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ANALYSIS OF THE PARTICLES DISTRIBUTION INFLUENCE ON THE RECYCLED RUBBER PROPERTIES TO BE USED AS A MATRIX OF LOW-COST SEISMIC ISOLATORS

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Abstract

This paper presents the research on recycled rubber material design, made from vehicle tires, to be used as a matrix of low-cost seismic isolators' prototypes for risk mitigation in South America buildings. Four mixes were contrasting to determine the influence of the particle size distribution on the recycled rubber characteristics, three of them with different size particle composition and the last one with a non-control distribution. Mechanical properties such as density, hardness, and tensile stress, were studied, and stereoscopic images were taken. In the controlled size distribution case, the experimental results showed an improvement in the packing capacity of the particles with a better consolidation of the material under the same processing conditions as a consequence. Regarding the tension stress, the controlled mixes achieved a maximum strength higher than the non-controlled mix (up to 70%), and their spectroscopy images show consolidated materials without voids or pores. All the samples presented a similar hardness with values higher than the natural rubber one (60). Therefore, the development of recycled rubber material with a control size distribution allowed to improve the material behavior without changes in the manufactured process.

Keywords: Seismic Isolation, Low-Cost Seismic Isolators, Recycled Rubber, Particle Size Distribution.

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1 INTRODUCTION

Seismic isolators are proposed as technologies for the mitigation of seismic risk to be applied in various structures and are currently accepted by several countries [1]. Current efforts are mainly directed towards reducing manufacturing costs and reducing the weight of devices, exploring variations in the matrix material [2], [3], and the reinforcement material [4]–[6]. Studies focused on the matrix of the devices offer interesting environmental benefits when using recycled rubber for their manufacture. The consolidation of the material from recycled rubber can be with additives such as binders or without using them [7].

The recycled rubber as a raw material of the seismic isolators has been studied by several authors [8 – 12] to gain insight into the possible parameters and their influence on the material performance and presented the viability to use it for commercial production [11]. These studies employed a manufactured molding process to consolidate the material, with additives [12] or without it [8-11]. They also studied the influence of the manufactured process parameter such as molding time and pressure time.

The tensile strength increases with higher pressure and more extensive molding time, which means the cohesion between particles improves to obtain density with values higher than 1.18 g/cm3, as shown at the diagram at figure 1 [8]. A relation between the size distribution on the particle rubber and the behavior of the final material was proved.

Higher results in tension were obtained for tertiary distributions with 25% of medium particles and 25% of large particles, in contrast to the distribution composed for 100% of fine material that presented comparable tension values but 62% of maximum elongation [9, 10]. The designed material from the studies mentioned previously were used to produce commercial devices such as anti-vibration tiles and tiles [11].

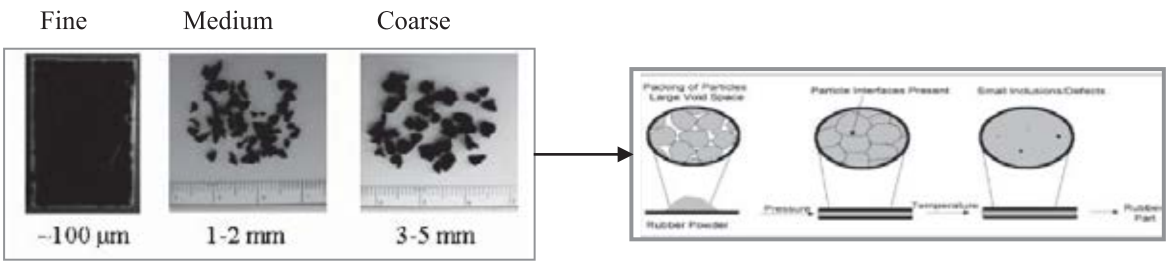

Figure 1: Work diagram of Guglielmotti [8].

According to the studies previously mentioned, the results obtained evidenced the influence of the particle distribution on the material properties for the same processing conditions. The current study proposes the design of a recycled rubber matrix by evaluating different particle size distributions to improve the performance of the recycled rubber material.

2 EXPERIMENTAL PROCEDURE

The samples were made with rubber particles recycled from tire used coming from the productive process of a Colombian Company (Occidental de cauchos). This company is dedicated to recycling and reusing tires used to produce simple components, like car mats and others. To obtain the particles of rubber, the tires were classified, separated, adequate, shredder, sieved, and packed; the process uses particles with a primary diameter higher than 2.00mm, which correspond to the material retention of 10 mesh sieves [13]. To consolidate the matrix, the particles were agglomerated with a polyurethane binder manufactured by molding compression.

The design of the rubber matrix was made to obtain insight into the effect of the size distribution in the performance of the rubber matrix, an additional separation after the recycle tyre process mentioned in the raw material section was made with mesh sieves. Table 1 shows the classification of the rubber particles used to design the rubber material.

Size (mesh sieve)	Diameter (mm)	Classification
5-200	0.074-0.297	Fine
10-30	0.595-2.00	Medium
10	>2.00	Coarse

Table 1: Particles classification.

Three size particle distributions were designed using the particle classification presented in Table 1. The denomination letter and composition in weight percentage of each mixer is show at the Table 2. These mixes were evaluated in contrast with a non-control distribution (NC) obtained from the separation process that the company currently uses at their productive process, using sizes of particles of 2.00 mm and less.

Mix	Fine (%)	Medium (%)	Coarse (%)
A	50	25	25
B	50	50	0
C	75	25	0

Table 2: Mixer composition.

The characterization techniques were tensile strength (ASTM D412-06, ASTM D3039), and hardness (ASTM D2240-05) [14]. Due to the dependence of the compression time by the sample size, each test requires different amounts of time to be manufactured. Table 3 shows compression times and molding temperature.

Test	Shear	Tensile	Hardness
Compression time (min)	15, 20	3, 5, 7	10
Compression temperature (°C)	140	140	140

Table 3: Fabrication process of sample rubber matrix.

To evaluate the matrix's conformability regardless of its compatibility and presences of porous, stereoscopic images were taken with a Stereoscopic Stereo Discovery V8 of Carl Zeiss with an AxioCam ERc5s camera in the facilities of the Pontificia Javeriana University.

3 RESULTS AND ANALYSIS

3.1 Tensile test

The samples are denominated by letter and compression time, the first one was indicated at Table 2, and the last one was indicated at Table 3. For example, the A3 denomination is for mix A compressed for 3 minutes. Figure 2 shows the experimental results of the tensile test for each Mix and compression time. Results include the samples of non-control distribution made at this study and the results obtained in other studies [15].

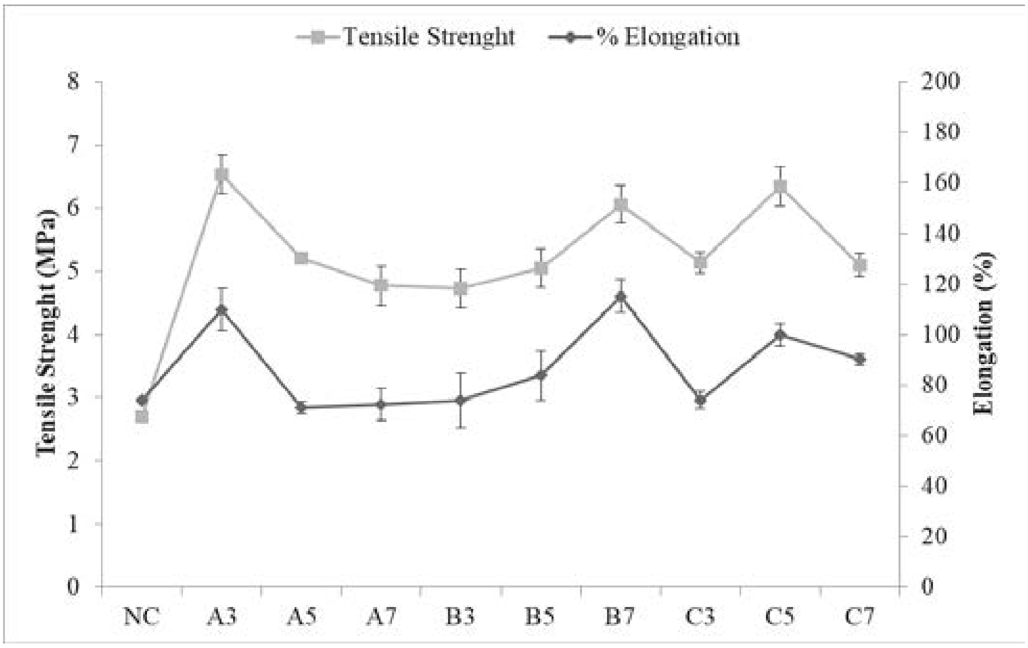

Figure 2: Experimental results for tensile test.

The tension test provides information about the adhesion between the rubber particles; therefore, the material's behavior will depend on its consolidation. Figure 2 shows a proportional relationship between maximum stress and deformation, where the highest values of maximum stress correspond to the largest deformations. The dispersion founded in the results may be due to purely procedural conditions, such as the heat transfer that produced a loss of mold temperature.

In general, all the proposed mixtures (A, B, and C) reached values greater than 6 MPa with deformations greater than 100%. It was found that mixture A showed the highest value of maximum tensile stress, with 6.53 MPa for 109.7 % deformation, with differences of 7.2% and 2.8% compared to the maximum values of maximum stress of mixtures B and C, respectively. The synergy between particle sizes led to improved packing capacity in the material, increasing the contact surface area between them, and the density obtained from these samples was 0.94 g/cm3.

3.2 Hardness

The hardness samples were denominated similar to the tensile test. The three mixes are indicated by the letter (A, B, C), and the number 1 and 3 indicated 10 and 15 minutes of compression, respectively. Figure 3 shows the results of hardness for the different mixtures.

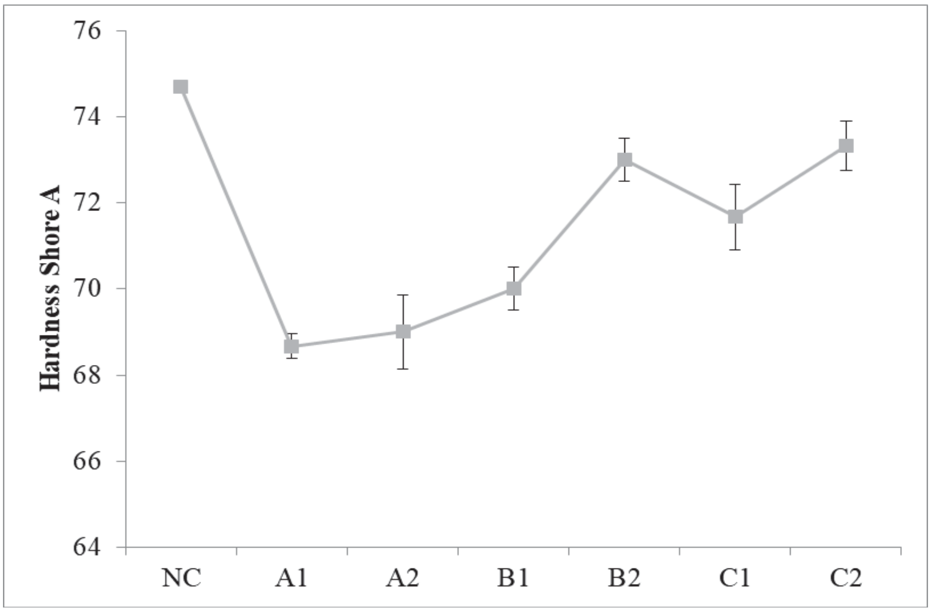

Figure 3: Shore A hardness of the samples.

Hardness is a surface property; it provides an idea of the surface resistance of the samples and the state of consolidation in this area. The hardness results show that mixture C presented the best performance for the shortest molding time evaluated, with 71.67 for 10 minutes, in contrast to 70 and 67.7 for the same molding time of mixtures B and A, respectively.

Similarly, the recycled rubber agglomerate material with the composition of the mixture C presented the highest hardness values, with 73.3 shore A for 15 minutes of molding time. In general, there is an increase in hardness with increasing molding time, although the values are very close to each other. These results are higher than those obtained from materials made from natural rubber, for which 50 Shore A is reported [16], but it is an acceptable difference for use in seismic isolators.

3.3 Stereoscopic Images

The stereoscopic images were used to evaluate the sample's failure zone to define the material behavior in the test. Figure 4 shows the 3 mixes (A, B y C) and the non-controlled sizes distribution sample. Each mix exhibits their own and particular surface provided by the compactibility due to different particle sizes where the fine particles fill the voids between the coarser particles.

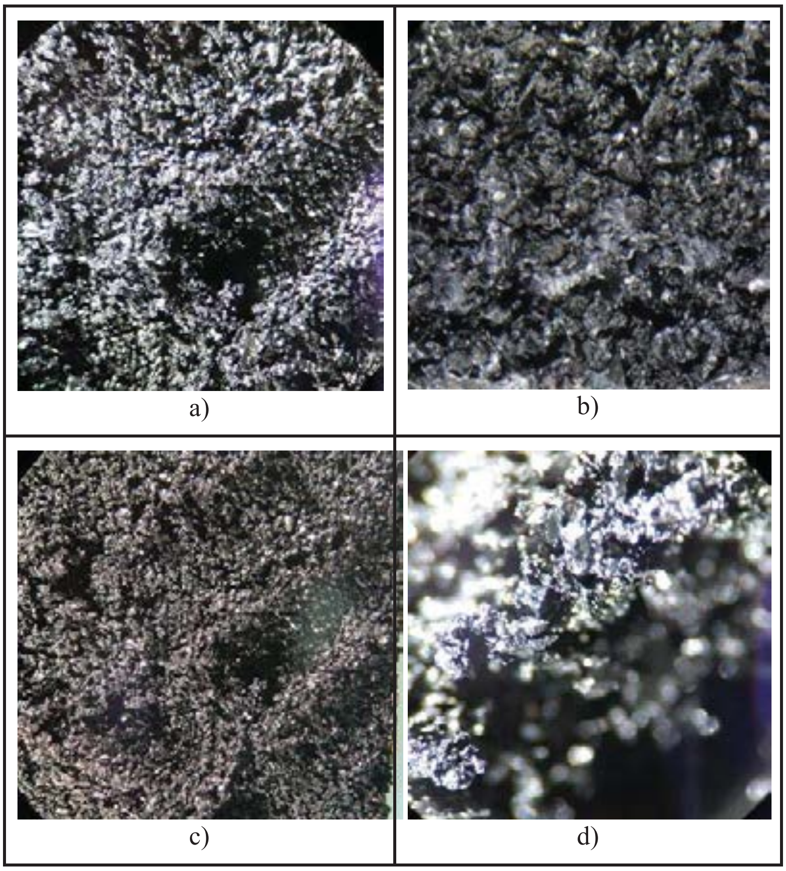

Figure 4: Stereoscopic images of failure zone of the samples.

As shown in figure 4, the material failure occurred in the interface between the rubber particles and through some rubber granules, preserving the integrity of the adhesive and rubber adhesive interfaces. The tensile test proves the relation between compactability and material behavior. The adhesion between rubber particles grows as the compactability increases, producing higher tensile strength and percentage strain due to the bigger superficial area. The hardness does not exhibit a relation with the particle's sizes distribution. That fact could be related to the superficially feature of the property, which shows the adhesion between particle in a superficial way but does not reflect the property across the material.

4 CONCLUSIONS

From the results obtained in this study, it can be concluded that the design of the matrix material made from recycled rubber particles, having the granulometric distribution as a control parameter, allows obtaining materials with good mechanical performance. This happens when 50% of its composition are fine grains, and the remaining percentage is distributed evenly between coarse and medium particles, producing synergy of sizes that increases the compaction capacity.

The stereoscopic images show the effects of different particle size distributions designed to provide synergy between sizes to increase the effective superficial area. These changes in the arrangement of the rubber particles produce a variety of mechanical behavior, affecting properties like tensile strength, as was shown in the experimental results of the present study.

The hardness results for the different mixtures (A, B, and C) presented very similar values, with a small increase with increasing molding time for each mixture. On the other hand, it was found that an improved behavior of the material fabricated with the particle size distribution, where Mix A presented an increase of 71.8% of maximum stress in tension for similar values of deformation concerning the results obtained with granulated rubber matrices without control over the distribution of particle sizes.

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