The influence of physical and mechanical properties of additional materials on the recycled rubber structure during its disposal

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Abstract. During the rubber long-term storage in the open air and under the influence of certain temperatures, there is a real threat to the environment where environmental damages cannot be ignored. The objective of this paper is to study the mechanical properties of rubber during its processing by vulcanization after adding some materials to improve their properties. The used materials are: rubber from tires where the proportion of rubber varies from 70-78%, vulcanization granules of rubber, non-vulcanized natural NR rubber, and granulated sulphur. Curves of stress-strain of the recycled rubber are modelled at different diameters of the granules added to the materials for vulcanization removal. As result, the improvement of the mechanical properties are obtained by increasing the diameter of the granules but there a threshold which should not be exceeded.

1 Introduction

Rubber is used in industry to produce tires, and its ratio in these materials is 65%. A question about the disposal of worn tires accumulated in specialized points in large quantities has been arisen during the time. According to the Rubber Manufacturers Association, in 2011, it had about 284 million damaged tires that needed to be disposed. Moreover, during their long-term storage in the open air and under the influence of certain temperatures, there was a real threat to the environment where environmental damages from which could not be ignored [1]. So the assembly of tires and rubber products in private landfills was considered, so that this damage was minimal. Directed research concerning this problem is to develop alternative methods by which it would be possible to get rid of the "rubber-sulphur" bridges [2].

In the middle of the 19th century, Charles Goodyear invented the process of vulcanization [3, 4], which is based on the formation of bonds (bridges) of rubber-sulphur, located tangentially and perpendicular to the main chains. These bridges give the rubber additional elasticity and make a significant contribution to the final structure of the material. The curing

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process binds the formed bridges in the rubber according to the chemical reaction as described in figure 1.

Fig. 1. Interaction of rubber vulcanization and form of the structure of the three-dimensional interlocking transversality.

Prior to the vulcanization process, rubber consists of materials of long flexible molar continuous motion chains, giving it a wider spread randomly under normal temperature conditions. Among these materials, the natural NR rubber which is an industrial composite material such as polyethylene and the PIR isoprene which is a synthetic version of industrial and natural rubber [5]. The rubberized products obtained from these materials are characterized by high flexibility, elasticity, and impact resistance, and it is believed that it can be simplified by a three-dimensional network in the rubber material [6]. The operation of a pulsed flexible three-dimensional network restores the external stresses in the centre of the fracture and gives the rubber material an appropriate geometric texture, which is important for engineering applications.

The general principle of the vulcanization structure is carried out through the process of vulcanization of randomly entangled structures with a spatial structure, which can be acceptable. This pattern follows from the conditions of the process leading to the basic form of a linear chain connected at a certain level by vertical sulphur bridges and which consist of finished rubber polymer chains of granular structure [7–9].

The conversion process is carried out by vulcanization of the rubber mass with a long polymer chain of high molecular-molar mass ($M = 500000 \text{ g/mol}$), which leads to an increase in its molecular-mass molar value consisting of small chains of sulphur, molar molecular-mass value which does not exceed 10000 g/mol .

In practice, to increase the yield of the product quantitatively, during the curing process, the rubber mass is mixed with sulphur and treated under high temperature, irradiation and hot air, and placed in a hot salt bath.

The aim of this work was to study the mechanical properties of rubber during its processing by vulcanization after adding some materials that improve their properties.

For research, we used tires where the proportion of rubber in which varies from 70–78%. The different stages processing the vulcanized rubber are: reclamation, processing, breakdown and grinding, and finally removal of curing [10, 11].

2 Experimental section

2.1 Materials and sample preparation

The materials used in the study are:

1. Rubber extracted from tires removed from metal wheels and then crushed into small pieces. The presence of a cooling circuit ensures that at high temperature, it is possible to obtain crushed granules where the average diameter is limited between 1 mm and 4 mm [12].
2. Vulcanization granules of rubber and limestone having sizes average from 0.8 to 1 mm, and also some mineral oils used in automobile engines and materials of oil circulation for intensification of process of removal of vulcanization.
3. Non-vulcanized natural NR rubber which is not previously used.
4. Granulated sulphur which has the diameter average of the granules equals to 160 microns.

The sample preparation process was carried out according to the following steps:

- 1 – The classification of materials added for vulcanization removal into several groups according to the average values of granule diameters, starting from the average diameter of 80 μm and ending with 1 μm ;
- 2 – The choice of four groups with a highest fraction of granules representing a group where, the diameter averages are: 170-290-370-430 μm ;
- 3 – The mixture of crushed particles with the removal of vulcanized materials was carried out in the mixer at a controlled temperature of the cooling circuit surrounded by the mixture. At this stage, there is a process of removing the vulcanization of rubber, resulting in incoherent paste;
- 4 – The test mass was mixed with 25% sulphur (from the mass of natural rubber) by scrolling the components in the mixer several times in order to obtain the homogeneity of the mixture and access to the micro texture of rubber. Then, the mixture was prepared for the next stage and obtaining the final product;
- 5 – The rubber in a special mould was vulcanized at a temperature of 150°C and for 20 minutes exerting a certain pressure on the resulting product.

3 Results and discussion

After the sample preparation, the axial tension test was carried out at a speed of 50 mm/min and the samples with standard length and dimensions meet international standard specifications [13] for polymer and rubber deformation. In figure 2, the curves obtained reflect the mechanical behavior of rubber specimens as a result of axial tension test. When performing the test, granular materials of different intermediate diameters added to remove the vulcanization of rubber cars.

When analysing these curves, we can note that:

1. The destructive stresses of the processed rubber are noticeably increased with the increase in the average diameters of the granules of the added material for the removal of vulcanization of rubber tires.

- 2. The relative elongation increases with the destruction of recycled rubber with an increased average diameter of the granules of the added material to remove the vulcanization of rubber tires.
- 3. The area fits is almost the same in all graphs, that shows the lack of elasticity of the material factor affected by the change when the average diameter of the granules is added to the materials to remove the vulcanization of rubber tires (figure 2).

Fig. 2. Curves of stress – strain recycled rubber at different diameters of the granules added to the materials for vulcanization removal.

In order to emphasize the role of the average diameter of the particles of the added material to remove the vulcanization of rubber tires on the strain and fatigue failure of recycled rubber, their changes with the average diameter of the granules of the added material were noted. Figure 3 shows the fracture stresses of the recycled rubber with the average diameter of the granules of the added material to remove the vulcanization of rubber.

Fig. 3. Stress values of the recycled rubber at different diameters of the granules added to the materials for vulcanization removal.

When analyzing figure 3, we note that the stress increases from 3.7 MPa, with an average diameter of the granules of the added material of 170 microns to 5.6 MPa, with an average size of the granules of 430 microns. The increase in the fracture stress of over-processed rubber with an average diameter of the granules of the added materials, was extra-vividly written for any proportionately defined trend, and even with an average diameter of 370 μm granules. After this diameter value, and when the average particle diameter reached 430 μm , it was observed that the slope of the curve becomes smaller. Therefore, a such percentage of increase in the fracture stress of the processed rubber was not taken into account.

With the increase in the average diameter of the granules, the elongation of the shear deformation increases with the destruction of the rubber, as shown in figure 4.

Fig. 4. Strain values of the recycled rubber at different diameters of the granules added to the materials for vulcanization removal.

The influence of the size of the granules of the added materials for the removal of vulcanization on the mechanical properties of the processed resin is discussed from two positions, on the basis of the properties of the surface area between the lime granules and the resin material. This surface decreases as the diameter of the particles increases, and the mechanical properties are improved with the increase in the interface between the lime and rubber.

On the other hand, the increase in the diameter of granules leads to an increase in the proportion of contact between limestone particles and sulphur atoms at the connecting bonds, which is a positive moment for the destruction of mechanical intermolecular bonds.

With the increase of the diameter of the granules, the mechanical properties of rubber were reduced, but the destructibility of mechanical bonds increased. This was observed until the diameter of the granules reached 370 microns, which explains the direct dependence of the increase in mechanical properties, and upon reaching this value. A decrease in properties was observed, which was facilitated by the deterioration of material.

4 Conclusions

In this work, we study the mechanical properties of the rubber during its processing by vulcanization after adding some materials that improve their properties. The improved mechanical properties are obtained by increasing the diameter of the granules. The average

increase is observed less often after the average diameter of the particles does not exceed 370 microns. Therefore, it is desirable to use a material in addition to the available for the removal of vulcanization, the diameter of the granules does not exceed 400 microns.

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