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FENCE POST MANUFACTURING SYSTEM WITH MODIFIED ASPHALT FROM USED TIRES

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ABSTRACT

This article presents the design of a system for manufacturing fence posts by reusing end-of-life vehicle tires combined with asphalt, obtaining modified asphalt (CIB asphalt was chosen). A verified design is shown employing simulation, in addition to the evaluation of the industrial operation of the proposed design, obtaining a statistical analysis utilizing computational tools that allow the real system to be emulated (from a computational model) in which the interaction of each of the elements that make up the proposed system is to be shown. We are looking for an approximate and adequate response that meets all the requirements of the process in order to carry out its respective implementation and start-up in future works.

Keywords: CIB asphalt, rubber crumbs, used tires, polymer, simulation.

Manuscript Received 18 February 2023; Revised 16 July 2023; Published 25 July, 2023

1. INTRODUCTION

Recycling vehicle tires is a task that is becoming more and more important every day due to the enormous amount of tires that have already reached the end of their useful life and are discarded every year around the world, causing a great deal of pollution [1].

In Colombia, the Ministry of Environment and Sustainable Development, through Resolution 1326 of 2017, obliges tire manufacturers and producers to collect used tires and find ways to recycle them [2]. This allows tires to be put to better use to promote the circular economy and avoid all the risks of road accidents and the problems associated with the well-being of citizens and the environment [3]. In 2020, 1, 350, 000 tires were imported into Colombia, of which 71% were discarded (correctly or incorrectly), i.e., 958, 500 [4].

Used tires recycled in the city of Bogotá, for example, are used as inputs for new products as an alternative to the city's circular economy (Figure-1). The most significant volume of recycled tires is used for processing or energy recovery. For example, in cement manufacturing, where tires are used as part of the product design and as part of the fuel. Another use is the shredding of the material, i.e., the generation of granules that can produce synthetic sports fields to benefit sports practice in the city. In addition, energy recovery by incineration/combustion, co-combustion with coal or other fuels, pyrolysis and gasification [5] - [7]. Also, the mixture of shredded tires with asphalt is used to make layers in repair or patching works on public roads in Bogotá. [3]

Figure-1. Tire recycling days in Bogotá (Colombia) [3].

One of the preliminary steps for the construction of parts and systems nowadays is to make a computer simulation as accurate and close to the real desired system as possible; this step avoids and reveals the possible errors obtained, which can be previously solved before falling into unnecessary and high insurance costs as it usually happens in the industry, the objective of this paper is to evaluate the process for the design of fence posts based on mixtures of recycled vulcanized elements from car tires with asphalt material that is currently used for the construction of roads and access roads, employing a software used in the simulation of industrial processes called Promodel.

Promodel is a simulator with animation and optimization for personal computers. It allows you to simulate manufacturing, logistics, material handling and other systems. Conveyor belts, overhead cranes, assembly, cutting, workshops, logistics, etc., can be simulated. Once the model has been created, it can be optimized to find the optimal values of its key parameters [8]- [10].

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2. PROCESS MATERIALS DESCRIPTION

2.1 The Tire

The structure of this element is complex; tires can be classified into radial and diagonal according to the structure of the carcass and occupy 60% of the annual production of rubber in the industry, also known as elastomers; these polymers can vary their dimensions according to the effort to which they are subjected and recovering its shape once the force is removed [11]. In the manufacture of tires, different types of rubbers are used, among which are the natural rubbers that are extracted from the tree HeveaBrasiliensis; these in the industry occupy 30% of its use and the other 70% is obtained from synthetic rubbers such as Styrene - Butadiene, Polybutadienes and Polyisoprenes.

Once the useful life of a tire is over, it is considered waste, which causes not only a tremendous environmental impact but also problems when it is destroyed, which is why, in recent times, its reuse has been sought.

A tire is usually made up of the following parts [12], which can be seen graphically in Figure-2 and is described below:

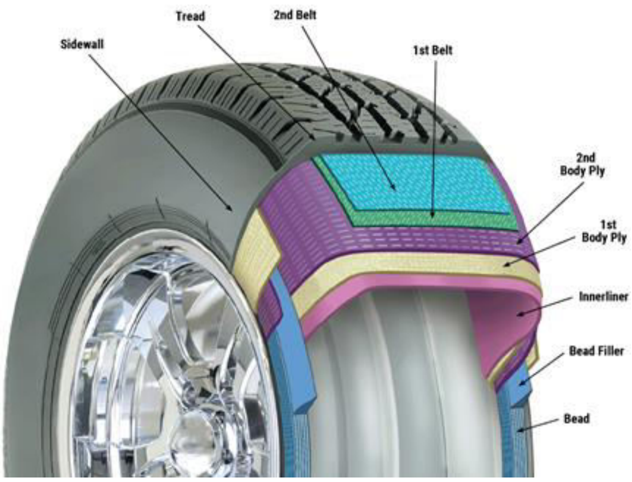

Figure-2. Tire parts [12].

- **Bead:** Tire bead beads (usually wire strands) fix the tire to the wheel; contribute to the transmission and tightness.
- **Bead filler:** A rubber compound that is placed on top of the bead bundle and can be used between the carcass plies that wrap around the bead to adjust the ride and handling characteristics.
- **Belts or Radial Ply:** Typically, two belts with steel cables placed at opposite angles. The belts provide stability to the tire tread, which contributes to wear, handling and traction.
- **Body Ply:** Most tires have one or two plies; each ply, usually composed of polyester, rayon or nylon cords within a layer of rubber, supports load and speed. These plies act as the tire's structure and provide the necessary strength to contain inflation pressure.
- **Innerliner:** A rubber compound used to retain inflation pressure inside the tire.
- **Sidewall:** Rubber compound used to cover the tire's sidewalls, providing abrasion, scratch and weather resistance, specially compounded to resist flexing.
- **Tread:** The rubber compound and tread pattern (allows for directionality) provides grip and abrasion resistance. This is the area that has direct contact with the surface, allows grip on all types of terrain, and also contributes to traction and tread wear [12].

2.2 Tire Chemical Composition

Combinations of different types of natural [13] and synthetic rubbers serve a purpose in tire construction, with natural materials aiming for elasticity and synthetic materials aiming for thermal stability. Figure-3 shows the structure of natural rubber.

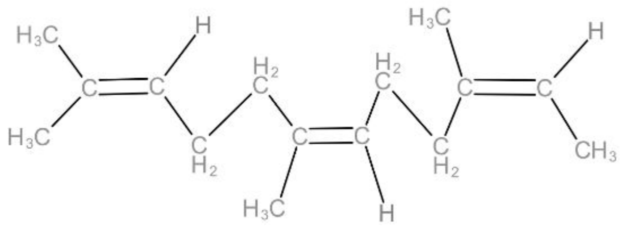

Figure-3. Chemical composition of natural rubber [13].

The structure of the tires consists of cis-1,4-polysoprene2 mixed with small amounts of proteins, lipids and inorganic salts, among others, resulting in a long-chain, coiled polymer with a medium molecular weight of 5x105 g/mol, which at room temperature is in a state of continuous agitation, this chain is complemented by another structural isomer called gutta-percha [11]. The structure of gutta-percha can be seen in Figure-4.

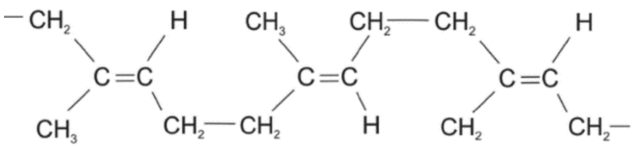

Figure-4. Chemical structure of gutta-percha [14].

In this process, the rubber changes from thermoplastic to elastomeric materials. The styrene makes it possible to obtain a more complex and tenacious rubber (achieving thermal stability), which crystallizes under high stresses [15].

2.3 Modified Asphalt Morphology

Different methods have been developed to study the morphology of modified asphalts, the most popular of which are:

- Optical microscopy.
- Fluorescence microscopy.
- Scanning electron microscopy.

To determine whether there is compatibility between the asphalt material and the polymers used, these methods require accurate and manometric (200 nm) thick samples to obtain reliable results.

One of the most widely recognized works, which is also one of the oldest and most comprehensive on the subject of polymer-modified asphalts, is presented in [16], in which the authors demonstrated the effectiveness of polymers as elements that improve the properties of asphalt at both high and low temperatures. The appropriate choice of asphalt, asphalt grade, polymer type and polymer concentration determines whether a network-like structure is formed. This structure was studied by transmission and scanning electron microscopy by preparing thin sections of the sample, embedding the asphalt-polymer mixture in a resin and sectioning it at minus 110 °C [15].

3. SIMULATION AND RESULTS OF RAW MATERIAL EXTRACTION FROM USED TIRES

3.1 Crushing Process

To obtain the material from the used tires, known as crumb rubber, the workflow of the tire recycling system starts with the cutting of the tire circle; this machine, called tire circle cutter, is in charge of removing the sidewall of the tire (sidewall in Figure-2).

Once separated, it passes to the cutting section of the tire strip where a long strip of approximately 5x8cm is obtained and generated by a machine called a tire strip cutter, which is then divided into small pieces of approximately 5.5cm3; this process is performed by a machine called tire slice cutter; finally, the separation of the metal material is performed which is known as Body Ply shown in Figure-2, while simultaneously the shredding of the rubber is done to obtain the rubber crumbs. Figure-5 shows the summary of the whole process described above.

Figure-5. Process for obtaining rubber crumbs [17].

VOL. 18, NO. 10, MAY 2023 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-1 shows the technical characteristics of the machines consulted to carry out the process of shredding used tires to obtain crumb rubber.

Table-1. Features of tire shredding machines.

Name	Power	Weight	Capacity	Tire specification
Tire Circle cutter	4KW	650kg	40pcs/h	650-1200mm (Both reinforced and nylon tires)
Tire Strip cutter	4KW	850kg	2500kg/h	Strip thickness: 5x8 cm
Tire slice cutter	4KW	800kg	800kg/h	Cutting sections: 3x5x8cm

3.2 Process Simulation

Using the Promodel computational tool described in section 1 of this article, the system responsible for carrying out the first stage of the process in which the rubber crumbs are obtained is designed, obtaining the design shown in Figure-6.

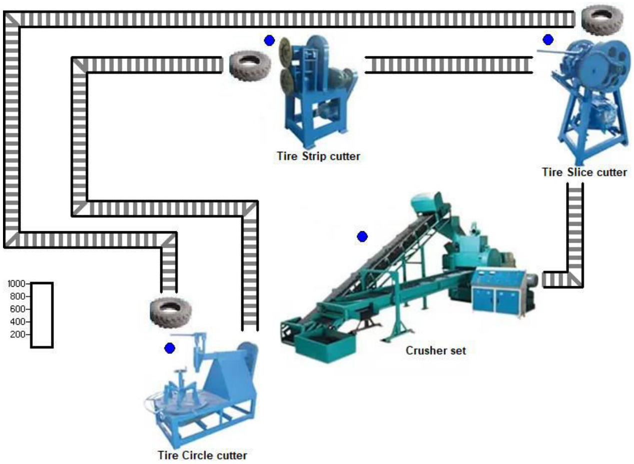

Figure-6. Design of the process to obtain rubber crumbs.

Taking into account the capacity specified in Table-1 for each machine, its process has been calculated in units per minute, which facilitates the calculations of the system operation; the results of this unit conversion can be seen in Table-2.

Table-2. Machine capacity in units per minute.

Name	Capacity
Tire Circle cutter	0.666pcs/min
Tire Strip cutter	41.666kg/min
Tire Slice cutter	13.333kg/min

3.3 Simulation Analysis

The results obtained from the simulation based on the design shown in Figure-6 were carried out at an interval of one hour, obtaining the following result (Figure-7):

- In a warehouse with a capacity to accumulate 100 units of used tires, 154 units are counted, arriving with an average of 23.97 units per minute.
- On the Tire Circle cutter, 54 units were processed with an average labor time of 0.59 minutes per unit.
- On the Tire Strip cutter, 39 units were processed.
- The Tire Slice cutter machine has several inputs of 37 and can process 36 units at the end of the simulation.
- These 36 units are pulverized into crumb rubber from 3 batches of 9 units (tires) for a total of 27 tires.

Name	Scheduled Time (HR)	Capacity	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Maximum Contents	Current Contents	% Utilization
Loc2	1,00	100,00	154,00	23,97	61,53	100,00	100,00	61,53
circle cutter	1,00	1,00	54,00	0,59	0,53	1,00	1,00	53,33
Loc3	1,00	100,00	53,00	7,73	6,83	14,00	14,00	6,83
Strip cutter	1,00	1,00	39,00	1,47	0,96	1,00	1,00	95,67
Loc7	1,00	100,00	38,00	0,98	0,62	1,00	1,00	0,62
Slice cutter	1,00	1,00	37,00	0,60	0,37	1,00	0,00	37,00
Loc8	1,00	100,00	37,00	3,28	2,03	7,00	1,00	2,03
Trituradora	1,00	9,00	36,00	11,25	6,75	9,00	9,00	75,00

Figure-7. Simulation results obtained.

The percentage utilization of each location, as shown in Figure-7 is distributed as follows:

- Tire Circle cutter = 53,33 %
- Tire Strip cutter = 95,67 %
- Tire Slice cutter = 37 %
- Trituradora = 75 %

It is clear from the working capacity of the individual locations that the warehouses are only partially occupied so that the storage capacity can be increased. In addition, the Tire Slice cutter has a utilization rate of 63%, with up to 25% of the maximum capacity of the shredder still to be utilized.

4. MANUFACTURE OF POLES BY ADDITION OF RUBBER TO ASPHALT MIXTURE

4.1 Asphalt Modification Method

Experiments have been recorded throughout history that involves recycled rubber as an alternative material that meets some needs and also solves an obvious problem formed by the pollution of waste tires in disuse; one of these studies conducted by the school of engineering of Antioquia [18] consists of the modification of asphalt from the Industrial Complex of

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Barrancabermeja (Santander, Colombia), known as CIB asphalt, is achieved by adding 14% tire rubber and 1% ground polystyrene before being incorporated into the asphalt, optimizing the particle size of the polymers in such a way that the expanded polystyrene is between the No. 10 and No. 40 sieve. The particle size selected for each modifier allows the formation of a homogeneous polymeric network between the asphalt and the polymer [19]- [22].

Figure-8 shows the rheological curve of a CIB asphalt sample; the viscosity can be seen in terms of temperature.

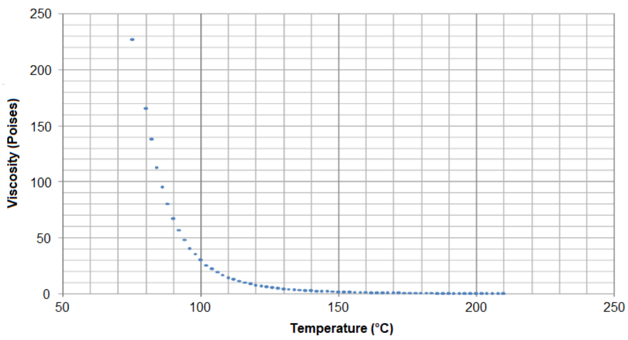

Figure-8. Rheology curve of CIB asphalt (modified from [18]).

4.2 Simulation and Results

The simulation process starts with the sieving of the crumb rubber to meet the requirements for the generation of a modified asphalt capable of compacting and withstanding the climate changes demanded by the field; this process lasts 15 minutes and then goes to a hopper where the asphalt cement is poured and mixed with 14% tire rubber obtained in the process shown in section 3 of this article, plus 1% polystyrene and 85% asphalt, this mixture is poured into molds and then flattened in batches of 6 packs. Figure-9 shows the design proposed in the simulator for the pole manufacturing system.

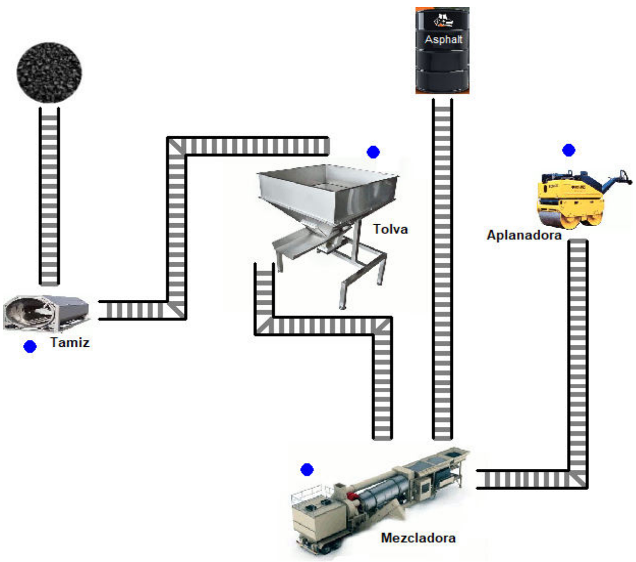

Figure-9. Pole manufacturing process design.

The manufacturing process of poles employing modified asphalt (CIB) generates a product that consumes considerable time, as shown in Figure-10 and Figure-11. The simulation for a 24-hour working interval of the production plant gives the following results:

- Tamiz = 71 units
- Tolva = 71 units
- Mezcladora = 65 units (15% of polymers and 85% of asphalt)
- Aplanadora = 7 batches of 6 units

Name	Scheduled Time (HR)	Capacity	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Maximum Contents	Current Contents	% Utilization
Loc1	24,00	999999,00	73,00	20,01	1,01	2,00	2,00	36,83
TAMIZ	24,00	1,00	71,00	15,00	0,74	1,00	0,00	73,96
Loc2	24,00	999999,00	71,00	5,31	0,26	6,00	6,00	4,28
TOLVA	24,00	1,00	65,00	1,89	0,09	1,00	1,00	8,53
Loc4	24,00	999999,00	64,00	11,35	0,50	4,00	4,00	11,15
MEZCLADORA	24,00	1,00	15,00	81,13	0,85	1,00	0,00	84,51
Loc6	24,00	999999,00	15,00	75,85	0,79	2,00	1,00	0,00
APLANADORA	24,00	1,00	7,00	10,00	0,05	1,00	0,00	4,86
Loc8	24,00	999999,00	15,00	324,78	3,38	5,00	0,00	58,99

Figure-10. Simulation results obtained.

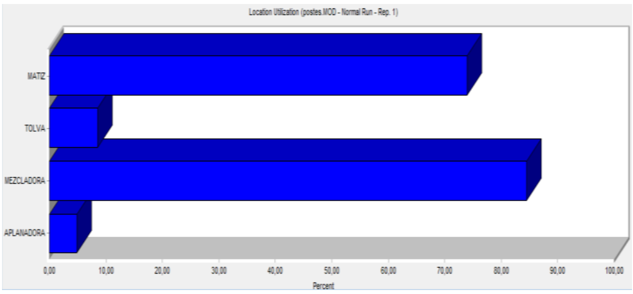

Figure-11. 24-hour utilization graph for each machine.

A crumb rubber utilization rate of 97.35% and a mold operation rate of 57.13% are obtained, as shown in Figure-12.

postes.MOD (Normal Run - Rep. 1)				
Name	% In Move Logic	% Waiting	% In Operation	% Blocked
Rubber crumbs	2,65	0,00	97,35	0,00
Asphalt	0,00	0,00	0,00	0,00
Mold	0,00	26,45	57,13	16,43

Figure-12. Percentage of raw material use.

5. CONCLUSIONS

With this design proposal, efficient use is achieved for disused tires, which benefits society and the environment, helping to reduce the pollution generated by this waste.

At the simulation level, it is observed that the time invested in the manufacture of poles from polymer-modified asphalt (rubber product of tire recycling) is high; therefore, it is required and suggested to whoever wishes to implement and assemble these plants to expand the mixing capacity and increase the number of molds to make production more efficient and agile.

In manufacturing rubber crumbs, waste is generated, including metal waste, which can be used in various ways to make the most of these disused tires.

ACKNOWLEDGMENTS

The authors would like to thank the Universidad Distrital Francisco José de Caldas and the LASER research group that supported the development and testing of the project.

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