The Influence of the Production Process on Mechanical Properties of Rubber Testing Samples

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Keywords: Injection molding, compression molding, mechanical properties, rubber, test sample

Abstract. The article deals with the influence of production technology on mechanical properties of rubber testing samples. In practice, rubber testing samples are cut out from a compression molded sheet, also in case of testing of rubber compounds appointed for injection molding. However, the different way of the preparation of testing samples and the production itself may have a negative effect on the mechanical properties of the final product. Thus the article judges, to what extent the mechanical properties (tensile strength, extension, tear strength and microhardness) of testing samples from selected rubber materials are influenced by injection molding, and evaluates the possible divergence.

Introduction

The research in rubber branch dwells on how the properties are influenced by the composition of the rubber compound formulations, or on the influence of technological conditions of a given production technology. However, it does not deal with the influence of the whole production process change. As for the manufacture of rubber products, the technology of injection molding is beginning to replace the usual technology of compression molding.

A rubber compound consists of different amounts of different admixtures. Thus, each compound is an original with different rheological properties. It is very complicated to predict how the compound will conduct when being processed into the final product. There are relevant tests to find out both the rheological and vulcanization characteristics. The tests can simulate how the compound conducts, but only in much lower rate of shear than the one in case of injection molding. High viscosity can cause that the melt might not fill in the cavity of the mold properly or it can generate too much heat during the filling, which may lead to compound`s overheating and burning. Due to low viscosity of the compound there might not be enough heat generated to allow accelerating of the vulcanization. If the compound`s vulcanization time is too short, the compound may start to vulcanize too early, before the cavity of the mold is filled. [1]

Compression molding is the oldest and most common production technology in rubber industry. One of the advantages of compression molding is its simplicity and the price of the mold. The internal tension is minimal as the material in the mold’s cavity is only exposed to a short and multi-direction flow. There are no more problems related to the gating system. However, this technology also proves some disadvantages, e.g. more demanding preparation of raw products. Also, it is prone to defects caused by insufficient breathing and humidity. On the moldings there are rather large molding flashes into mold parting surface.

The early days of the technology of injecting molding rubber compounds date back to 1940. At present, the process is used to produce a large assortment of industrial products, mainly in the automotive industry. Injection molding of rubber compounds is used mainly to produce smaller products, more demanding as for shape and more accurate as for dimension. Injection molding is most effective in continuous production operations. The costs related to injection molding can be significantly higher than in case of compression molding processes, but in case of continuous production and the number of manufactured products the costs have a fast returnability. The level of the technology is given mainly by the level of the injection molding machine, the mold itself and deep knowledge of the technological process. [2]

Experimental

For this research was chosen a rubber compound (on based SBR and BR) appointed for production of tire treads for this research. This compound shows sufficient scorch time and fluidity, which were verified by a measurement on RPA (Rubber Process Analyzer).

The curing temperature 160°C was chosen for both technologies (compression molding and injection molding). Optimum cure at this temperature is approximately 7 minutes. Curing parameters of the compound are listed in Table 1.

Table 1 Curing specification for 160°C

Scorch time (ts)	2,12 min
10% cure (t10)	2,28 min
50% cure (t50)	3,53 min
90% cure (t90)	6,43 min

For this research, the mechanical tension test according to the standard ISO 37 was chosen. The standard also prescribes the shapes and dimensions of testing samples. To perform this test, the testing sample dumbbell – type 1 (Fig. 1) has been selected. Another test confirming the mechanical properties is the test determining tear strength according to the standard ISO 34-1. To perform this test, the sample graves (without nick) was chosen (Fig. 2). For the instrumented microhardness test (DSI) according to the standard ISO 14577 can be used both test samples.

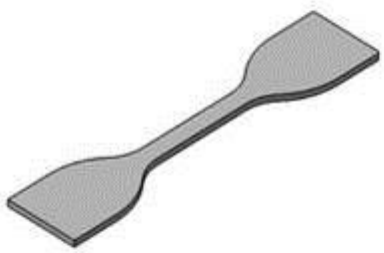

Fig. 1 Test sample – dumbbell (type 1)

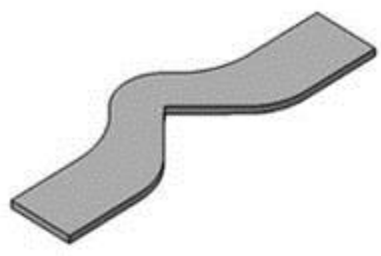

Fig. 2 Test sample – graves (without nick)

To carry out the experiment, it was necessary to design and produce an injection mold for testing samples. The designed mold includes a universal frame, into which mold plates for given shapes of samples are inserted as necessary.

The production of samples was carried out as follows. In case of compression molding, it was first necessary to remold the rubber compound with the assistance of a roll mill and to prepare the required thickness. Next the raw products were cut out in shape of the sheet. Then the raw products were inserted into the pre-heated molding machine and the sheets with dimensions 120 x 120 mm, 2 mm thick, were compression molding. Finally the testing rubber samples were cut out with the assistance of a shape knife, in the line of the material orientation to prevent mistaking the anisotropy direction.

In case of injection molding the pre-plasticated compound, 4 mm thick, was cut into belts 3 cm wide to fill in the injection molding machine (REP V27/Y125). Then the injection molding itself was performed. The injection molded samples after opening the mold are demonstrated in Fig. 3. After injection molding the runner system was removed. The samples were produced from one charge of material.

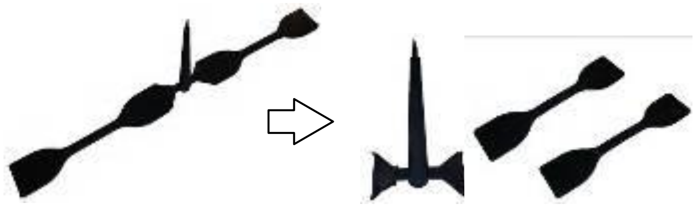

Fig. 3 Production of testing samples by injection molding

Table 2 Process conditions of production

		Compression molding	Injection molding
Temperature	Mold	160°C	
	Rubber compound	23°C	100°C[1])
Pressure	Closing	20 MPa	-
	Injection	-	20 MPa
Curing time		4; 5; 6; 7; 8; 9; 10 min[2])	

[1]) Time of preheating the rubber compound in plastication unit was 40 seconds.
[2]) Individual curing times were chosen in the same range (1 min) above and below the optimum cure (7 min)

After producing of the testing samples a test was carried out to determine the tensile stress-strain properties and also the test to determine the tear strength. In both cases the testing samples were clamped into jaws at both ends in the tensile stress machine Tensometer 2000 by Alpha Technologies. Testing samples were stretched by the prescribed constant speed 500 .mm/min until they were torn.

Instrumented microhardness test was done using a Micro Combi Tester, CSM Instruments. Load and unload speed was 1 N/min. After a holding time of 90 s at maximum load 0.5 N the samples were unloaded. The specimens were glued on metallic sample holders.

The indentation hardness HIT was calculated as maximum load to the projected area of the hardness impression according to: [3]

$$H_{IT} = \frac{F_{\max}}{A_p} \qquad (1)$$

As for both groups of compression molded and injection molded testing samples, 7 series of measurement with different curing time (4 up to 7 minutes) were carried out, with the repeatability of ten samples to one series of measurement.

Results and discussion

The measured values of the test which determines the tensile stress-strain properties (Fig. 4) showed that with the growing curing time, also the tension necessary to break a testing sample grows. This confirms the fact that with longer curing time the cured rubber achieves better tensile properties. With longer curing time the percentage of cross links created in the material structure grows, which is demonstrated in the ability to resist bigger tensile force. At the same time the material elongation increases. Other results (Fig. 5 – Fig. 7) show the values of individual modules and confirm this fact. The results of the test did not prove considerable influence of the different technology of testing samples preparation. The differences among the measured values of the maximum tensile strength in case of injection molded and compression molded testing samples are very small (up to 3%) and fluctuate within the measurement errors.

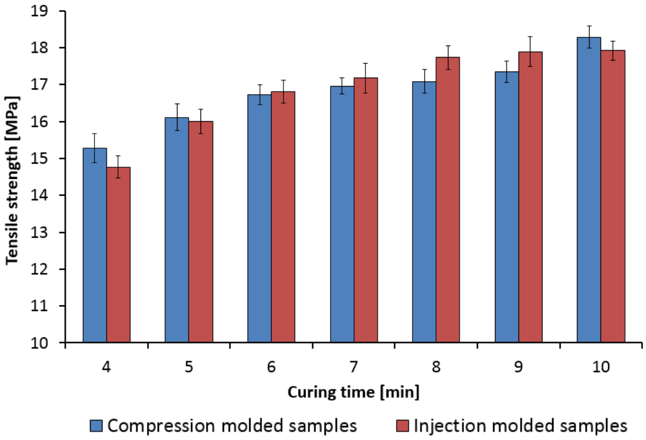

Fig. 4 Tensile strength vs. curing time

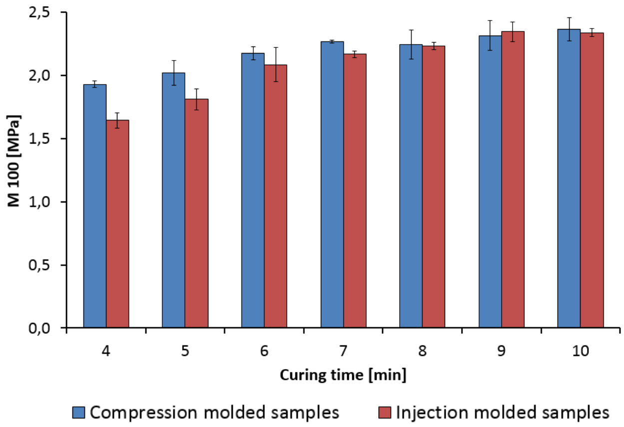

Fig. 5 Modulus 100 vs. curing time

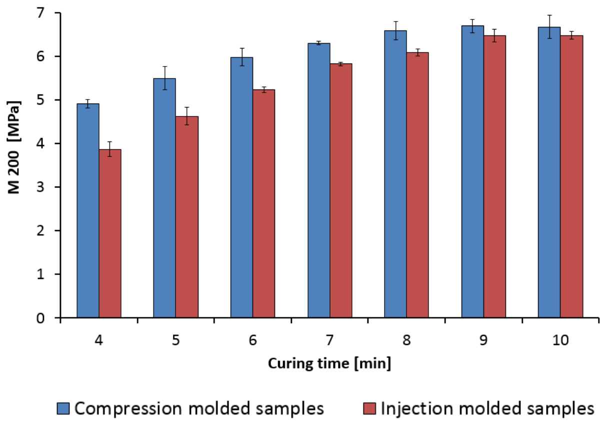

Fig. 6 Modulus 200 vs. curing time

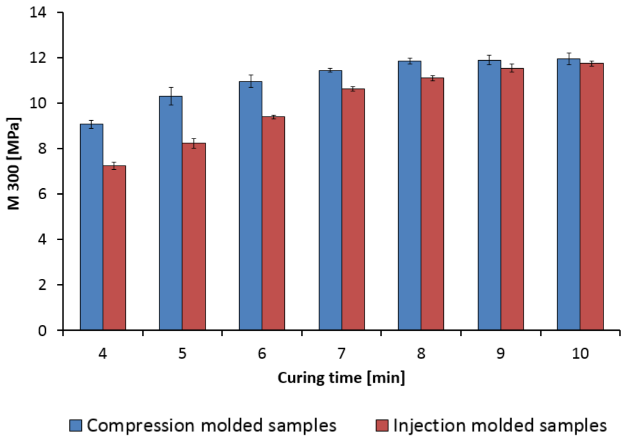

Fig. 7 Modulus 300 vs. curing time

Another test performed was the tear strength test. The results (Fig. 8) show that with the curing time the tear strength of the samples almost does not change. However, significant differences can be found between injection molded and compression molded samples, while the injection molded samples prove on average 38% smaller tear strength. This is probably caused by the different inner arrangement of the material macromolecules.

The last performed test was the test of instrumented micro-hardness test (DSI) which helped to evaluate the indentation hardness (Fig. 9). With the increasing curing time the value of the indentation hardness grows. Thus with the curing time, the samples acquire bigger hardness, which also corresponds with tensile properties of the previous results. The increase of indentation hardness from 4 minutes to 10 minutes of curing time makes 33%. The differences between compression molded and injection molded samples in separate curing times are again not very significant and differ within the measurement errors.

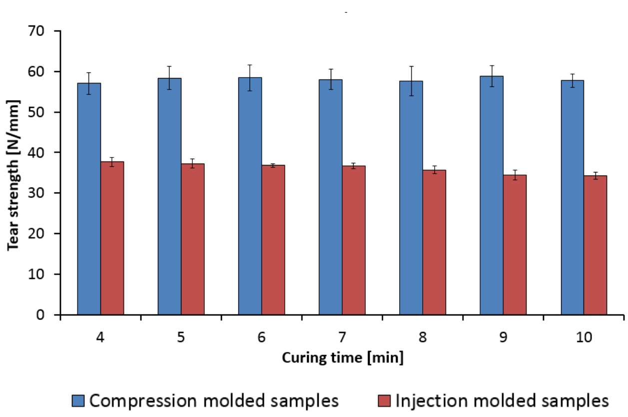

Fig. 8 Tear strength vs. curing time

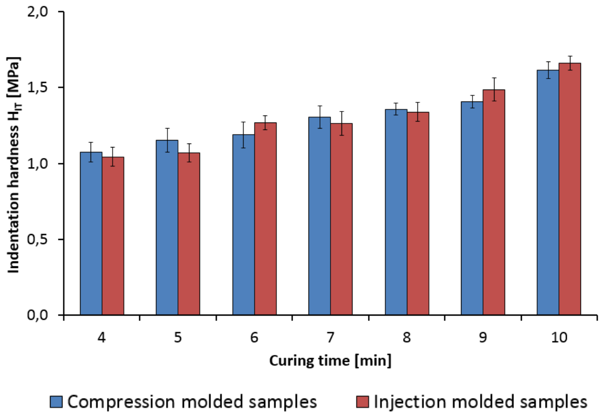

Fig. 9 Indentation hardness vs. curing time

Conclusion

The measured results allow us to state that injection molding of a particular rubber compound has no significant influence on tensile properties, such as tensile strength and We could see that injection molding has a large impact on the tear properties, as the injection molded samples show up to 33% smaller tear strength than compression molded samples.

It was also confirmed that with the increasing curing time the tensile strength, elongation and indentation hardness grow, which is caused by a higher degree of cross linking of the basic rubber of the particular rubber compound. The results gathered so far show that the technology of injection molding of rubber testing samples has a negative impact on the tear strength. This can be caused by different arrangement of macromolecular chains in the material structure due to the different deformation inside the mold. During injection molding, the material fills in the volume of the cavity in one direction and thus it is exposed to larger shearing deformation, mainly in the direction of the flow. However, in case of compression molding, the material is exposed to much lower shearing deformation and in a short multi-directional flow. The research that will follow is going to verify the already examined mechanical properties on other standardly used shapes of testing samples, and also to extend the research to cover other convenient types of rubber compounds.

Acknowledgment

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

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