filling time depended on flow rate. It was nearly 35 seconds. After the filling a cavity pressure was changed to holding pressure on 250 bar at first setting and 100 bar in second setting. It takes for other 25 seconds as it can be seen in tables below. After Injection and holding temperature and pressure was stable and vulcanization continued. More process parameters can be seen in Table 2, Table 3 and Table 4.

Tab.3 First setting of process

Flow rate	mm/s	5
Holding pressure	bar	250
Holding time	s	25
Melt temperature	°C	100
Mold temperature	°C	170
Vulcanization time	s	600

Tab.4 Second setting of process

Flow rate	mm/s	5
Holding pressure	bar	100
Holding time	s	25
Melt temperature	°C	100
Mold temperature	°C	170
Vulcanization time	s	600

Tab.5 Third setting of process

Flow rate	mm/s	5
Holding pressure	bar	70
Holding time	s	25
Melt temperature	°C	100
Mold temperature	°C	170
Vulcanization time	s	600

IV. Anallysis of Injection Molding Process

This research is supported by simulations of injection molding process which was set as in real process on REP V27/Y125. It was analyzed in Cadmould Rubber software.

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 analyses. With large number of layers time of computing increase rapidly on the other hand the results are more accurate.

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.

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.

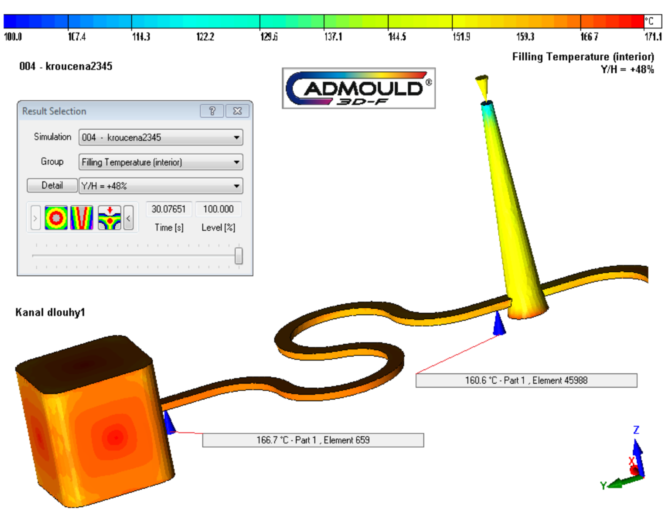

Fig.20 Sample of computational analysis in Cadmould rubber software

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.

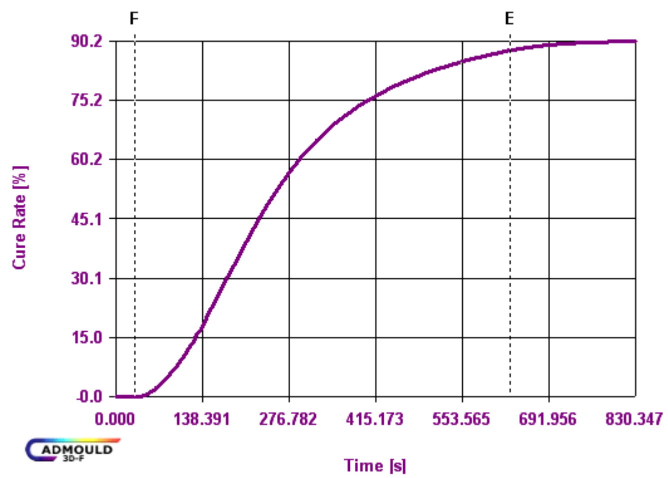

Fig.21 Sample of Cure curve Cadmould rubber software for this issue

V. Problem Solution

Melt is intensively heated by the wall of the mold as it can be seen in upper part of Fig.5 and Fig.6. More interesting is lower part of figure where is showed pressure in begin and in the end of runner.

Injection molding machine showed that injection pressure which is depended on flow rate is is 200 bars (It is a value in injection molding machine caused by piston). It starts rising on the beginning of runner (Sensor 1). Pressure, which is created in the beginning, is more than 700 bars and falls down to 50 bars in the end of runner in the both case.

After filling cavity machine changes pressure to holding pressure. In the first case holding pressure was higher and in second case was lower than filling pressure. In the diagrams there can be seen differences between courses in both cases in time. Higher holding pressure didn't have good effect on the shape of final part.

As it was told earlier this measuring was supported by flow analysis as it can be seen in Fig. 7. Cadmould rubber software shows similar tendency as a real process. Especially temperatures in beginning and in the end are nearly the same as in real process. As it was told with the help of computed analyses it can be received more important results as a temperature in the middle of the section of runner which is difficult to receive by measuring by sensors.

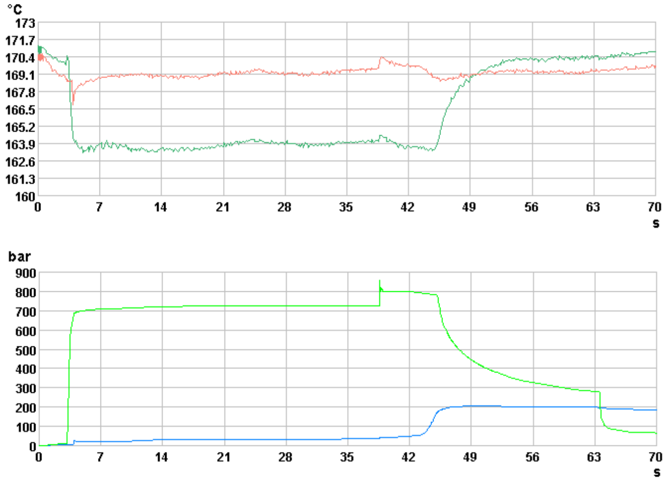

Fig.22 First results from sensors

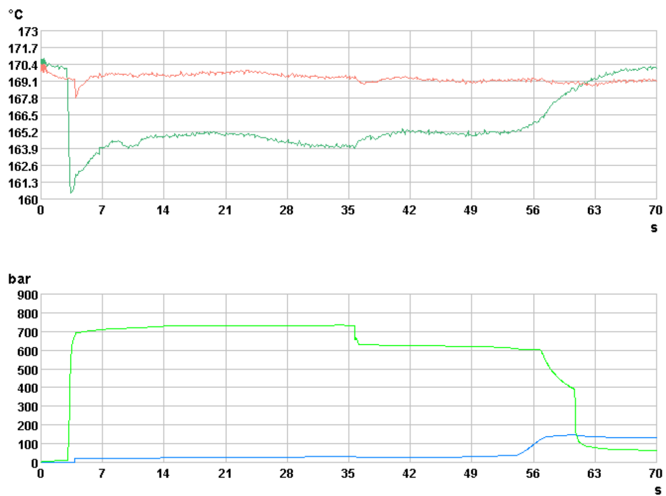

Fig.23 Second results from sensors

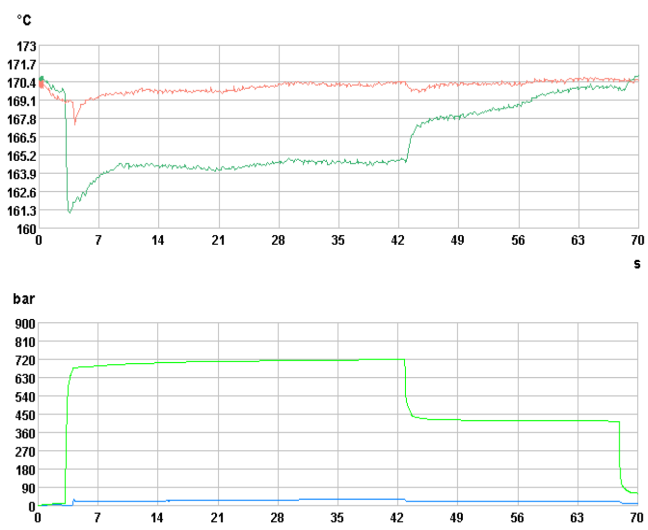

Fig.24 Third results from sensors

Fig.25 Illustration of manufacturing of cavity

Fig.26 Sample of Cure curve Cadmould rubber software for this issue

VI. Conclusion

Final product from injection molding process of rubber must be full cross liked. Crosslinking 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). Shortening of time of vulcanization rapidly leads to save energy. Maybe this time can be shorted by engineering change as can be change of trajectory of runner. These sensors can be used to somehow kind of mold or to somehow place in mold. This mold is prepared for further research.

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.

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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