Simulation of Injection Molding Process by Cadmould Rubber

M. Stanek, D. Manas, M. Manas and J. Javorik

***Abstract*—**Simulation analyses of plastics injection molding are a tool for increasing the quality of plastic products and tools, equipment used for shortening the time necessary for preparation of new products for the market and hence leading to lowering production costs. The simulation analyses are nowadays commonly used for production of thermoplastic parts. This article stresses on the fact that injection molding of rubber compounds could be from the calculation purposes analysed already in the constructive phase during the preparation of the production to achieve positive assets, till now related only to the thermoplastic parts.

***Keywords*—**Injection molding, Simulation, Compound, Process, Mold.

I. Introduction

POLYMER injection molding is the most used technology of polymer processing nowadays. It enables the manufacture of final products, which do not require any further operations. Injection molding reduces the time required for curing; eliminates the need to preform the rubber prior to molding; reduces the amount of mold handling and scrap in comparison with compression molding. On the other hand it is very sophisticated and complicated process. For its simulation could be used specials software. One of them is Cadmould Rubber.

Cadmould Rubber is the software generally called Computer Aided Engineering (CAE). It calculates the filling time, speed and vulcanization time in the mold and consequent after-curing depending on the material used and technological parameters. One of the most important outputs is, besides the representation of filling progress (weld lines, places where air bubbles may be held), the representation of pressure and voltage ratios in the component and determination of optimum technology.

The technological parameters during rubber processing have crucial impact on the final quality of the product; simultaneously it is possible to project adequate period of the production cycle which may lead to significant savings. Original and patented calculative FEM net is worth mentioning, automatically prepared by Cadmould Rubber software, its features likened to complex 3D FEM meshes, however enabling markedly faster calculations even though the thinnest walls are in their thickness divided into 25 calculation knots. This feature allows a very precise analysis having the possibility to carry out range of control calculations.

Cadmould Rubber enables designing different profiles of the runner system including the possibility of cold runners. It is possible to calculate multiple and compound molds, eventually apply the function of entering symmetrical cavities in the mold shortening the time needed for simulation calculations.

The injection molding is a cyclical process, each cycle comprising 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 heating of rubber compound inside the mold, mold opening and ejection or removing of molded part. In figure 1 there is shown time influence for each parts of cycle.

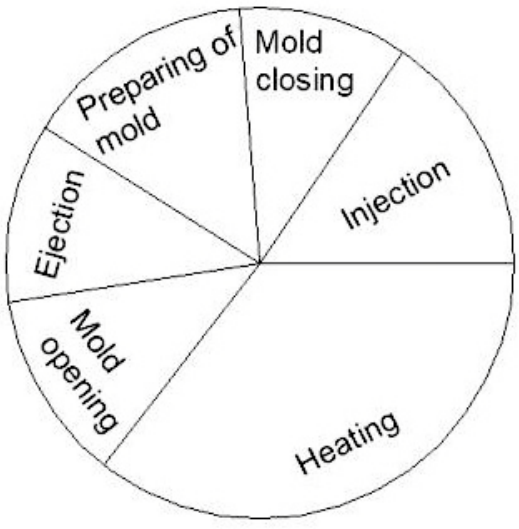

Fig. 1 Rubber injection molding cycle

Manuscript received June 29, 2011: Revised version received June 28, 2011. This work was supported in part by by the Ministry of Education, Youth and Sports of the Czech Republic under the Research Plan No. MSM 7088352102 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@ft.utb.cz).

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

II. Enter Data for the Simulation

A. Part Design

The basic file format used by the Cadmould Rubber analysis is the STL. The part design to be simulated is converted into this format. STL is the default document for automatic net formation of the final elements. Even though the simulation software uses very good correction features, it is beneficial – also, besides other, due to the calculating times – to use STL file without crucial mistakes for the analysis, especially without gaps and without immersed false constructions. In most of the CAD software, the features used for creation of good transfer are of STL format.

Nevertheless, not only the Cadmould software users, who do not have any CAD software, benefit from the software for creations and corrections of STL format, for instance 3Data Expert for STL, produced by DeskArtes. Fig. 2 shows an example of STL construction of a rubber part – Insulator – and automatically processed calculating net. A denser calculating net is created on the places of wall connection on the corresponding surfaces for more effective evaluation of potential sink marks.

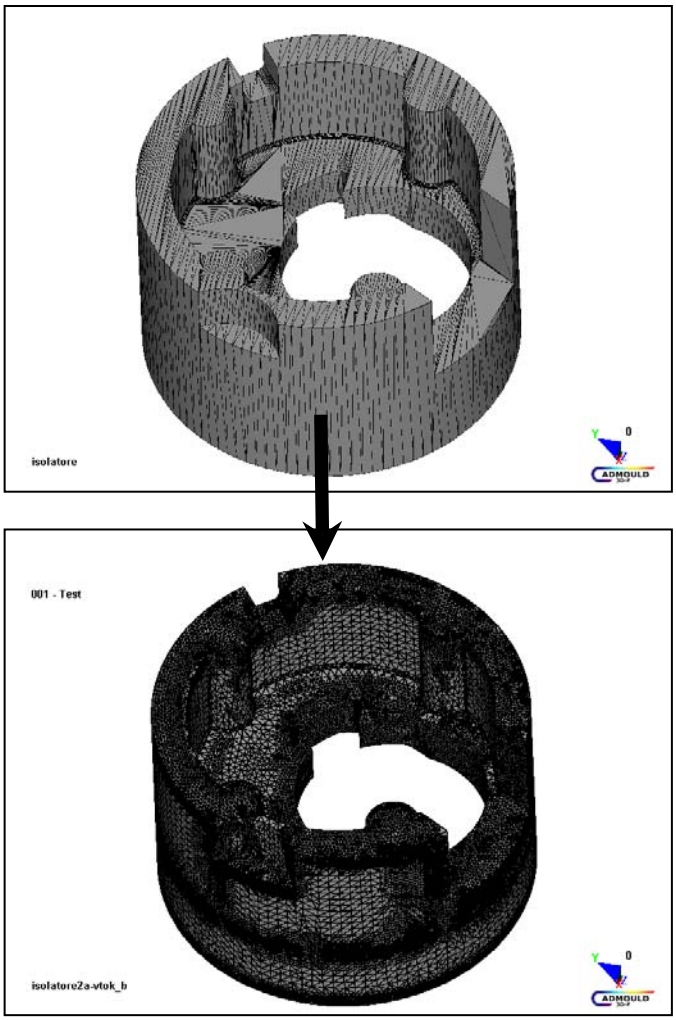

Fig. 2 STL model and calculating mesh Cadmould 3D-F of the insulator component

B. Runner System Design

With respect to the requirements of the customer, the user may create (according to his experience or template) runner system directly in Cadmould Rubber. It has got prepared smart constructive tools for this purpose with all necessary options.

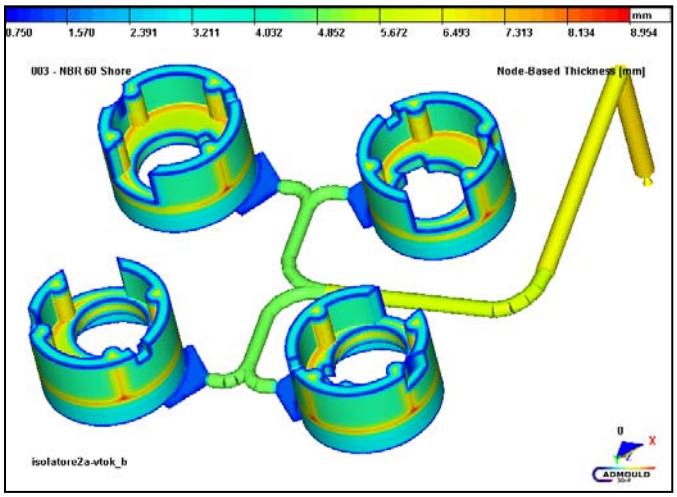

Fig. 3 Runner system for 4 shaping cavities

In case the runners are already designed in CAD, they may be saved as axis in IGES format and transferred to calculating software. The program user easily “wraps” the axis by canals of required diameter. An example of runner system for 4 shaping cavities is shown in Fig. 3.

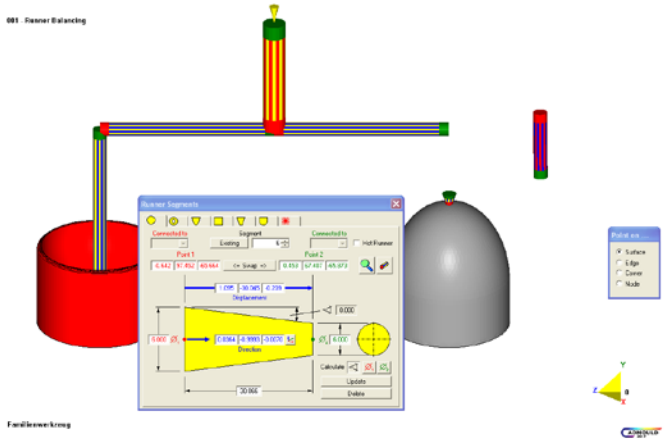

Fig. 4 Runner system creator

D. Part Material

It is necessary to enter the exact rubber type from the material database Cadmould Rubber into the simulation calculations, which is editable by the user.

However, it is beneficial to know approximate material data essential for the calculations. As it was told, rubber compound consist of different additives and different quantities, therefore each compound is the "original" and they have differences at

flow characteristics and its behavior. These properties can be measured for example by Rubber Process Analyzer (RPA 2000).

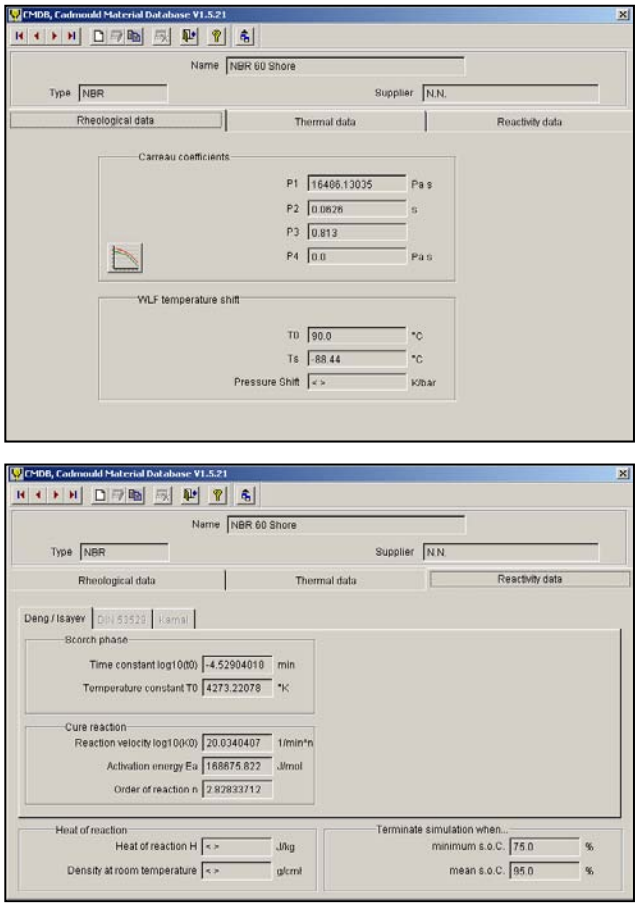

Fig. 5 Material data list from the database

The amount sample of compounds should be approximately 100 g. These prepared samples of rubber compound which weighs about 5 g is placed into the measuring device and is closed by force 15 kN. Top and bottom side of the injection mold are heated with accuracy ± 0.3 °C.

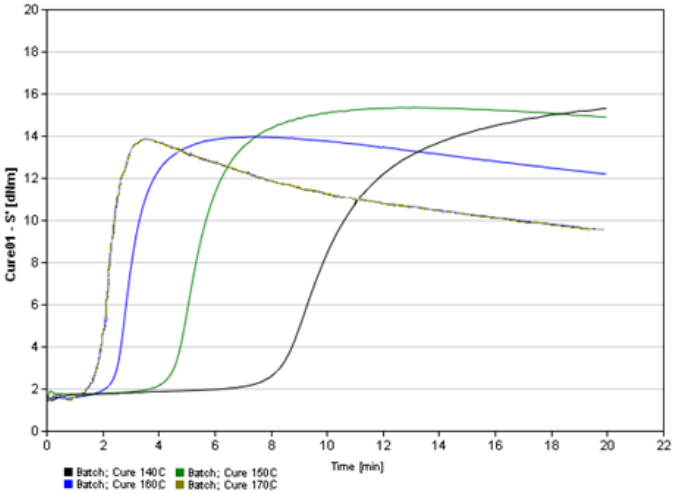

Fig. 6 Cure rate for different temperatures

The rubber compound contained vulcanization system is used for measuring the curing characteristics (Fig. 5) and without the vulcanization system is used for measuring the complex dynamic viscosity (Fig. 6).

These data are processed and imported to Cadmould Rubber program, where the analysis of injection molding process can be done now with real material (rubber compound).

These data are processed and imported to Cadmould Rubber program, where the analysis of injection molding process can be done now with real material.

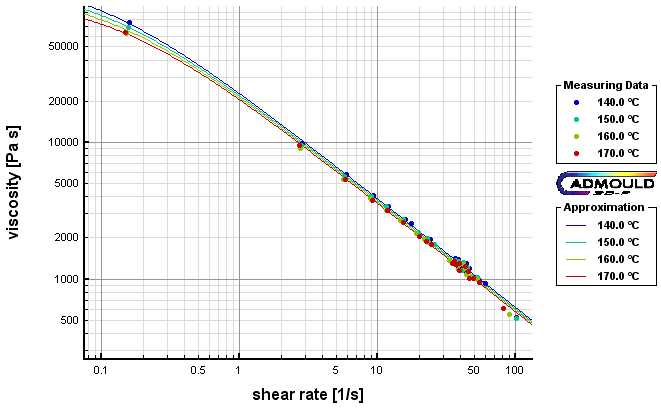

Fig. 7 Viscosity for different temperatures

E. Technological Parameters of the Process

The determination of technological parameters is one of the outputs of the Cadmould Rubber simulation analyses. It is necessary to enter the whole estimated data for the first calculation to take place. These data are specified in the following calculations. It is however possible to input variations of chosen technological data and carry out automatic optimization of the technology in cases where is difficult to make prediction.

Overview of technological data:

- filling time,
- temperature of the injected rubber material (preset value),
- mold temperature (preset value) – temperature spread on the shaping cavities surface area may be calculated using the Cadmould Cool/Heating software,
- curing time, eventually min. and max. percentage of vulcanized bonds,
- ambient temperature (preset value),
- temperature transfer coefficient (preset value),
- post-curing time outside the mold, eventually minimal and maximal percentage of vulcanized bonds.

III. Some Results of Cadmould Rubber Calculations

Cadmould Rubber software offers many figures and graphical and table results, which may help the user analyses entered task. The results are available also in 3D cuts and animations. It is possible to generate the report. Some of them are stated below.

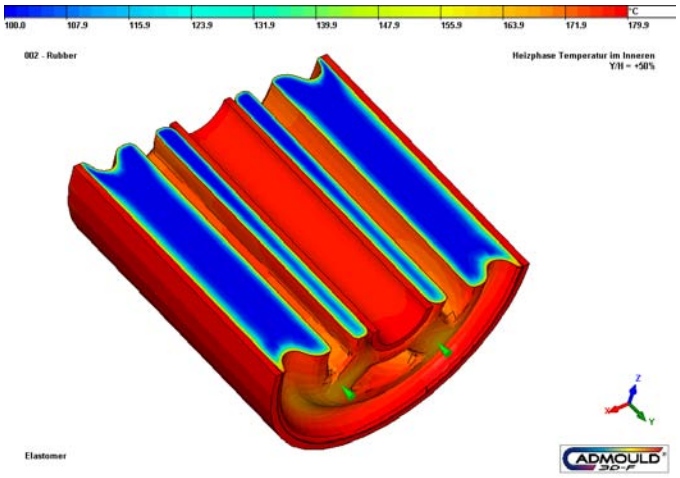

Fig. 8 3D cut of the part example

A. Filling Progress, Filling Pressure and Material Temperature

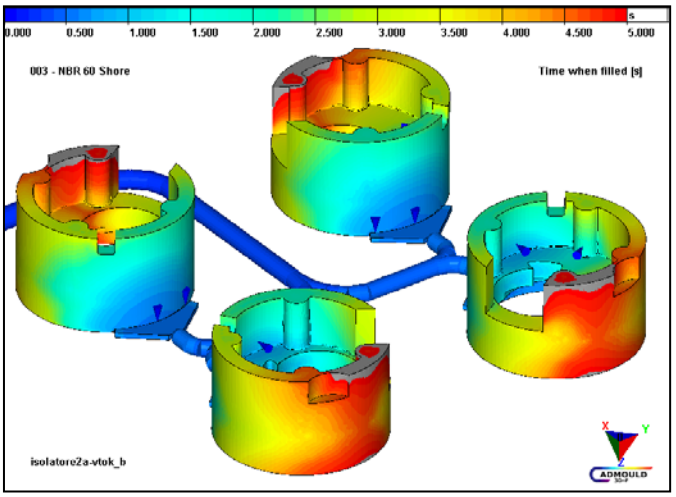

Fig. 9 Time progress of filling,
state at 99.1% shaping cavity filling

Figure 9 shows the filling phase progress. Filling progress analysis can determine the position of weld lines, places liable to trapped air; places filled the last, places with incorrect filling progress etc.

There is possible to observing the injection pressure in each moment of cavity filling. The example is shown on Fig. 10. Average temperature of the material in wall thickness at the time = 208 s of the curing time is shown on Fig. 12.

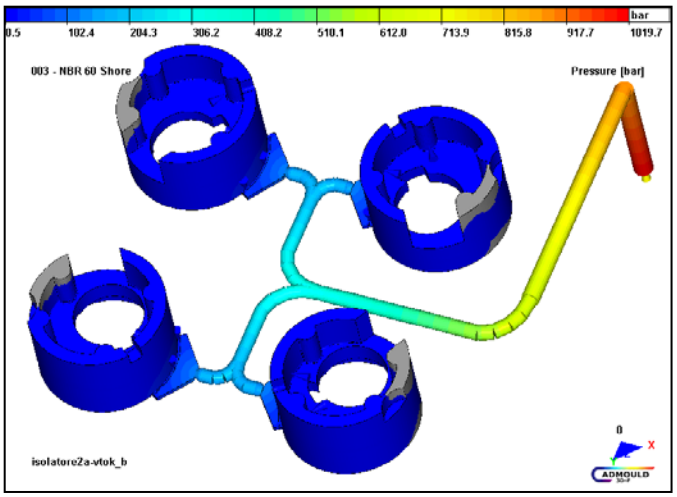

Fig. 10 Filling pressure,
state at 98% shaping cavity filling

B. Scorch

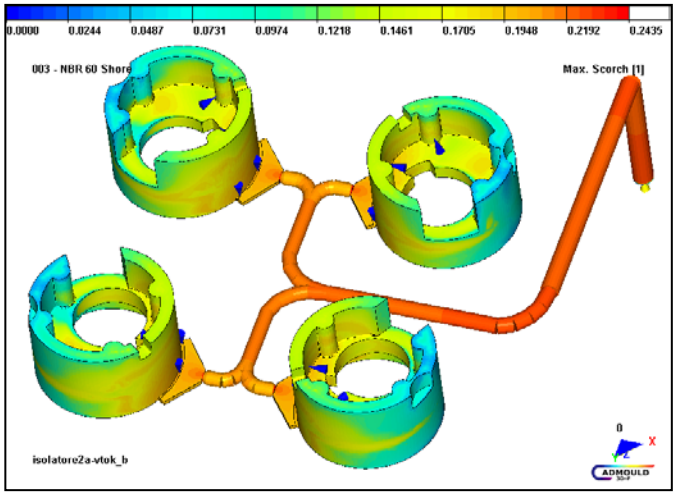

Fig. 11 Maximal scorch at the end of filling time

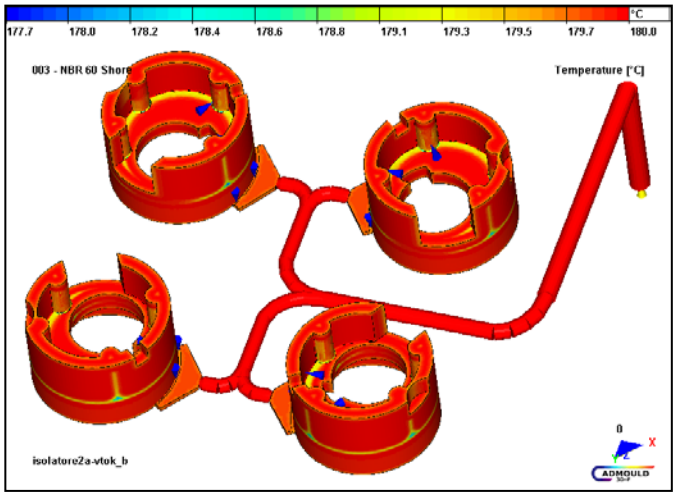

Fig. 12 Temperature of the material
in 208 s with cure time

The scorch expresses above all time period during which the rubber mixture may be injected into the shaping cavities. Max. scorch = max. drop of filling safety: values related to the end of the filling time.

Scorch time progress in the most crucial places of the shaping cavity (here the minimal scorch = minim safety drop time progress). Middle value of scorch time progress at the chosen point in the shape.

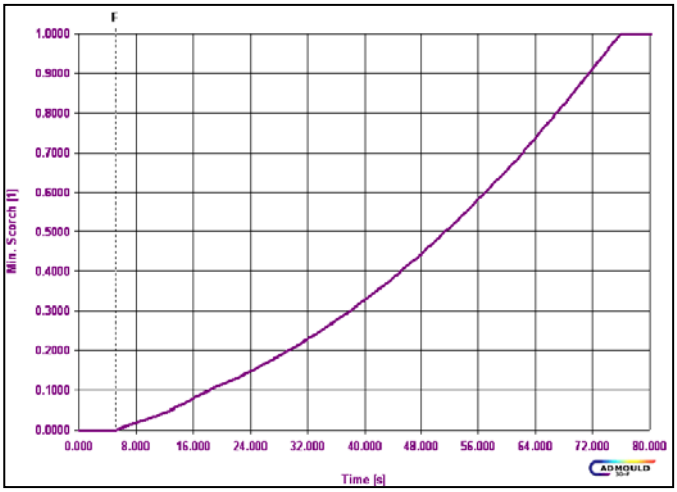

Fig. 13 Time progress of scorch of rubber compound – minimal scorch

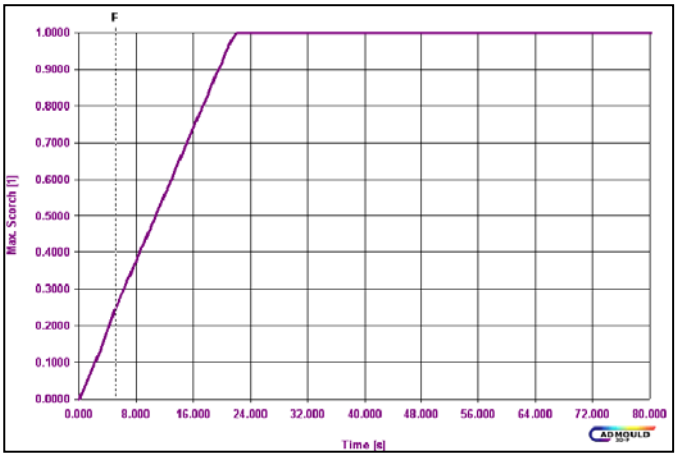

Fig. 14 Time progress of scorch of rubber compound – maximal scorch

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

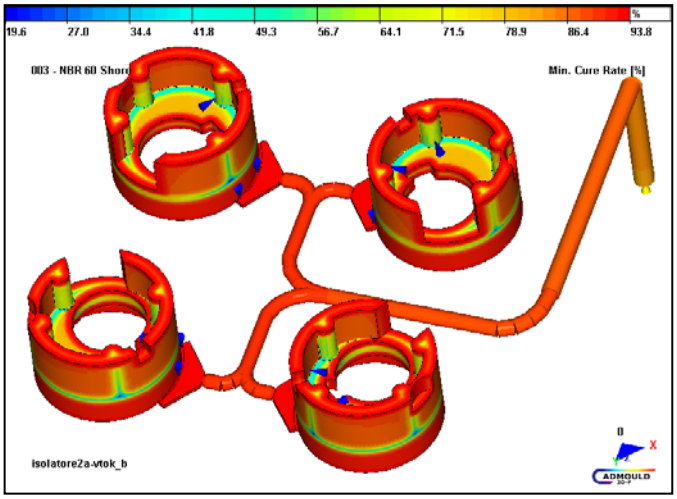

Fig. 15 Cure rate expressed by middle % of vulcanized bonds in 208 s, % vulcanized bonds in the wall thickness and time progress in the middle safety value at the selected spot

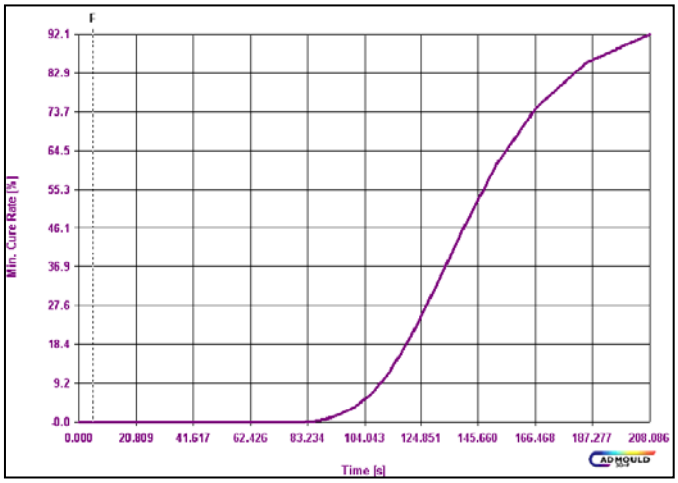

Fig. 16 Time progress of scorch of rubber compound – minimal cure rate

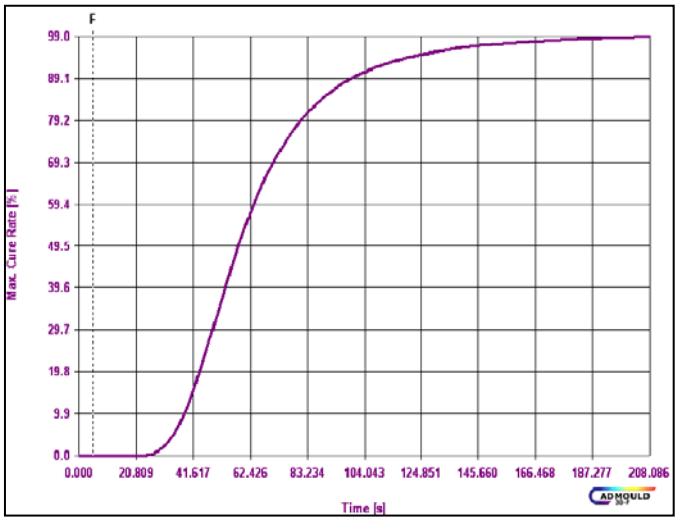

Fig. 17 Time progress of scorch of rubber compound – maximal cure rate

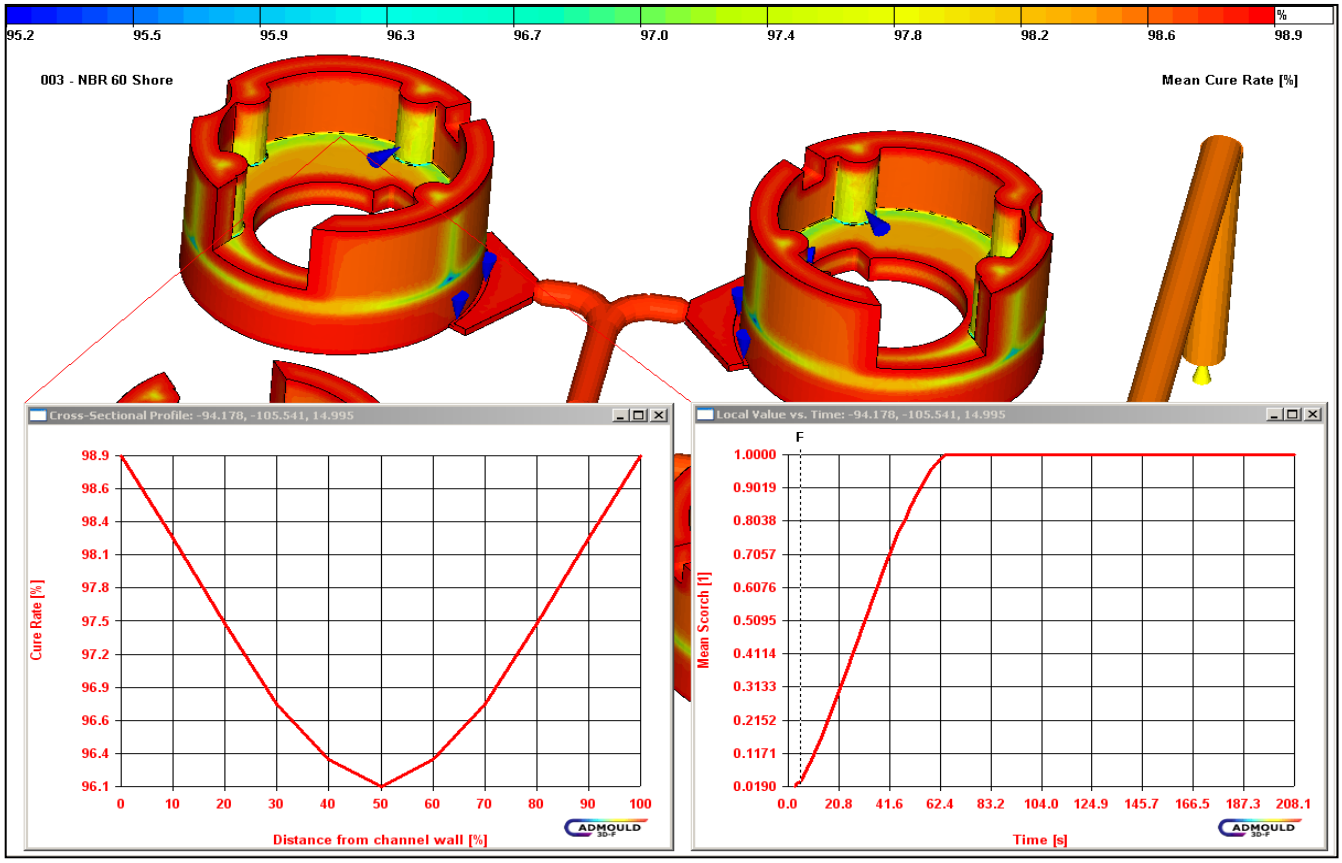

Fig. 18 Cure rate expressed by middle % of vulcanized bonds in 208 s, % vulcanized bonds in the wall thickness and time progress in the middle safety value at the selected spot

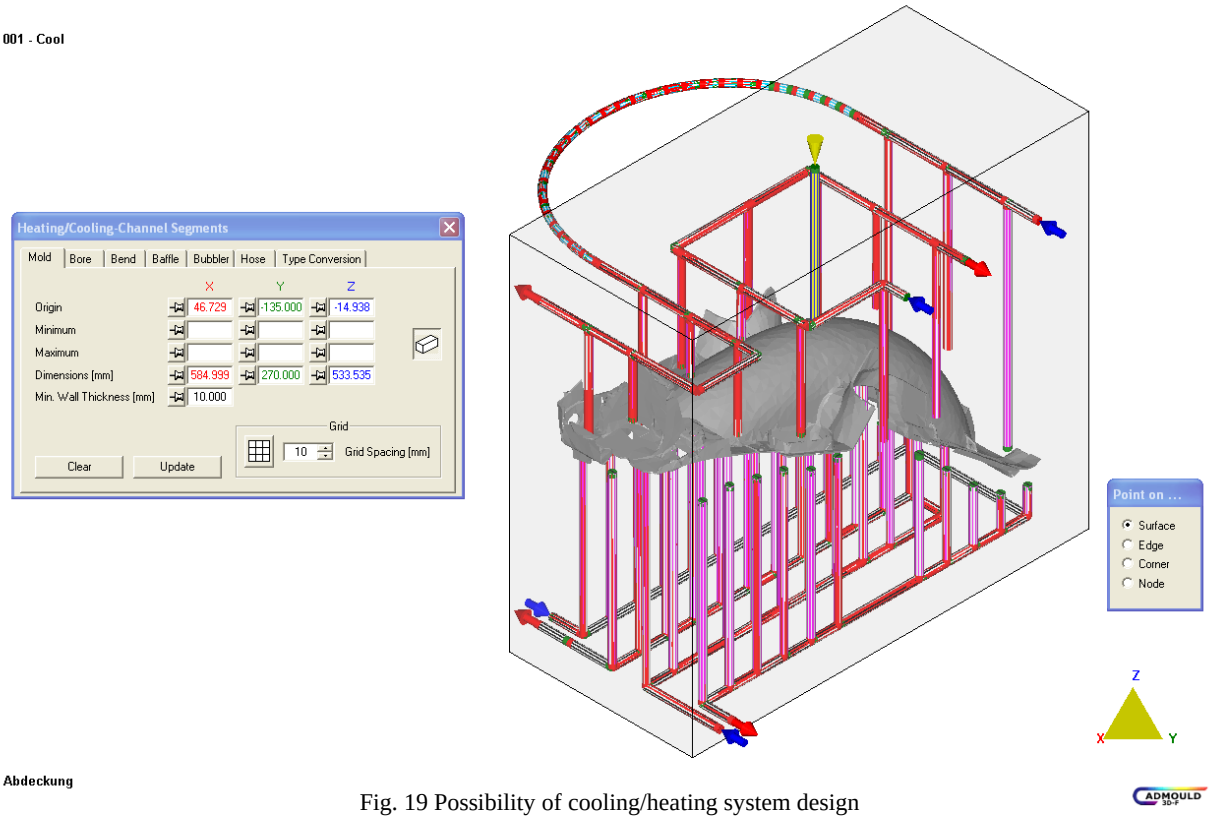

Fig. 19 Possibility of cooling/heating system design

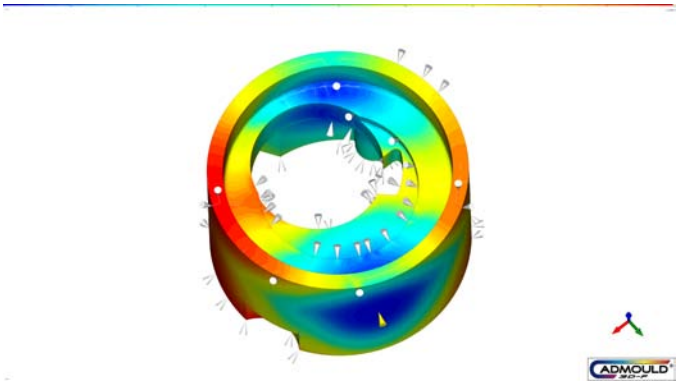

Fig. 20 Visualization of the air traps

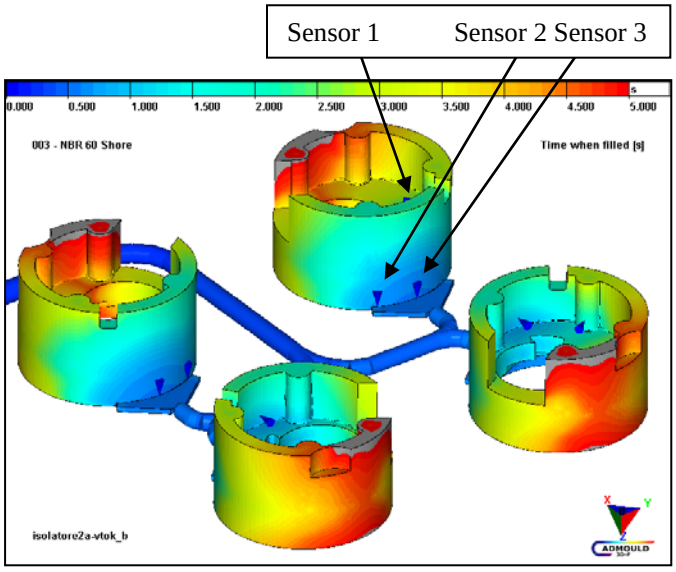

Fig. 21 Places of sensors

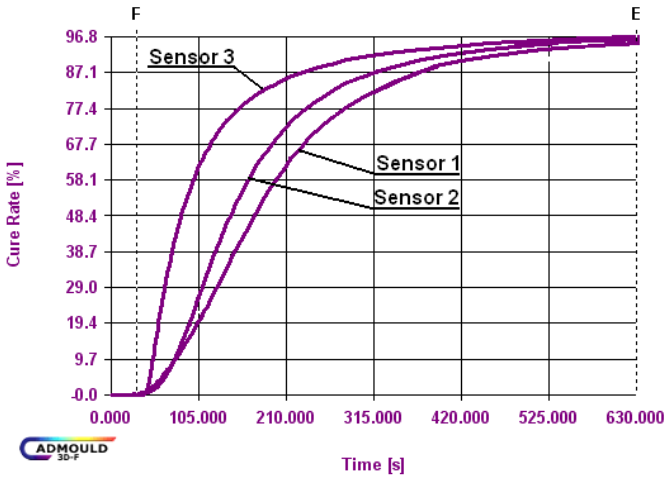

Fig. 22 Cure rate for each sensor

On a figure 21 there is shown a detail of part. For the better understanding of injection moulding process is necessary to know how elastomeric compound behave in each places of part and sensors are right tools to show behaviour of material. It can rendered results of pressure, temperature, viscosity, shear rate and in figure 6 there are rendered curves of cure rate for each of used sensors.

These results can help to set up rubber injection molding cycles of injection molding machine. Especially cure rate is necessary for setting of the longest and most energy-consuming cycles and it is heating time which can takes a few minutes in comparison with plastic injection molding cycle (seconds).

IV. Conclusion

The simulation analysis Cadmould Rubber represents quality and interesting calculation tool which may increase the quality of injected rubber parts, cut the costs connected to the mold repair and accelerate the preparations of new productions especially new tool design. It is evident from the experience with the situation analyses that it is better to analyze than try and repair.

In behalf of advantages rubber injection molding simulations could be refer:

- Significant cost and time saving
- Cost and time saving by optimization of machine utilisation ratio, extension of mold lifetime, improved labour allocation and reduction of start-up scrap
- Reduction of delivery times (set-up, initiation and down times)
- Reduction of injection mold trial loops
- Evalution of variants in early design stages concerning functionallity, design as well as injection molding and heating time optimised realisation
- More precise evalution of the project costs
- Early detection of possible problems (FMEA) and elimination of failure causes
- Support of injection mold and produced part cost assessment
- Faster and better founded quotation assessment and preparation
- Professional presentation at the customer to be able to adapt to customer wishes on side
- Better nogotiation position by filling patterns, air trap, curing distribution and history, etc.
- Easy to use - fast to learn.

Acknowledgment

This article is financially supported by the Ministry of Education, Youth and Sports of the Czech Republic under the Research Plan No. MSM 7088352102 and by the European Regional Development Fund under the project CEBIA-Tech No. CZ.1.05/2.1.00/03.0089.

REFERENCES

[1] 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

[2] 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

[3] 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

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

[5] 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.

[6] 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.

[7] J. Javorik, Z. Dvorak, "Equibiaxial test of elastomers," *KGK – Kautschuk Gummi Kunststoffe*, issue 11, vol. 60, 2007, pp. 608-610.

[8] 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.

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

[10] 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

[11] 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

[12] 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.

[13] 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.

[14] 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.

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

[16] 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.

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

[18] 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.

[19] Simcon Kunststofftechnische Software GmbH. Available: http://www.simcon-worldwide.com

[20] 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.

[21] 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.

[22] 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.

[23] 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.

[24] 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, Lanzarote, Canary Islands, 2011, p.212-215.

[25] M. Stanek, D. Manas, M. Manas, J. Javorik, "Simulation of Injection Molding Process", *in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands, 2011, p.231-235.

[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.

[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

[28] 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

[29] 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

[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.

[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.

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

[33] 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.

[34] 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.

[35] 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

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

[37] 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

[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

[39] 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

[40] M. Stanek, M. Manas, T. Drga, D. Manas, "Influence of Mold Cavity Surface on Fluidity of Plastics", Chapter 55 *in DAAAM International Scientific Book 2007*, DAAAM International, Vienna, Austria p.627-642

[41] D. Manas, M. Stanek, M. Manas, "Workability and Wear of Rubber Parts", Chapter 54 *in DAAAM International Scientific Book 2007*, Published by DAAAM International, DAAAM International, Vienna, Austria, p.611-626