Influence of Runner section on Curing Rate during Injection Molding of NBR Compound

K. Kyas, M. Stanek, A. Skrobak, M. Manas, D. Manas, M. Reznicek, V. Senkerik

Abstract— Right used computational analyses are commonly good tool for technical industry to improve process. This paper show using computational analysis during injection molding process. With using two different shape and two different section dimensions of injection molding channel there is shorted cycle time for product which is represented by 30 mm cube. Results show the save of time for different temperatures of injection mold. 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 thermoplastic polymers. [2,4 - 38]

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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 Differences between thermoplastic and elastomeric polymers.

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

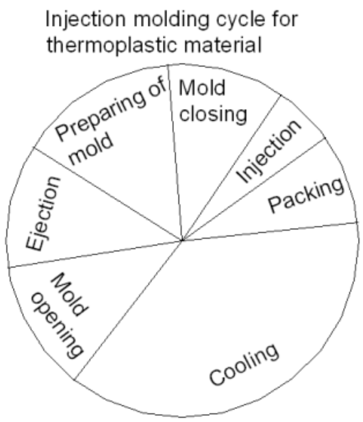

Fig.1 Thermoplastic injection molding cycle

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.

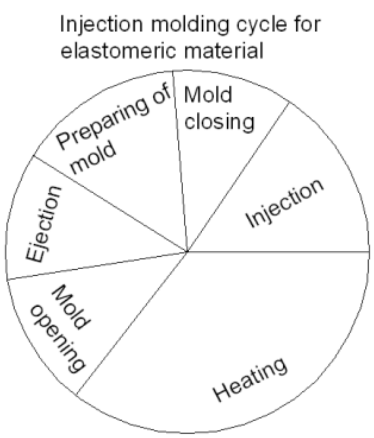

Fig.2 Elastomeric injection molding cycle

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. DESING OF MOLD AND TESTING SAMPLE

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 designed two cavity injection molds for this experiment. There were used trapeze and circular runners with two difference dimensions. 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.

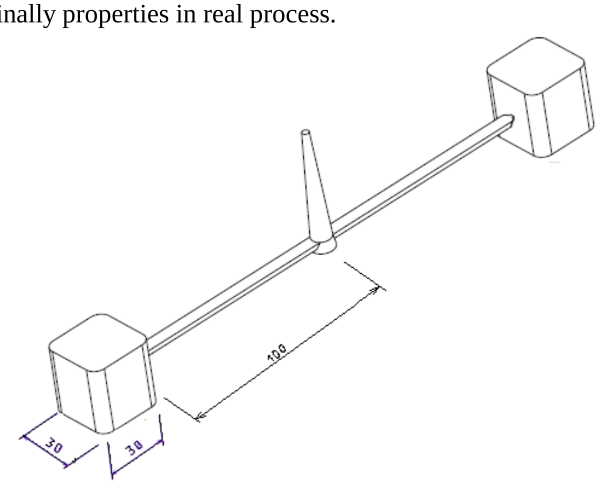

Fig.3 Dimensions of product and runners

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 on convectional machines. Mold is prepared for further research.

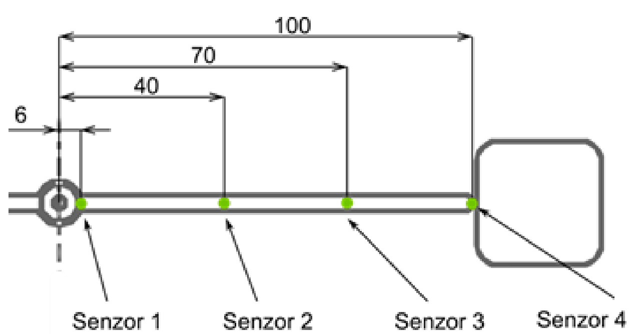

Fig.4 Dimensions of runner with used sensors

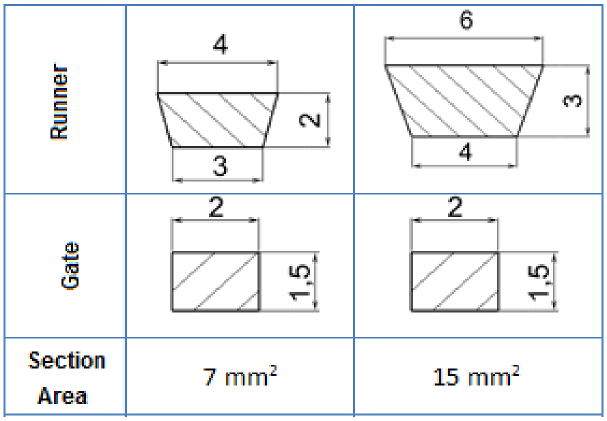

Fig.5 Narrow and wide trapeze runner

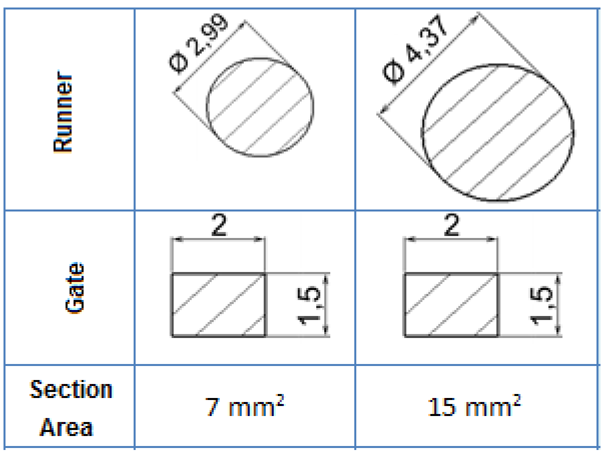

Fig.6 Narrow and wide circular runner

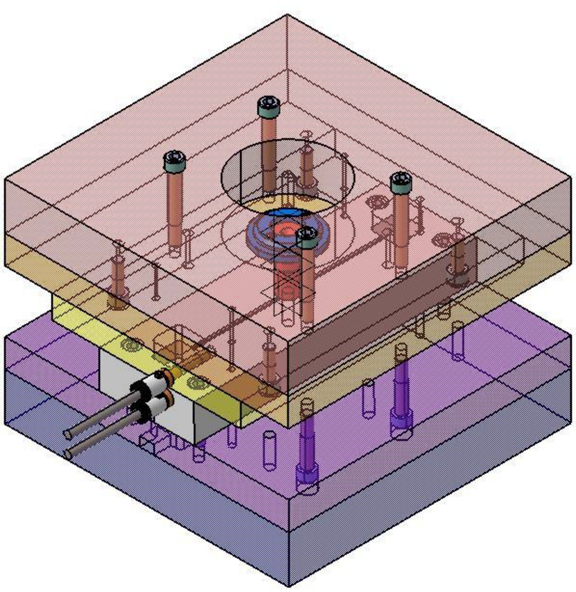

Fig.7 Model of assembled mold

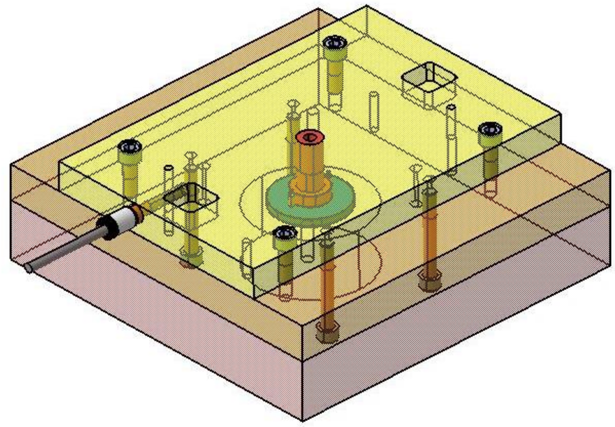

Fig.8 Model of upper part of mold

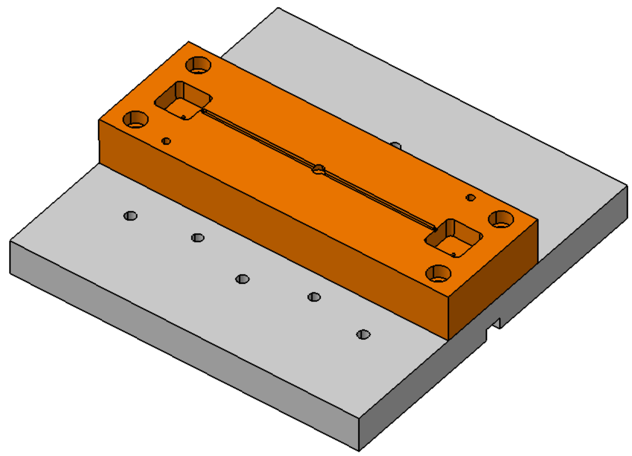

Fig.9 Universal frame with cavity plate (lower part)

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.

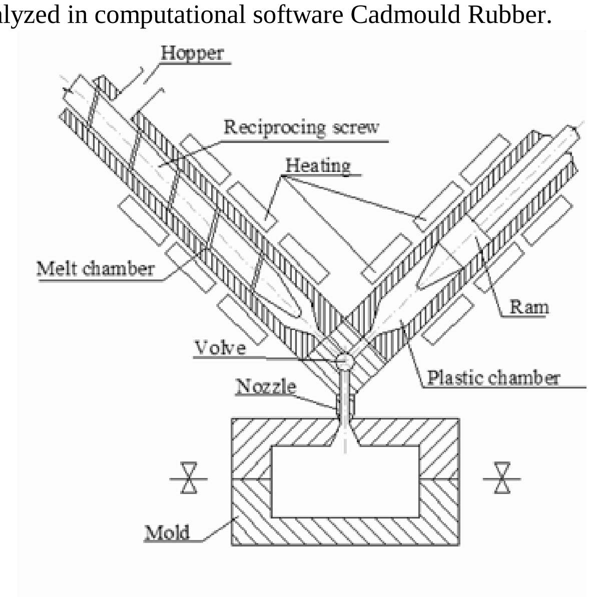

Fig.11 Schema of REP V27/Y125 machine

Fig.10 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

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 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.

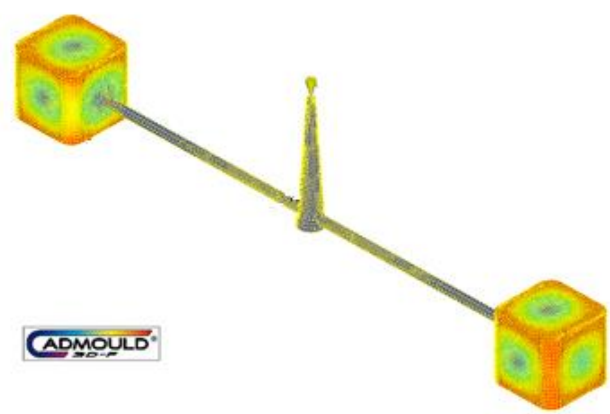

Fig.11 Sample of meshed product

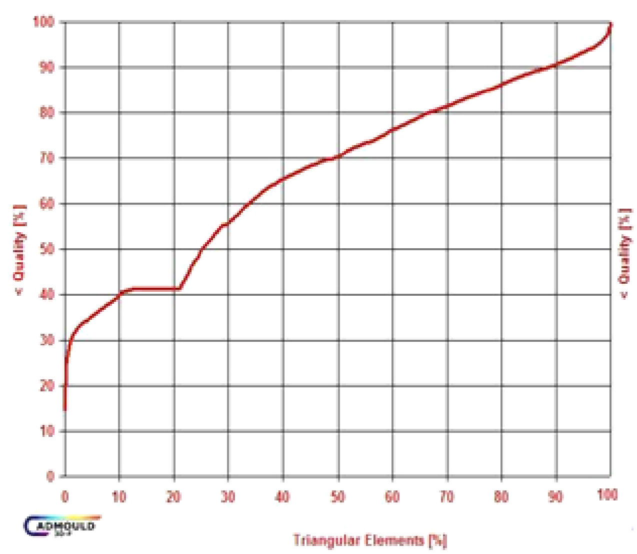

Fig.12 Mesh quality for narrows runners

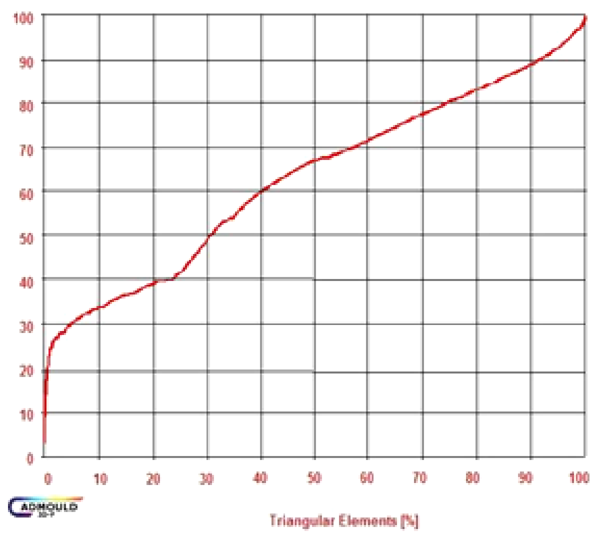

Fig.13 Mesh quality for wide runners

In the previous two 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.

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.

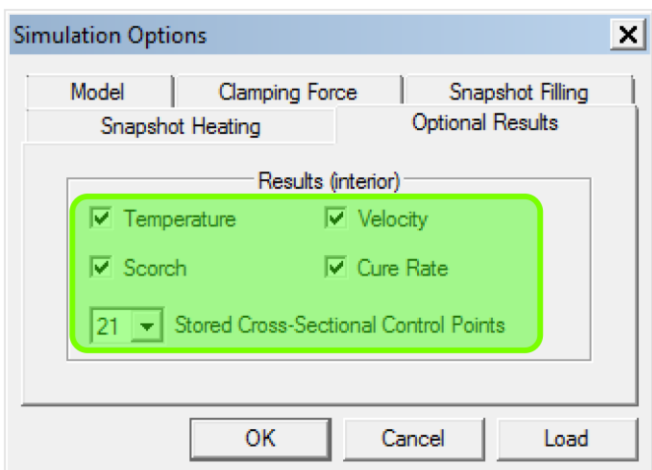

Fig.14 Simulation Options menu

There were switched on advanced results of analisis in Simulation Options menu. For the get fluent curved in figures there were chosen 21 layers in Cross – Sectional Control Points. Computational anaysis were computed on personal cumputer station with parameters which can be seen in follow Tab.

Tab.3 Computer parameters

processor	**Intel® Core 2 Quad Q6600 2,40 GHz**
RAM	2048 MB
HDD	500 GB
Graphic card	NVIDIA Quadro FX 570 1010 MB
System	Windows 7 Professional 64-bit

Material characteristics of rubber compound were received at RPA (Rubber Process Analyzer). Output data were used as input data to Cadmould Rubber.

Fig.15 Rheometer RPA 2000

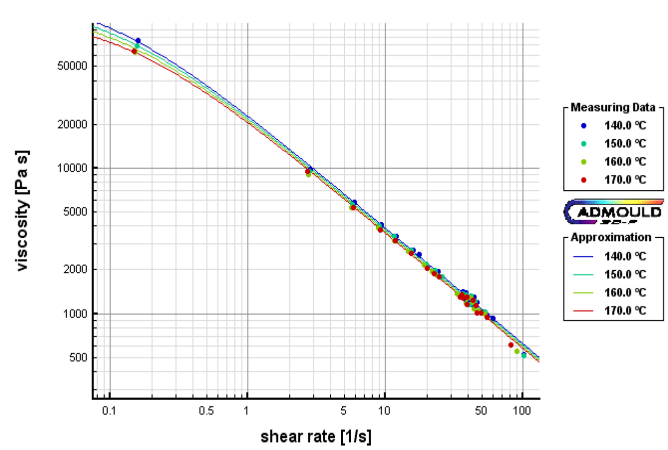

Fig.16 Viscosity vs. Shear rate

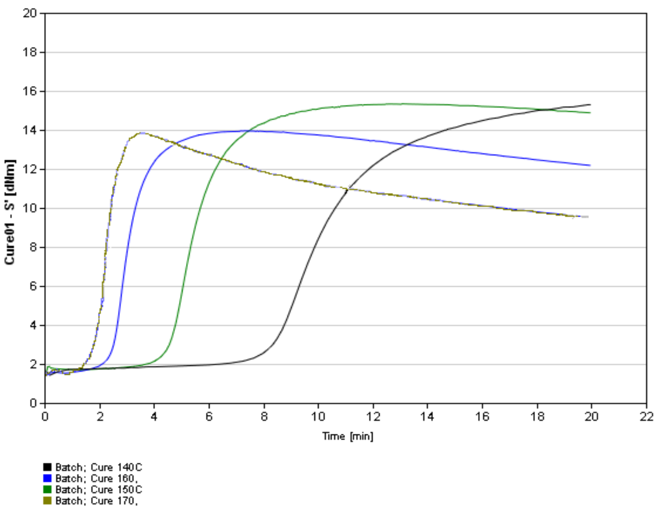

Fig.17 Cure data

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.

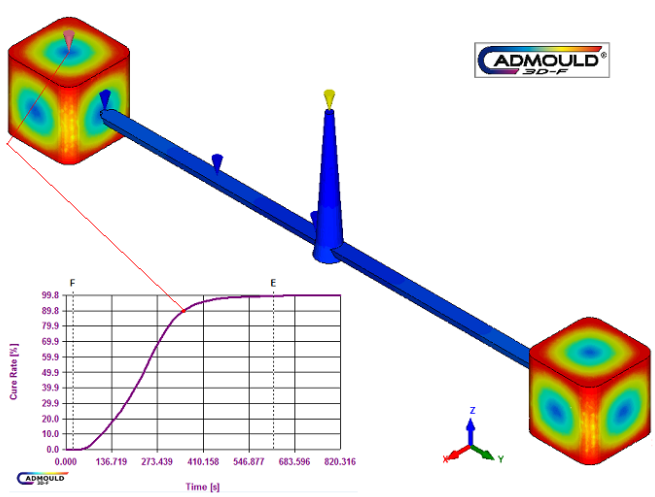

Fig.17 Sensor, where were taken results

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. Sensor where were taken results was the place where the material was affected by heating at the last time.

Tab.4 Process parameters

Piston rate	mm/s	*5;10;15;20;30*
Flow rate	cm^3/s	*0,7;1,5;2,3;3;38*
Pressure/controlled	%	99
Mass temperature	°C	100
Mold temperature	°C	*155*
Heating	s	600
Post curing	s	200

V. Results

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

In this case there is compared to different channel (circular and trapeze). The length from the wall to the center of the section of runner and perimeter of section are.

In the firsts tables of each results there is shown that injection time is the same for different mold temperature. So it is affected by the trajectory in mold and pressure in molding machine

There is significant different among each flow rate. And it can be seen differences among channels and piston rates for each temperature (155,170,185) in the charges. Differences between circular and trapeze channel is enormous in lower flow rate.

Tab.5 Results for straight channel, T=155

T=155°C	**Injection [s]**			
	narrow		wide	
Piston rate [mm/s]	curical	trapeze	curical	trapeze
5	79,7	79,9	81,8	82,0
10	37,2	37,3	38,2	38,3
50	7,3	7,4	7,5	7,5
150	2,5	2,5	2,5	2,5
250	1,5	1,5	1,5	1,5

Tab.6 Results for straight channel, T=155

T=155°C	**Injection + cure time [s]**			
	narrow		wide	
Piston rate [mm/s]	curical	trapeze	curical	trapeze
5	536	490	541	492
10	523	499	527	496
50	515	510	519	515
150	516	512	522	519
250	514	509	519	515

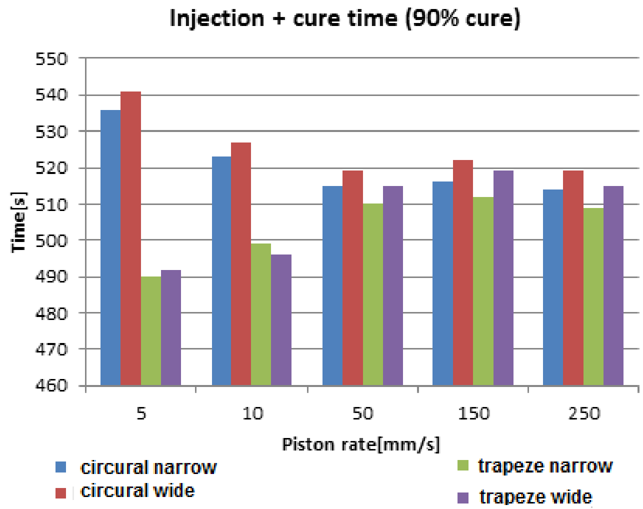

Fig. 18 Time to achieve optimum vulcanization, T=155°C

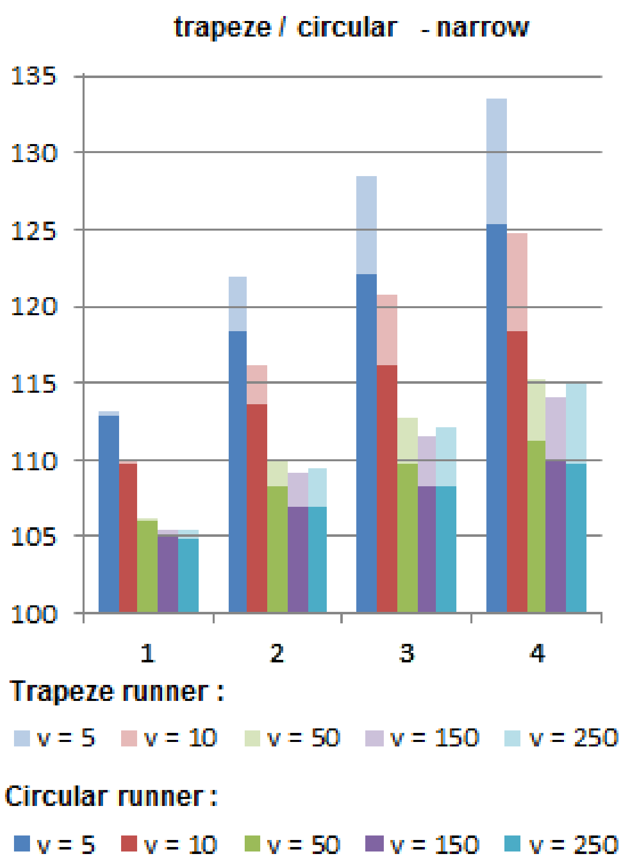

Fig. 19 Temperature of Flow front in sensors 1-4, T=155°C

Tab.7 Results for straight channel, T=170

T=170°C	**Injection [s]**			
	narrow		wide	
Piston rate [mm/s]	curical	trapeze	curical	trapeze
5	79,7	79,9	81,9	82,0
10	37,2	37,3	38,2	38,3
50	7,3	7,3	7,5	7,6
150	2,5	2,5	2,5	2,5
250	1,5	1,5	1,5	1,5

Tab.8 Results for straight channel, T=170

T=170°C	**Injection + cure time [s]**			
	narrow		wide	
Piston rate [mm/s]	curical	trapeze	curical	trapeze
5	436	386	443	389
10	427	401	433	400
50	421	414	425	417
150	418	416	424	421
250	417	415	424	420

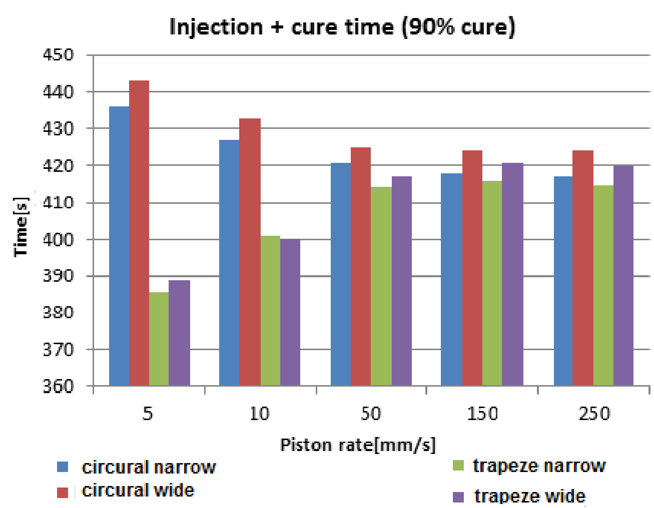

Fig. 20 Time to achieve optimum vulcanization, T=170°C

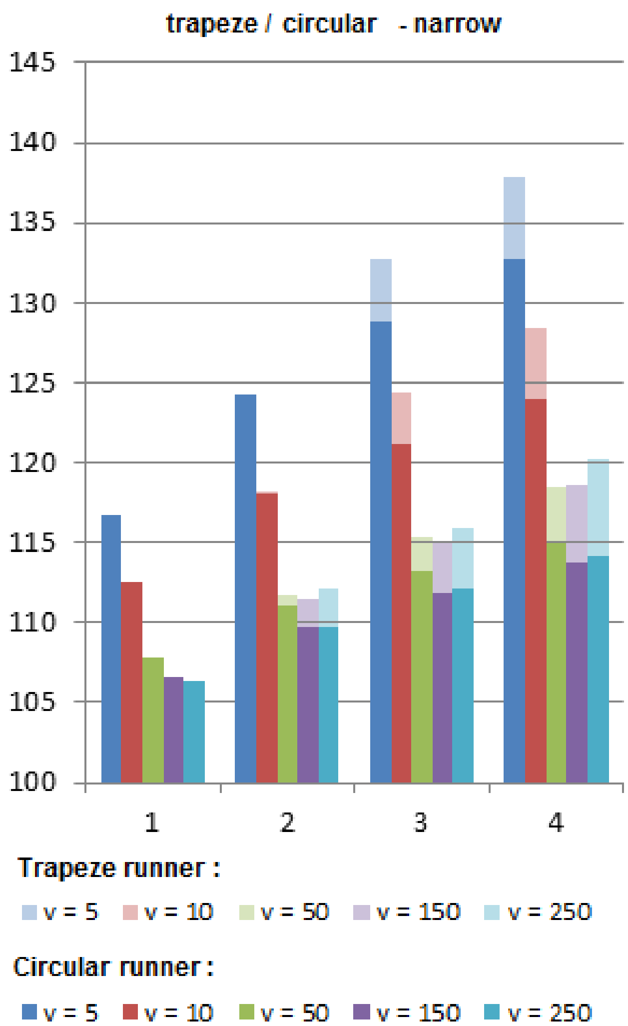

Fig.21 Temperature of Flow front in sensors 1-4, T=170°C

Tab.9 Results for straight channel, T=185

T=185°C	Injection [s]			
	narrow		wide	
Piston rate [mm/s]	curical	trapeze	curical	trapeze
5	79,7	79,9	81,9	82,0
10	37,2	37,3	38,2	38,3
50	7,3	7,3	7,5	7,6
150	2,5	2,5	2,5	2,5
250	1,5	1,5	1,5	1,5

Tab.10 Results for straight channel, T=185

T=185°C	Injection + cure time [s]			
	narrow		wide	
Piston rate [mm/s]	curical	trapeze	curical	trapeze
5	372	322	379	325
10	364	338	369	339
50	360	355	364	357
150	358	356	363	360
250	358	355	363	361

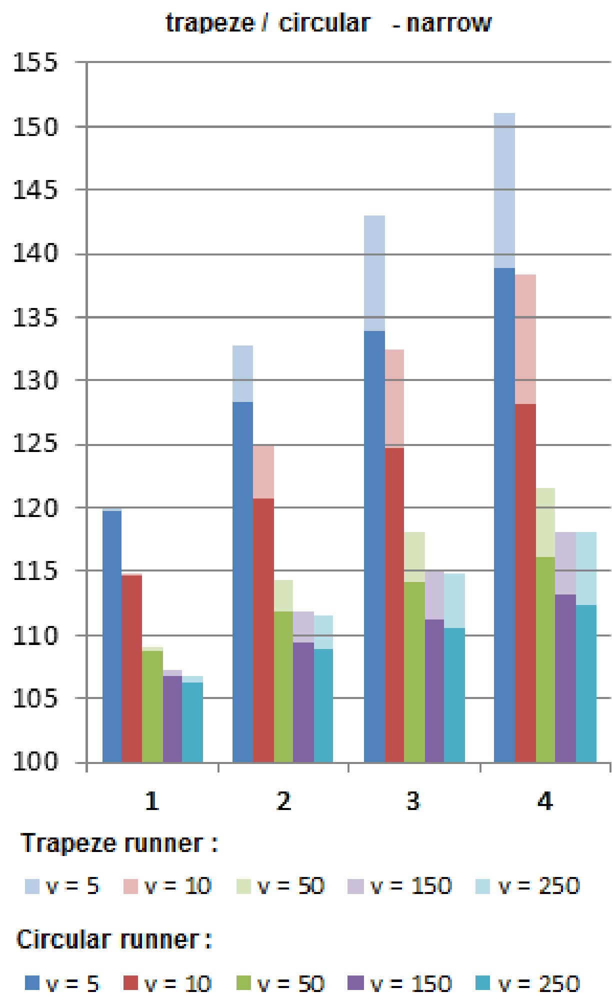

Fig.22 Temperature of Flow front in sensors 1-4, T=185°C

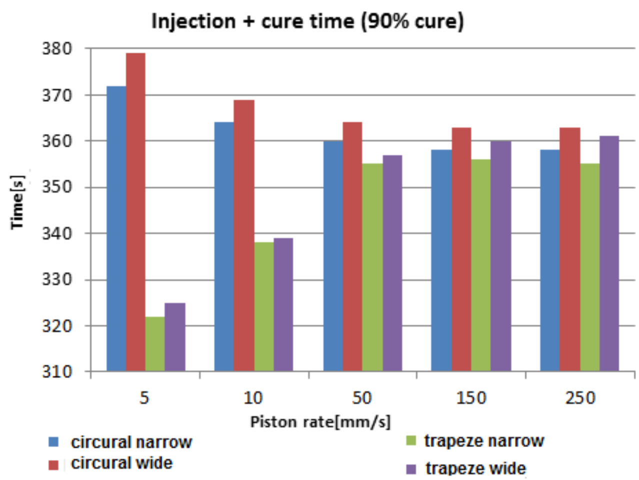

Fig.23 Time to achieve optimum vulcanization, T=185°C

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. Holes 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 This paper showed influences on changes temperature, flow rate and type of trajectories. It is important to find right combination of mentioned parameters. Cadmould rubber software can be right tool how to save time, energy or expenses.

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