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A study into the use of crumb rubber in railway ballast

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HIGHLIGHTS

- An alternative solution to improve ballast performance in railway.
- Viability of using crumb rubber as elastic aggregates mixed with ballast particles.
- Laboratory study of the ballast performance with diverse percentages of rubber.
- An optimal quantity of rubber is defined to be used in ballasted tracks.

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ABSTRACT

Ballasted track is the most common form of construction used in railway transportation due to a number of benefits in comparison with other solutions such as slab track. However, the degradation of the ballast particles and the layer settlement lead to important maintenance costs. Thus, diverse research has been carried out to develop new materials with the aim of increasing the service life of the track. To this end, the present paper focuses on the use of crumb rubber (from end-of-life tires) as elastic aggregates mixed with ballast particles, which could reduce ballast degradation and consumption of natural aggregates. At the same time, an abundant waste source is reused and the use of raw binders (proposed technique employed to bond elastic particles to ballast particles) is not necessary, which potentially reduces costs and consumption of raw materials. For this reason, the influence of different percentages of crumb rubber was studied in the laboratory using a ballast box. In addition, once the optimal quantity of rubber had been determined, its effect on ballast behaviour under high stress level was analysed. Results show that the use of 10% of crumb rubber (by volume) could reduce ballast degradation and at the same time as the capacity of the ballast layer to dissipate energy is increased and its stiffness is reduced. Additionally, based on the present laboratory study, the track settlement could be reduced with 10% rubber particles used as elastic aggregates.

1. Introduction

Railway track founded on a ballast layer is the most common solution used in rail transportation since this type of track presents a series of benefits associated with speed and cost of construction. The ballast layer consists of a granular material that supports railway sleepers and its main functions are the reduction of loads and vibrations transmitted to sublayers, water drainage and resistance to lateral and longitudinal forces [1,2]. However, the passage of trains leads to ballast degradation, which could instigate changes in the vertical stiffness of the railway track, and track differential settlement takes place since ballast is the most influential component in track vertical deformation [3]. Thus, ballast degradation necessitates maintenance tasks like tamping or stone blowing, when geometric parameters reach critical values, to recover the quality of the track geometry.

With the purpose of increasing the service life of ballasted track, diverse practical solutions have been developed in recent decades. The most widely used techniques are under-sleeper pads, under-ballast mats and geogrids. The first two solutions are mainly to reduce degradation of ballast since under-sleeper pads allow the reduction of stress transmitted to the granular layer [4], while mats achieve greater and softer surface contact with rigid substructures such as tunnels or bridges [5]. In addition, these elastic components are efficient for obtaining an optimal vertical stiffness of the railway track and absorbing loads and vibrations. On the other hand, Walls and Galbreath [6] reported that the use of

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geogrid reinforcement in the ballast could increase the periods between maintenance operations due to the decrease in vertical and lateral deformation of the ballast layer. Thus, the effect of geogrids has been widely studied [7,8,9] and they have been successfully applied in railway track ballast [3,10].

Innovative technical solutions have also been developed by using polymers as elastic elements between ballast particles with the same objective of improving ballast performance and durability. Some authors [11,12] have analysed the effect of filling the voids between particles with bonding polyurethane. These studies have concluded that it is possible to increase the elasticity and the resistance to plastic deformation of the ballast layer. In the same way, other researchers have focused their studies on using crumb rubber as a modifier of ballast behaviour, since the material from used tires has been proved to be appropriate to manufacture elastic elements for railway tracks [13]. One of these solutions is called "Resiliently Bound Ballast", which is a mixture of standard ballast stones and tire aggregates bound together with a resilient epoxy binder [14]. Another project entitled "Neoballast" aims to reduce ballast deterioration by bonding small particles of rubber to the ballast aggregates [15].

The application of crumb rubber (from used tires) bonded to ballast particles could be an appropriate solution since it allows reduction of an abundant waste material at the same time as improving ballast behaviour due to the elastic properties of rubber. However, the use of binders could increase construction costs and the durability of the mixture could limit the life-cycle of the material. Thus, the present paper aims to study the viability of using crumb rubber (CR) from used tires as elastic aggregates (without any binder) between ballast particles in order to reduce its degradation while that the track behaviour is modified. This solution could reduce the consumption of raw bonding materials at the same time that the quantity of waste tires used as elastic elements could be increased with respect to applications with bonding materials. In addition, it would be possible to decrease the consumption of natural aggregates since ballast replacement frequency could be reduced due to lower material degradation.

The study is divided into two different stages: (i) analysis of the influence of the percentage of crumb rubber used as elastic aggregate on ballast behaviour; (ii) evaluation of rubber particles effect on ballast response under high stress. These studies were carried out in the laboratory by using a ballast box. In order to determine the effect of the crumb rubber, the behaviour of the ballast box without elastic elements as well as the system with a standard rubber mat under the ballast layer were used as references.

2. Methodology

2.1. Materials

The ballast used in the study was from Cliffe Hill quarry in Leicestershire, United Kingdom, and is composed of granodite. The material can be described as uniformly graded, crushed hard stone. Table 1 shows the main physical and mechanical properties of the aggregates, which indicate that the granular material is appropriate to be used as ballast in railway tracks according to BS EN 13450.

The crumb rubber used as elastic aggregate in the ballast layer was obtained by cutting up end-of-life tires. The particles size was mainly between 16 mm and 8 mm, with a granulometric distribution as presented in Table 2, where the main physical properties and material composition are also listed. Fig. 1 shows the visual appearance of the crumb rubber, ballast particles and the mix of both materials.

A piece of synthetic rubber was used as a standard elastic mat in order to compare the mechanical performance of ballast with crumb rubber. This type of mat was cut to size with the purpose of being used as a common elastic solution that is utilized under the ballast layer in sections over rigid substructures. The thickness of the mat was approximately 20 mm whereas its static bearing modulus was 0.35 N/mm^3 and its dynamic modulus at 5 Hz was roughly 0.85 N/mm^3, these last two parameters being obtained according to the loading conditions listed in the Standard DBS 918 071-01.

Table 1
Characteristics of ballast.

Properties	Sieve (mm)	Ballast % Passing	BS EN 13450 % Passing
Granulometry EN 933-1	63	100.0	100
	50	78.2	70–99
	40	38.2	30–65
	31.5	6.9	1–25
	22.4	0.4	0–3
	31.5–50	71.34	>50
Content of fine particles (<0.5 mm) EN 933-1 (%)		0.2	0.6
Fines content (<0.063 mm) EN 933-1 (%)		0.1	0.5
Particles length (>100 mm) (%)		0.1	<0.4
Density EN 1097-6 (mg/m^3)		2.88	–
Resistance to fragmentation (L.A.) EN 1097-2 (%)		9	<12

Table 2
Properties of the crumb rubber used in the study.

Properties	Sieve (mm)	Crumb rubber % Passing
Granulometry EN 933-1	22.4	100.0
	16	87.8
	11.2	28.8
	8	0.2
Density (Mg/m^3)		1.15
Particle morphology		Irregular
Moisture content (%)		<0.75
Metal content (%)		<0.1
Textile content (%)		<0.5

Fig. 1. Visual appearance of the ballast and crumb rubber used as well as the mix of both materials.

2.2. Test planning

During this work, the crumb rubber was used as elastic aggregate in the ballast layer, evaluating its effect by mixing both materials and testing in a ballast box. In an initial step, the effect of using different quantities of crumb rubber on the behaviour of the ballast was evaluated. The percentages studied were 5%, 10%, 20% and 30% by volume in a box with dimensions 460 mm × 200 mm (horizontal surface) and 300 mm height. Fig. 2 shows the appearance of the bottom layer of the ballast mixed with different quantities of rubber particles, and the appearance of the box configuration, where a wooden block with aluminium base (148 mm in width, 190 mm in length, and 100 mm in height) is used to simulate the sleeper, and therefore, to transmit the stress to the ballast layer. The maximum percentage was established as 30% in order to study the ballast behaviour with almost all air voids filled with rubber, according to the average percentage of voids in ballast layers [16].