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Mechanical Properties of Injection Molded and Compression Molded Samples from Nature-Butadiene Rubber

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Abstract. The aim of this paper is to show what extent there is an impact on the mechanical properties (tensile strength and tear strength) of a standardized testing sample made of rubber compound based on nature rubber and butadiene rubber produced by injection molding in comparison with a sample produced by classic preparation (cutting out a compression molded plate) according to the standard ISO 23529. For realization of this study it was necessary to design and produce an injection mold for all types testing samples. Subsequently, mechanical properties such as the tensile stress-strain and tear strenght of compression molded samples and injection molded samples were studied, compared and discussed.

1 Introduction

When producing rubber products it is necessary to watch and check the mechanical properties whether it be the properties of the processed material, i.e. the rubber compound, or properties of the product itself. This control aims primarily on how the mechanical properties are influenced by the preparation of the rubber-processing compounds itself, or the change of technological conditions, e.g. the curing time, the curing temperature etc. However, it does not deal with the impact of changing the whole production technology. One of the very productive technologies, which is coming forth, is the production by injection molding. Control of the mechanical properties of rubber products produced by injection molding is mostly performed on testing samples produced in another way, i.e. cutting off a compression molded plate. [1-13] This distinct way of producing testing samples and final products can result in different mechanical properties. Injection molding of rubber compounds is used mainly in the automotive industry to produce a large assortment of products which are more demanding as for the shape and dimensional precision. Injection molding is most effective in continuous production operations. Injection molding differs from compression molding mainly in different remolding of the material. During the injection molding the rubber compound comes in the mold cavity, having been preheated to a higher temperature, i.e. with lower viscosity, and owing to the injection speed and pressure it is subject to higher shear stress. [14-23] This distinct way of remolding can result in a different disposition of macromolecules in the material structure and different internal strain, which has an impact on the resulting properties of the final product. [24-33]

2 Experiment

For this research, a rubber compound on based nature rubber and butadiene rubber (curing agent - sulphur) appointed for production of automotive parts was chosen. Approximate composition of the compound shown in Table 1. 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).

Table 1. Composition of the compound.

Nature rubber (NR)	35 %
Butadiene rubber (BR)	20 %
Plasticizer	6,5 %
Filler (carbon black)	27 %
Sulphur curing agent	11,5 %

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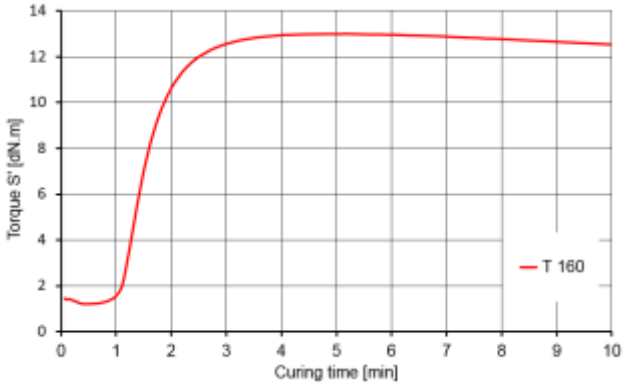

Figure 1. Curing curve for 160 °C

Optimum of cure at this temperature is approximately 2.4 minutes. Curing parameters of the compound are listed in Table 2.

Table 2. Curing specification for 160 °C.

Max. torque S'	13.01 dN.m
Scorch time (t_S)	1.04 min
10% cure (t_{10})	1.14 min
50% cure (t_{50})	1.50 min
90% cure (t_{90})	2.40 min

2.1 Production of testing samples

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. 2a) 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 samples crescent, graves and trousers were chosen (Fig. 2b, c, d).

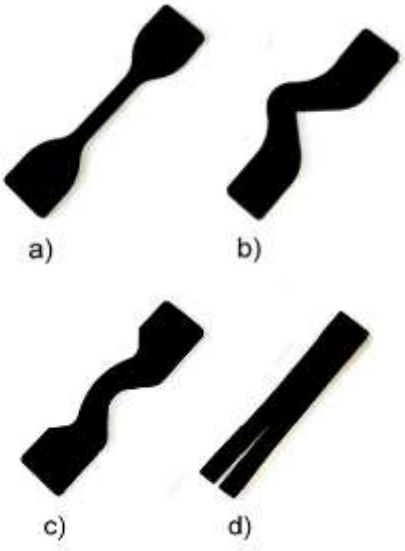

Figure 2. Test samples: a) dumbbell (type 1); b) crescent; b) graves; d) trouser

To carry out the experiment, it was necessary to design and produce an injection mold for all types 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 rubber compound.

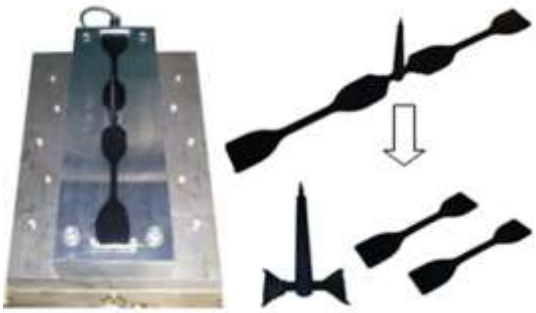

Figure 3. Production of testing samples by injection molding

Table 3. 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		2; 3; 4; 5; 6; 7; 8; 9; 10 min[2])	

[1]) Time of preheating the rubber compound in plastication unit was 30 seconds.
[2]) Individual curing times were chosen in the same range (1 min).

Figure 4. Injection molding machine REP V27/Y125 with injection mold

2.2 Mechanical tests

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. (Fig. 5). Test sample dumbbell was stretched by the prescribed constant speed 500 mm/min until they were torn.

In case of test sample crescent, graves and trouser, stretching speed was 100 mm/min. As for both groups of compression molded and injection molded testing samples, 9 series of measurement with different curing time (2 up to 10 minutes) were carried out, with the repeatability of ten samples to one series of measurement.

Figure 5. Tensile stress machine Tensometer 2000

3 Results and discussion

The evaluated data of the tensile test (Fig. 6) indicate that with the growing curing time the tension necessary to tear the testing sample grows. When the curing time of 3 minutes is exceeded the ultimate tensile strength decreases gradually in case of both preparation methods. The decreasing tendency of the tensile strength is caused by over-curing of the compound. This supports the fact that the vulcanizate based on India rubber obtains better mechanical properties with a longer curing time, but only until the reversal occurs, i. e. until the gradual decay of cross links and degradation of most of the mechanical properties.

The results also show that samples produced by injection molding have higher strength (by 12.4 % in approximately optimal curing time of 3 minutes) than compression molded samples.

Other obtained results show the tear strength of the graves sample (Fig. 7), the crescent sample (Fig. 8) and the trouser sample (Fig. 9) in dependence on the curing time.

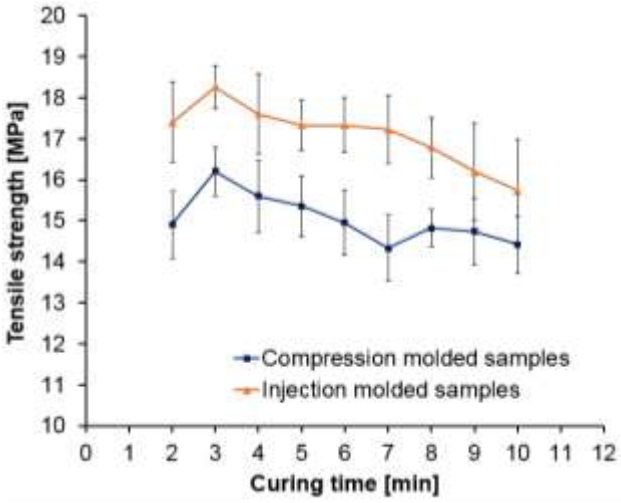

Figure 6. Tensile strength vs. curing time

With the growing curing time the tear strength of the graves, crescent and trouser samples does not significantly change. This means that the degree of crosslinking of the vulcanizate does not have a substantial impact on the tear strength, which supports the information quoted in literature. However, there are evident differences between individual preparation methods. The tear strength of the injection molded graves samples decreased during the optimum cure by 14.4 % compared to the compression molded samples.

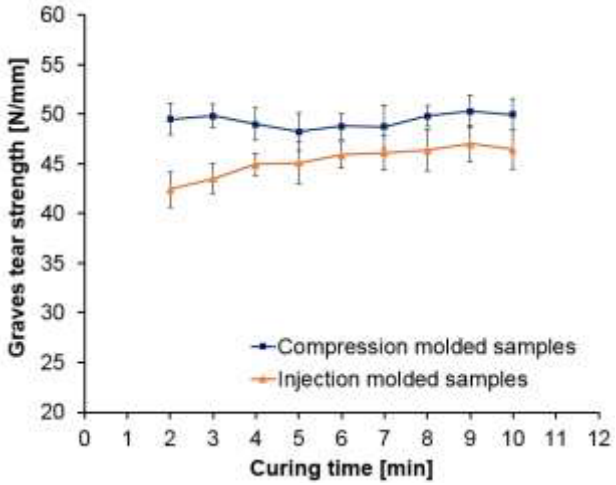

Figure 7. Graves tear strength vs. curing time

To the contrary the tear strength of the injection molded crescent samples during the same curing time increased by 24.4 % and in case of the trouser tear strength the difference is 17.3 % in favor of injected samples. The crescent samples do not have significant notches that would contribute to concentration of the tension. During stretching the deformation energy is mainly used for stretching of the sample rather than for broadening the cracking. This is why the tear strength of this type of sample reaches generally higher values.

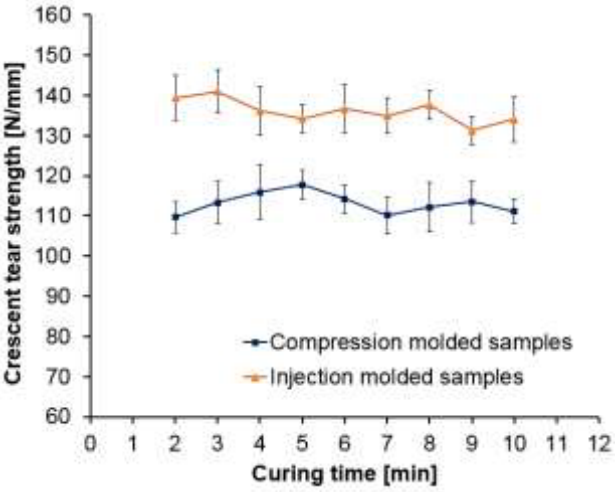

Figure 8. Crescent tear strength vs. curing time

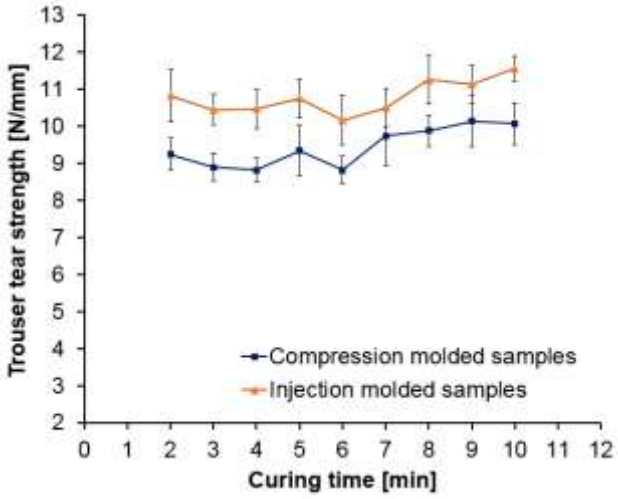

Figure 9. Trouser tear strength vs. curing time

The obtained results of tests performed on the produced testing samples showed certain differences in mechanical properties. To provide clearer evaluation there is a table (Tab. 4) which shows the increase (+) or decrease (-) in percentage of the measured properties of injected samples with respect to the samples produced by the standard method. The table evaluates the quantities measured in the time close to the optimum cure (3 minutes).

Table 4. The relative increase (decrease) in the measured properties of injection molded samples.

Measurement property	Injection molding
Tensile strength	+13 %
Graves tear strength	-14,4 %
Crescent tear strength	+24,4 %
Trouser tear strength	+17,3 %

4 Conclusion

The results of the performed tests showed that the standard preparation method used in case of testing samples (cutting out of the compression molded plate) can be applied also on compounds appointed to the production of injected products. However, the properties of samples produced by this method are not wholly objective, mainly in case of tear strength. The results of the tensile test prove that in the optimum of cure the injected samples have higher tensile strength than samples produced by a standard method. This is probably caused by a higher degree of cross-linking. This also supports the hypothesis that owing to pre-heating of the compound in the plasticizing unit of the injection molding machine the degree of cross-linking is in case of injected samples within the same curing time higher than in case of samples produced by the standard procedure, like compression molding.

The stated results of this research open new possibilities of the testing samples preparation in rubber-making industry, mainly in companies where the injection molding technology is used. It was determined that the preparation method of injection molded samples is viable and for testing of rubber compounds, or products made of such compounds, is more evident than in case of samples prepared by the standard method used up to the present time. In view of the results of this research, when producing injection molded rubber products, it is also recommended to use injection molded testing samples to test their tear properties.

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