Comparison of Mechanical Properties of Injection Molded and Compression Molded Rubber Samples

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

***Abstract*—**This article demonstrates what influence has a change in production technology on mechanical properties of rubber testing samples. It compares two basic production technologies – compression molding and injection molding. The aim of this research is to show and evaluate to what extent the mechanical properties are influenced by the used production technology and to quantify this potential difference on the basis of mechanical tests.

***Keywords*—**Injection molding, compression molding, mechanical properties, rubber, dumbbell, graves.

I. INTRODUCTION

THE properties of elastomeric materials are different from other structural materials in many respects. The differences are both in physical and chemical properties in a limited temperature interval and they are time related. However, in spite of the limiting properties there is a large number of advantages. They are mainly the high elasticity, an ability to bear a significant deformation with a long durability, a possibility of damping, chemical stability in different environments, electrical properties, liquid permeability, etc.

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, pressing predominates, mainly in the production of tires. But if possible, the technology of injection molding is beginning to replace the usual technology of compression molding.

At present, the problems of injecting molding of thermoplastics or thermoplastic elastomers are being investigated, but not elastomers as rubber-making compounds. 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] [2]

The material parameters that define the mold-filling process are based on the thermal and rheological properties. When the cavity is filled, temperature gradients persist in the rubber. This results in temperature distributions within the bulk of the rubber. Material residing at the end zone of the filling section is subjected to an extensive heating regime during the mold-filling stage, and therefore, the material in this region is at a higher temperature than the material near the gate. As the mold is set at a high temperature, the material continues heating because of convection and begins to cure when a certain critical temperature is achieved. This temperature depends on the curing system used in the formulation recipe. Each material zone suffers a different time – temperature history. This leads to a distribution of cure levels. The degree of cure achieved depends on the main process parameters:

- The temperature of the rubber compound and the temperature of the mold cavity.
- The compression molding (injection molding) pressure.
- The time for which the material is kept in the mold, that is, the cure time. [3]

A. *Compression molding*

Compression molding is the oldest and most common production technology in rubber industry. Compression

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molding is a cyclic molding process, in which vulcanization of rubber compound is performed by heat and pressure in a mold. During vulcanization, the rubber product also gets its final shape. The material in the pressing mold is molded by the pressure of the compression molding press at normal or increased temperature. The scheme of the compression molding cycle for rubber compounds can be seen in Fig. 1. The length of the compression molding cycle depends mainly on vulcanization kinetics and on the rubber compound heating. (An important influence on the duration of the heating is the thickness of the products walls.)

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.

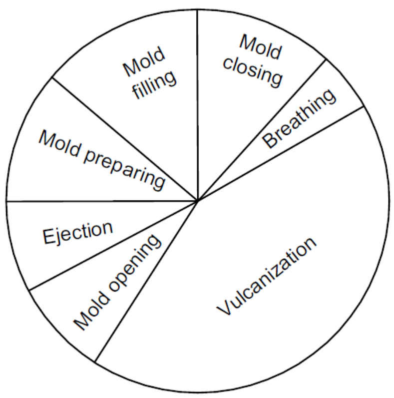

Fig. 1 Work cycle of compression molding

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 (batches). 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. This method is not suitable for production of thick-walled parts or parts with longer flow. In case of pressing, these disadvantages indicate limited productivity of production.

B. Injection molding

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. [5]

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. [3], [4]

Unlike the usual compression molding or transfer molding, in case of the injection molding the clamping pressure acts earlier than the pressure that transfers the compound into the cavity of a mold, which enables perfect, no flash compression molding, even in case of large and thick-walled products. Another difference is that the compound is heated before the injection molding itself, which allows another significant reduction of the vulcanization period. To achieve untimely scorching of the compound the temperature of the heated compound must not exceed 100 °C. The temperature of the mold, and thus the temperature of the vulcanization, is usually between 150 and 200 °C. These conditions require no heat losses or temperature varying. [7]

The injection cycle includes two fields, one of which is related to plastification, the other one to the mold (Fig. 2). This results in rather high productivity.

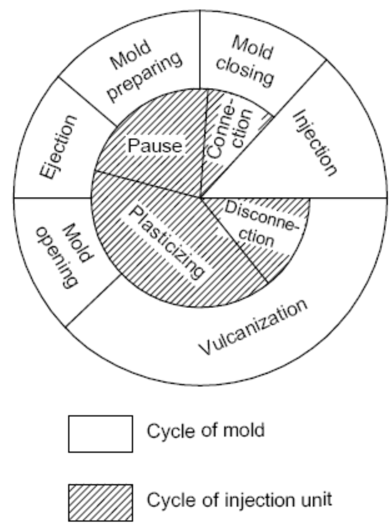

Fig. 2 Work cycle of injection molding

Rubber compounds for injection molding differ mainly in the shapes of the vulcanization curves. Appropriate induction period with constant plasticity and high speed of vulcanization are required. This is achieved by a suitable combination of vulcanization accelerators and retarders in the selected vulcanization system. In case of rubber injection molding, screw plastication units are used. The material is filled either in form of a belt or granules. Due to the properties of rubber compounds the plastication is carried out in a cylinder with a significant assistance of dissipated energy. The plasticated material is often transferred into an injection cylinder, goes through it and is injected into the cavity of the mold. When filling the mold, the material also flows in the surface layer because the temperature of the mold is higher than the temperature of the injection molded material. It is necessary to choose sufficient diameters of the runners and the cavity of the mold, too. The mold must have impeccable breathing. The ejecting system must be selected with respect to the high elasticity and low strength of the injection molded pieces. The injection molding of rubber compounds allows production of thick-walled products in a reduced time and higher quality of the vulcanized rubber. However, it requires more complex processing equipment and, unlike the previous technologies, it is less convenient for piece production. [6]

C. *General properties of rubber materials*

According to their use for structural members, the properties which characterise materials can be divided into two basic groups. The first group includes the physical properties (mechanical resistance), the other one includes chemical properties (chemical resistance). The properties can further change according to the action of the pressure, temperature, time and mainly the course of the production.

In practice, physical properties of structural materials are mainly characterised by properties, such as elasticity, plasticity, strength, hardness and toughness. There are many more physical properties of materials which designers evaluate. For example, for a designer`s needs, the elasticity is further described by the modulus of elasticity - Young’s modulus E, the modulus of compression, modulus of shear - G, volume modulus of elasticity - K and lateral contraction coefficient μ (the Poisson`s ratio). The reason for this is also the nature of physical experiments and measurements. The physical properties of materials are determined during the course of their development, production, use, sale etc. To allow the repetition of the test, it is carried out according to the standardized procedure at workplaces equipped with a device set by the standard.

According to the composition of the elastomeric material it is possible to achieve different sizes of deformations. According to the kinetic theory of elasticity, in an elastomeric material, unaffected by deformational forces, there are chain macromolecules in disordered, distorted condition. During an action of the deformational force, the chains unroll, straighten and orientate in the line of the stress, which causes inner tension. This tension is connected with the chains` effort to return to the original state – the state of higher entropy. A prerequisite to this theory is the fact that the chains need to be arranged into such a condition that their deformation will be possible and their links could turn round. The elastomer is characterised by the arrangement of macromolecular chains and their mutual reaction in the course of the deformation. The properties of elastomers can be modified by formation of primary bonds between macromolecules which develop during vulcanization. Apart from these bonds, among the molecules of elastomers there are also intermolecular secondary bonding forces. However, they are dependent on the temperature. [7]

D. *Testing of rubber materials*

Tensile testing according standard ISO 37 can be used to relate to the ultimate state of cure as well as crudely relating to the cure rate (by measuring tensile properties of some undercured sheets). This method simply consists of cutting out dumbbells from standard cured ISO sheets, using a cutting knife, and pulling them apart with a tensile tester at a standard rate of 500 mm/min to a distance of at least 750 mm using special mechanical grips at each end of the dumbbell. Tensile properties have traditionally been the most commonly cited physical properties for a cured rubber compound. From the separation of a cured dumbbell rubber sample, tensile properties such as ultimate tensile strength, ultimate elongation, and stress at 100 and 300 % elongation are measured. Ultimate tensile strength and ultimate elongation result from pulling the dumbbell sample to rupture (failure). This is a destructive test, which relates to the intrinsic strength of the rubber compound. This strength is usually related to such properties as the quality of the base rubber that was selected, the type of filler/oil system used in the compound, and the ultimate crosslink density and type of crosslinks resulting from the selected cure system. As a rubber compound development tool, this test is very useful.

Tear resistance according standard ISO 34-1 is very important in many rubber applications. Usually tear properties are reported as file force required to pull a rubber test sample apart using a tensile testing instrument under controlled conditions given in standard. Sometimes a special cut is applied to the sample. [8]

Another important property of rubber materials is hardness. Test method for measuring the shore hardness according ISO 7619-1 allows for hardness measurement on rubber specimen using a specified standard indenter. The method consists of indenting the specimen using a hardened steel indenter with specific geometry and force, based on the chosen scale of measurements. This is a quick way to determine if a rubber specimen has achieved a given crosslink density from file curing process. This method is quick but precision is not as good as some other methods, example maximum torque measurements from a rotorless curemeter according standard ISO-6502.

II. Experiment

A. *Material*

Based on previous experience, we have chosen a rubber compound 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). Figure 3 shows the vulcanization curve of the compound at 160°C. Other parameters of the compound are listed in table I.

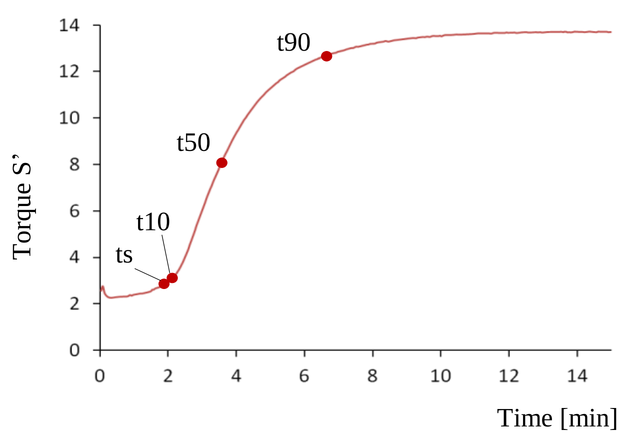

Fig. 3 Vulcanization curve for temperature 160°C

Table 1 Cure specification

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

B. Mechanical tests

For this research, the mechanical tension test following 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. 4) 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. 5).

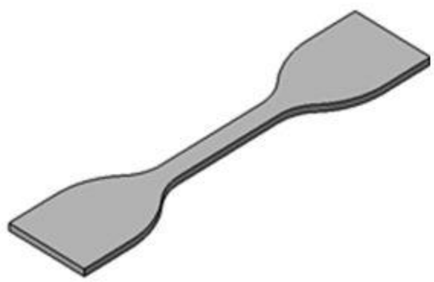

Fig. 4 Test sample – dumbbell (type 1)

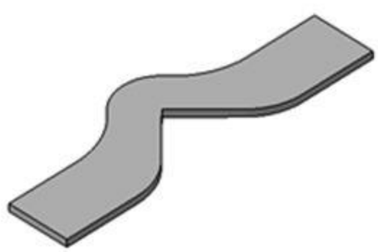

Fig. 5 Test sample – graves (without nick)

C. Injection mold

To carry out the experiment, it was necessary to design and produce an injection mold for the dumbbell and graves testing samples (Fig. 6.). The designed mold includes a universal frame, into which mold plates for given shapes of samples are inserted as necessary. The mold is made of aluminium alloy, which is why heating to the required temperature takes less time than in case of a steel mold. The mold is heated by heating plates of the injection molding machine and the temperature is regulated by temperature sensors. The injected samples are removed manually. The mold was produced with respect to possibilities of the vertical injection molding machine REP V27/Y125.

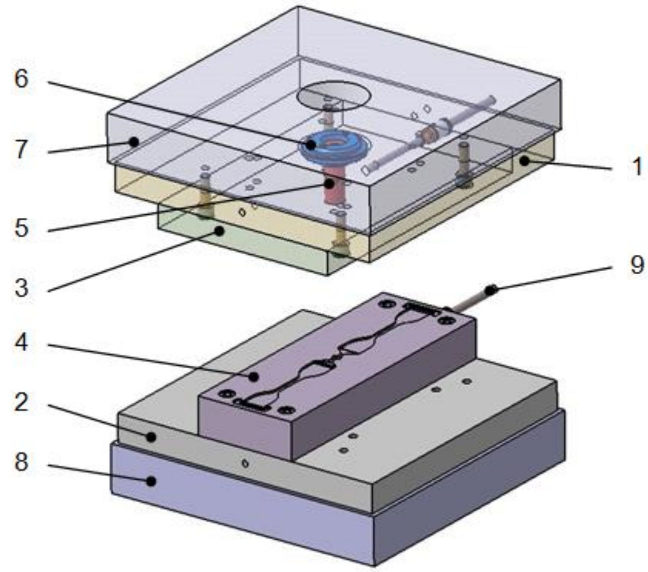

Fig. 6 Assembly of injection mold
1 – upper clamping plate, 2 – lower clamping plate, 3 – upper molded plate, 4 – lower molded plate with cavity, 5 – sprue bush ,
6 – centering ring, 7 – upper heating plate, 8 – lower heating plate,
9 – temperature sensor

Fig. 7 Injection molding machine REP V27/Y125

D. Production of test samples

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 (Fig. 8) 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 (Fig. 9).

Fig. 8 Molding machine

In case of injection molding the pre-plasticated compound, 4 mm thick, was cut into belts 4 ÷ 5 mm wide to fill in the injection molding machine. Then the injection molding itself was performed. The injection molded samples after opening the mold are demonstrated in figure 10. After injection molding the runner system was removed (Fig. 11). The samples were produced from one charge of material.

With respect to the mutual comparison of just the influence of the production technology, the degree of vulcanization must not influence the properties of the compression and injection molded testing samples. For this reason the vulcanization time was set above the value t90. In case of injection molding, the time can be shorter, as the compound is preheated in the injection unit of the machine. The process conditions of individual production processes are listed in table 2.

Fig. 9 Production of test sample by compression molding

Fig. 10 Production of test sample by injection molding

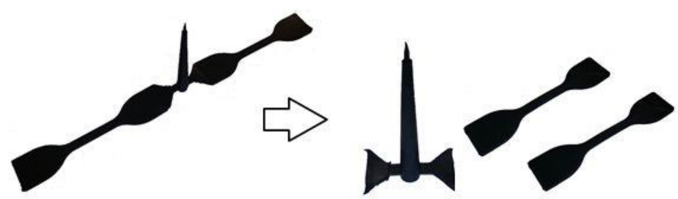

Fig. 11 Removal of runner system

Table 2 Process conditions

Process conditions		**Compression molding**	**Injection molding**
Temperature	Mold	160°C	
	Rubber compound	23°C	100°C
Pressure	Closing mold	20 MPa	
	Injection molding	-	20 MPa
Cure time		10 min	6 min

E. Mechanical tests

In both cases the testing samples were clamped into special pneumatic clamping jaws at both ends in the tensile stress machine Tensometer 2000 by Alpha Technologies. Testing samples were stretched by the prescribed constant speed 500mm/min until they were torn.

Tensometer is able to evaluate data automatically, in case of evaluating tensile properties it is tensile stress, stress at given elongation (100%, 200%, 300%, 400%) – modulus and, in case of structure properties, it is the maximum strength necessary for tearing and the intrinsic strength. For both of the groups of compression molded and injection molded samples, 30 measurements were performed.

Another examined property of the testing samples was the indentation hardness Shore AM according to the standard ISO 7619-1. To measure the hardness we used the indenter AM for thin testing samples with common hardness, with shapes and dimensions prescribed by the standard. To obtain more accurate precision of the measurement, the tensometer was provided with a stand with a centred weight in the indenter`s axis to secure the proper contact of the bearing base with the testing sample (Fig. 12). 50 measurements in total were performed, always 5 measurements on one grave produced by pressing and injection.

Fig. 12 AFFRI Shore Hardness Tester

III. RESULTS

The data from all the mechanical tests were processed and evaluated. The figure 13 shows the shapes of tensile curves of the tested samples, that is the dependence of the tension on the elongation of the pressed and injected testing samples (dumbbell). The values of maximum tensile strength and maximum elongation are listed in table 3. Figures 14 ÷ 17 show the values of separate measured modules. In all the cases the compression molded samples show higher strength than the injection molded samples. With increasing elongation, the difference between the module of an injection molded and a compression molded sample increases (average figures are listed).

The figure 18 shows the course of the force to tear the testing samples (graves) produced by compression molding and injection molding. The measured values of the greatest force to tear F and values of the tear strength are then listed in table 4 (all of them are average values).

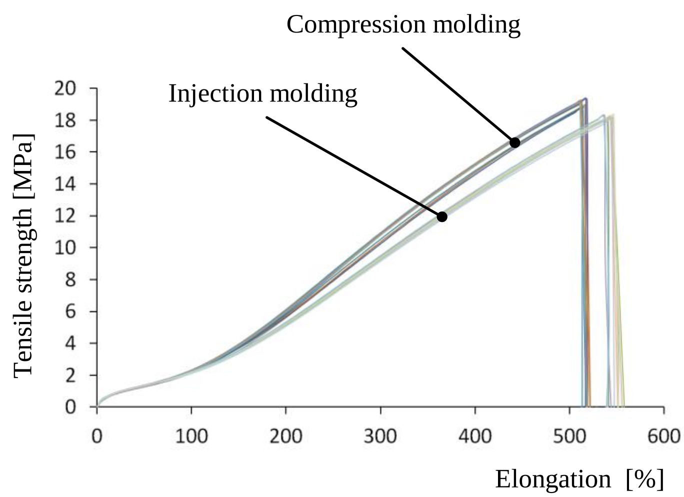

Fig. 13 Comparing tensile curves of both production methods (tensile test)

Table 3 Results of tensile test – max. tensile strength and max. elongation.

Production method	**Max. tensile strength (Rm) [MPa]**	**Max. elongation (A) [%]**
Compression molding	18,98	515,00
Injection molding	18,19	542,15

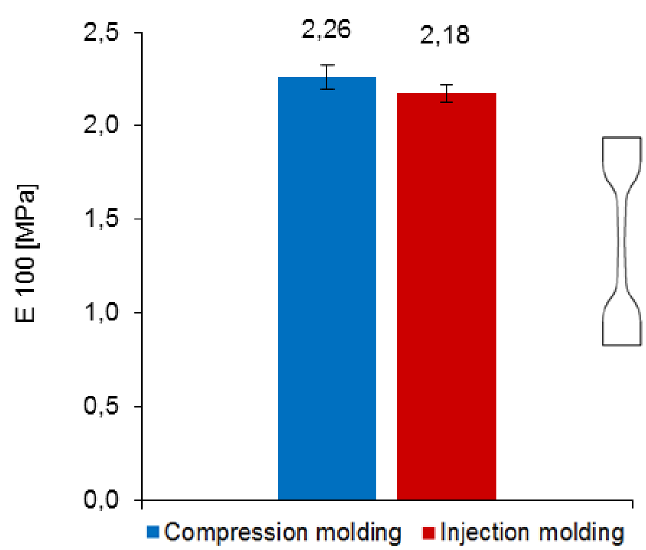

Fig. 14 Results of tensile test – Modulus 100%

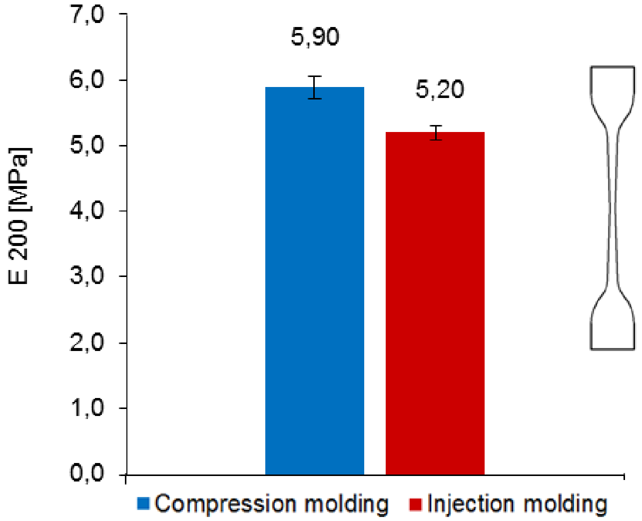

Fig. 15 Results of tensile test – Modulus 200%

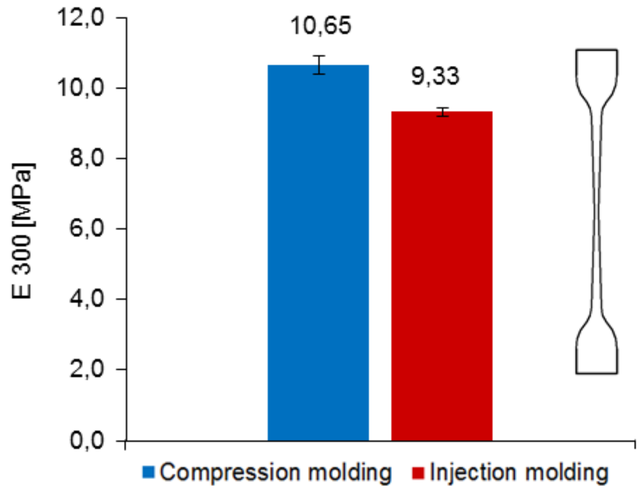

Fig. 16 Results of tensile test – Modulus 300%

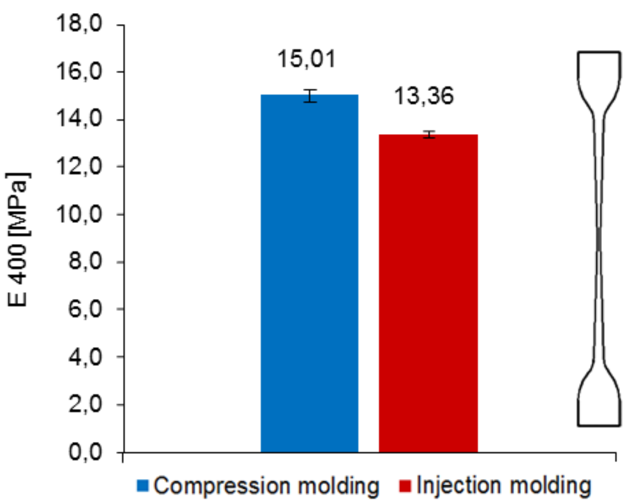

Fig. 17 Results of tensile test – Modulus 400%

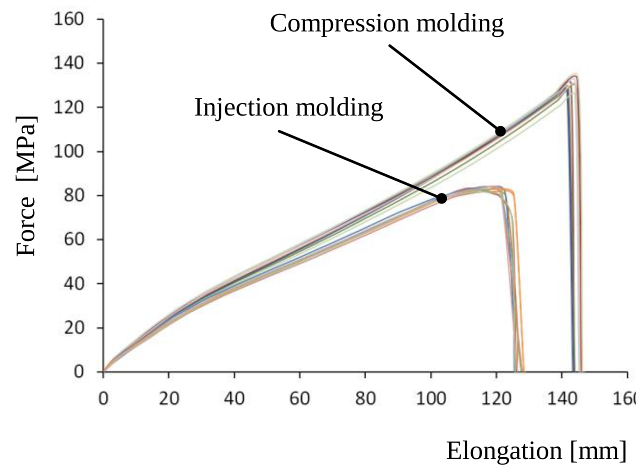

Fig. 18 Comparing load force curves of both production methods (tear strength test)

Table 4 Results of tear strength test – max. force to tear and tear strength

Production method	Max. force to tear (F) [MPa]	Tear strength (Ts) [N/mm]
Compression molding	129,83	55,01
Injection molding	82,92	35,88

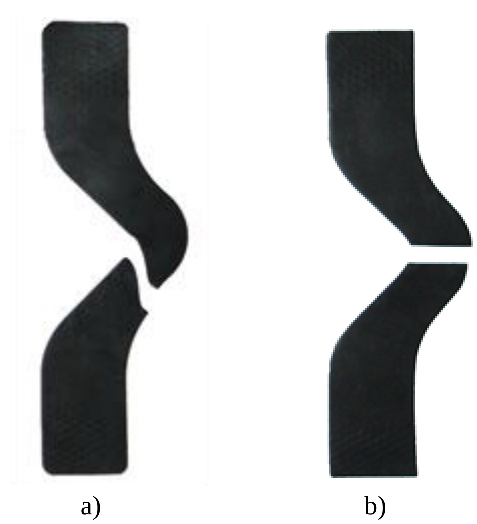

Fig. 19 The different way of tear

a) Injection molded sample b) Compression molded sample

The injection molded samples do not reach such tear strength as the compression molded samples and they can bear maximum 36 % lower load. The course of the fracture and the behaviour in the course of the tests themselves was also different. In case of injection molded samples, the damage and gradual rupture occurred, while in case of compression molded samples, a sudden transverse rupture occurred within a second (Fig. 19). Different behaviour in case of the rupture is also proved by the courses of curves of the load force (Fig. 18).

The results of the indentation hardness Shore AM can be seen in table 5. The hardness values of the compression molded and injection molded samples are almost the same. We can say that during compression molding and injection molding the same degree of vulcanization was achieved, which points to the fact that the different values of the compression molded and injection molded samples in the tensile and structural test are caused by a different way of deforming the material inside the mold, not by a different degree of vulcanization.

Table 5 Result of harness test

Production method	**Shore AM**
Compression molding	65,47
Injection molding	65,38

IV. Conclusion

The performed tests and measured values show that the different way of production of rubber samples has an impact on their mechanical properties. Although the differences in tensile strength of compression molded and injection molded samples are minimal, the biggest difference could be seen in the tear strength, where the injection molded test samples show up to 36 % lower 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.

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