Polymer Fibers from Waste Tires and Sugarcane Molasses for Soil Improving

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Abstract This research shows results about the use of recycled tire polymer fibers (RTPF) and sugarcane molasses, both blended with kaolin clay for soil improving applications. RTPF were obtained from a tire recycled company and the molasses was obtained from a sugarcane manufacturer. Both materials are considered as wastes in some locations and therefore the first positive impact of this research is to have a green solution for these by-products. The materials characterization was performed with scanning electron microscopy and compression strength tests. Results showed that unconfined compressive strength improved from about 1419 kPa for the sample without the addition of fibers and molasses to 2037 kPa for the sample with 0.1 wt% of fibers and 2.0 wt% molasses, contents taken with respect to the dry weight of the soil.

Keywords Waste tires · Polymer fibers · Molasses · Clay · Soil improving · Soil microorganisms

Introduction

The accumulation of tires that ended their useful life has become a worldwide problem that has been the subject of study by the academic community for years, but due to the scale of the car's demand, the problem is still far from a solution. Therefore, innovative reuse methods are required in order to contribute to solve the problem via initiatives such as circular economy, particularly in developing regions such as Latin America [1–3], where multiples options are now in developing such

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as the tire rubber waste addition to pavements [4] and to cementitious materials [5]. Every year, 1.4 trillion tires are produced worldwide, which generate 17 million tons of used tires per year [6]. Only in 2017, 4.7 million tons of tires were discarded in the United States [7].

To supply the high mechanical stresses in the tires, these are made of rubber reinforced with steel and polymer textile. The compound generated by these materials favors the conditions so that the tires have long degradation times. Cross-links between the rubber polymer chains, additives, and stabilizers used in tires manufacturing, make the tires resistant to biodegradation and even to hard environmental conditions [8].

Sienkiewicz et al. [6] identified five processes that can be used for the handling of discarded tires: retreading, energy recovery, pyrolysis, product recycling, and material recycling. Retreading is the way in which the worn tread is replaced with a new one [9], although, some results show that vehicle safety is affected by retreaded tires [10]. Energy recovery is the way of tire recovering, where the tires are used as an energy raw material [1]: used tires have a high calorific value of about 32 MJ/kg [11]. Pyrolysis is the process that converts waste tires to flammable gas, pyrolytic oil, carbon black liquid fuel, and pyrolysis char [12, 13]. Product recycling means to recycle of entire used tires in their original form [1]. Material recycling is realized as mechanical grinding of tires, which yields rubber materials of different degrees of grinding [14].

Multiple research has shown results regarding used tire-recycling by-products in engineering problems. This is the case of RTPF and recycled rubber from discarded tires, which were included in different types of concrete to assess the change in mechanical properties [15–20]. Steel fibers have been studied as a reinforcing material for concrete [21, 22]. And rubber particles of different sizes and shapes from the tire-recycling process have been mixed with clay and sandy soils to improve engineering properties [23–26].

Molasses is an organic by-product of sugar, dark brown in color, highly viscous, and with a strong odor. Its main components are carbon and oxygen; while magnesium, sulfur, chlorine, potassium, and calcium are minor elements of its composition.

In the field of engineering, molasses has been used in different areas. It has been used to tailor properties of concrete and cement [27–29], as a stabilizer of expansive clays [30], and has been also investigated as a potential replacement of conventional materials for roads infrastructure [31].

Kaolin is a white clay soil from residual or sedimentary deposits, mainly composed of silica and aluminum. Its structural formation is constituted by octahedral aluminum and tetrahedral silica sheets [32]. The kaolin has been used in several investigations related to construction materials such as calcined kaolin, included in concrete mixes for better durability and mechanical strength [33–35].

Soil improvement is an engineering branch that is responsible for developing methods and materials to modify the engineering properties of the soil and thus converting it into an adequate space to develop construction projects. Mitchel [36] performed a comprehensive state of the art and classified different methods for soil improvement; later Terashi and Juran [37], based on Mitchel's work, reclassified the methods by fitting them into eight groups: replacement, densification, consolidation, grouting, admixtures stabilization, thermal stabilization, reinforcement, and miscellaneous.

In order to contribute to the state of the art in the management of waste from different industrial and agricultural processes, an environmentally friendly alternative for the disposal of two wastes was studied in this work. Molasses was used as a bonding material between soil particles, and matrix for fiber dispersion. Characterization tests were performed with scanning electron microscopy, and the soil improvement was evaluated via UCS tests.

Experimental Procedure

Materials

A tire recycled company located at Rionegro, Colombia, provided the waste fibers. This polymer fibers have an average of 22.4 μm in diameter, and came mixed with residual rubber. The residual rubber is average 46.0 μm and its concentration is about 60% by fiber–rubber weight. Molasses is a by-product of sugar manufacturing and it was supplied by a sugarcane manufacturer located at Medellin, Colombia. Kaolin soil in natural conditions used in this investigation was extracted from a regional residual quarry at Sonsón, Antioquia.

Soil Samples

Kaolin soil was crushed using hand roller until a homogenous grain-size was achieved. Molasses, polymer fibers, and water contents were all mixed using a Hobart N50 mixer machine for 5 min, with molasses and fibers previously mixed by hand for 3 min. The mixed soil was compacted according to the ASTM D1557–02 method A. Three soil samples were taken by each compacted mixture. 2" diameter aluminum tubes were introduced in mold with the help of a hammer. Then, the soil sample was extracted from the aluminum tube using a hydraulic jack. Then, the soil samples were covered with a plastic wrap. Finally, samples were kept in a room at 20 ± 3 °C and air atmosphere for curing for 28 days.

Tests

Soil improving was assessed conducting Unconfined Compression Strength test (UCS) according to ASTM D2166, which was performed using a Shimadzu AG250 KN universal testing machine at 0.68 mm/s. Dehydrated and gold sputtering soil samples were analyzed with a scanning electron microscopy (SEM) apparatus, a JEOL JSM 6700 R in high vacuum mode. Soil samples were dehydrated putting it in furnace at 30°C for 24 h. Gold sputtering was conducted using a Hummer 6.2 equipment at 15 mA AC for 30 s. Based on the SEM and optical images, the fiber diameter and the residual rubber grain-size were estimated using Image J software.

Results and Analysis

Table 1 shows the material composition of each soil mixture. Molasses and fibers content were calculated in the dry soil. Soil was mixed with water until 35% moisture. Seven types of samples were made, the fiber content was constant while the molasses content varied from 0% to 12% based on the dry weight of the soil.

Figure 1 shows rthe aw materials used in this research. Figure 1a represents a deposit of used tires, which are usually the final disposal sites for used tires. Figure 2b represents polymer fibers on micro-scale. The fibers are connected one to another due to recycling process, which destroys the polymer textile and forms short fibers. Figure 2c presents the real color and viscosity of molasses. Figure 2d is kaolin soil in natural conditions, with different particles size.

Figure 2 shows the diameter distribution of the fibers. These fibers have a diameter ranging from 10 to 40 µm, and with 22.4 µm as average diameter.

Figure 3 summarizes the residual rubber grain-size probabilistic distribution. Residual rubber grain can be from 15 µm to 105 µm in diameter; with 46.03 µm of average diameter.

Table 1 Soil mixtures

Designation	Molasses (%)	Fibers (%)	Soil (%)	Total % (By dry soil)	% Water content
M0	0	0	100	100	35
M2	2	0.1	97.9	100	35
M4	4	0.1	95.9	100	35
M6	6	0.1	93.9	100	35
M8	8	0.1	91.9	100	35
M10	10	0.1	89.9	100	35
M12	12	0.1	87.9	100	35

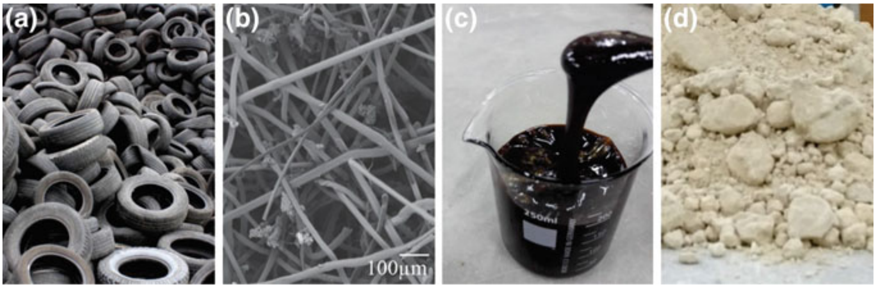

Fig. 1 Materials **a** deposit of used tires **b** waste tire fibers, **c** molasses, and **d** kaolin soil in natural conditions

Fig. 2 Nylon fibers diameter probability distribution

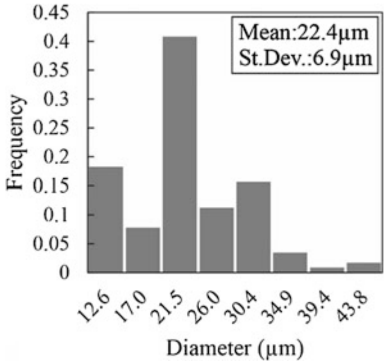

Fig. 3 Residual rubber grain-size probability distribution

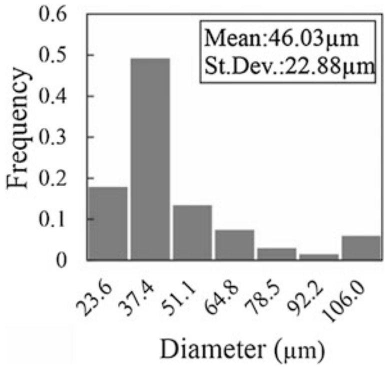

Figure 4 exposes UCS test results. The highest soil strength was 2037 kPa, which was achieved when 2% molasses content by dry soil was added. It was seen that as the molasses content increases, the ductility of the soil specimen increases as well.

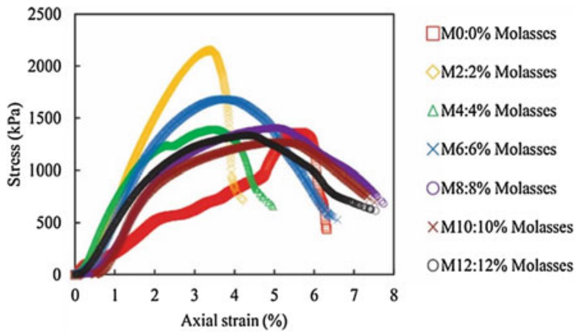

Fig. 4 Typical UCS test

Figure 5 shows SEM images. Figure 5a is a 2000X SEM image which shows the end of a single fiber. Figure 5b represents M2 soil sample at 2000X, which demotes the fibers and soil interface. Figure 5c exposes M4 soil sample at 500X, which shows the random dispersion of the fibers in the soil matrix. Figure 5d corresponds to M0 soil sample 500X. Figure 5e shows M8 soil sample at 500x, which shows the fiber coming out from the soil matrix. Figure 5f presents M12 soil sample at 500X, where the adhesion between the fibers and the soil with high molasses contents is observed.

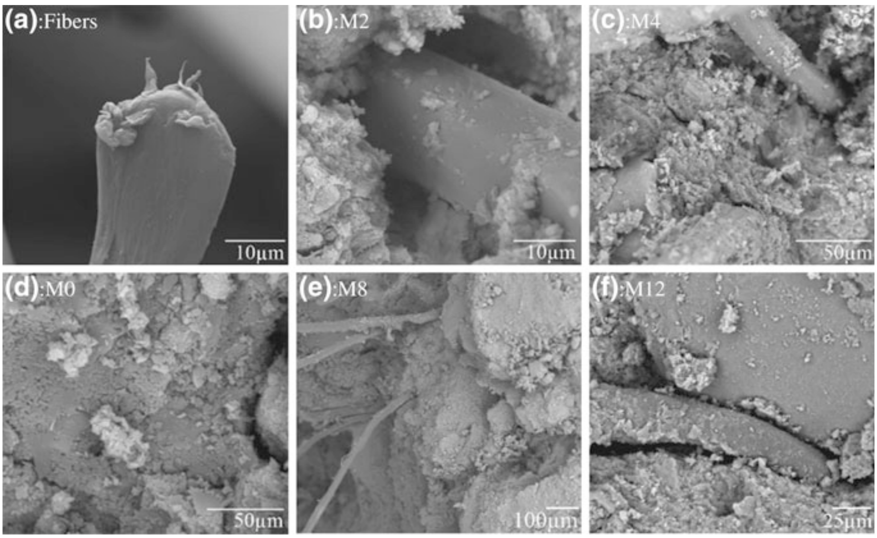

Fig. 5 SEM images for the soil composite fabricated in this research

Discussion

To some extent, molasses can be an unconventional material with cementing properties that could be used for soil improvement. Molasses is an organic product, soluble in water, and without toxic components that may pose a threat to tributaries, ecosystems, and people. It is a by-product, cheap and easy to acquire. Only low dosages are necessary to reach the highest strength, which corresponds to an approximate 20 kg of molasses being necessary to treat a ton of soil, and in this way, the maximum soil resistance would be achieved. The research done by Abdulhussein Saeed et al. [38] shows that a soil with similar characteristics and similar laboratory conditions used in this investigation required 10% cement to reach a resistance of 2100 kPa. In this context, for soil improvement under dry conditions, molasses can be a substitute for cement, and 2% molasses would roughly equal 10% cement. Finally, this research has shown the potential of the soil composite developed here, which upon optimization can be used in more applications, perhaps 3D printed for complex shapes with tailored compositions as other clay-based materials [39, 40].

Conclusions

- RTPF and molasses blend is an environment-friendly, economical, and technical option for soil improving. Molasses is ecological by-product without toxic elements which is able to be applied without causing damage to environment. Molasses viscosity permits to separate randomly RTPF in soil ground and generates randomly distribute composite.
- An improvement of about 43% was achieved, going from 1419 kPa for the base line sample to 2037 kPa for the mixture with 2% of molasses and 0.1% of RTPF by dry weight of the soil.

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