Influence of geosynthetic and rubber inclusions on shear and breakage behavior of rail track ballast

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ABSTRACT: Ballasted rail tracks and concrete slab tracks are the two major types of rail track structures all around the world. Due to the ease of construction and relatively low initial cost, ballasted tracks are popular compared to slab tracks. Ballast is a coarse and highly angular material with high shear strength and bearing capacity. Ballast is getting degraded over time due to the continuous transmission of energy by the wheel loads from freight and passenger trains, which leads to track settlement, track degradation, and high cost for maintenance. Rubber mats and geogrids are used in railways to improve the performance of ballast used in rail tracks. . In this study, several tests were conducted on fresh ballast and ballast stabilized with geosynthetic and rubber under direct shear loadings to check the performance of ballast. The outcomes in this study show that the combination of rubber mats with geogrid works well in terms of reducing ballast degradation and maintaining shear resistance of the ballast layer.

1 INTRODUCTION

Rail transport provides safer and economically beneficial passage to a large number of commuters and a large quantity of freights at once. It also has another advantage of having traffic problems faced in roadway transport. Typical conventional rail tracks consist of rails, sleepers, fasteners, ballast layer, capping layer, and formation soil (Alemu, 2011, Boler et al., 2014, Feng et al., 2019). The ballast layer is the primary load-bearing layer thus a thicker layer consists of granular aggregates with nominal size 40 - 50 mm (Claisse and Calla, 2006). It also provides easy water flow through its larger voids (Bian et al., 2016, Guo et al., 2020).

Ballast particles are undergoing corner breakage, crushing, and fouling due to either repeated train movements or operation during maintenance activities such as tamping. Aggregates become rounded as the corners are broken, thus reduction in particle interlocking within the ballast layer. This leads to excessive total and differential settlement hence discomfort and safety issues in train transport (Aursudkij, 2007, Dahal et al., 2018, Dash and Shivadas, 2012, Ebrahimi et al., 2015). Still, the ballast is more desirable to track structure compared to concrete or asphalt slabs. Therefore, it is essential to improve the performance and service life of ballast under repeated cyclic and impact loads using artificial inclusions.

This paper presents the application of artificial inclusions and the ballast performance improvement using rubber pads and geogrids. This paper also discusses the application and benefits, the experimental approach, results, and derived conclusions based on the laboratory tests carried out on ballast with rubber pads and geogrid under shearing load conditions using a large-scale direct shear test apparatus.

2 APPLICATION AND BENEFITS

2.1 *Rubber pads*

Rubber inclusions lessen the intensity of impact and cyclic loads generated by moving trains on the substructure and reduces the track degradation. It also absorbs the vibration and provides a more comfortable and less noisy travel experience to the commuters. Rail pads (RP), under sleeper pads (USP), and under ballast mats (UBM) are the commonly used different types of rubber inclusions in the track structure (Navaratnarajah et al., 2020). As shown in Fig. 1, these rubber elements are inserted in different positions.

The flexibility of USP material increases the number of load-bearing sleepers per axle and also increases the contact area between sleeper and ballast (Navaratnarajah, 2017, Navaratnarajah, 2019). This leads to a significant reduction of the stress on the ballast layer. Sleepers with USPs also improve the lateral resistance of the track (Gräbe et al., 2016, Navaratnarajah et al., 2015). UBMs are more effective on stiffer formation conditions as it reduces the faster ballast deterioration. Another advantage of the introduction of UBM is the reduced thickness of the ballast layer is sufficient to perform well (Indraratna et al., 2014, Indraratna et al., 2020). Nowadays researchers are working on the effect of placing recycled rubber clumps into the capping layer (Indraratna et al., 2019, Indraratna et al., 2020, Sun et al., 2020).

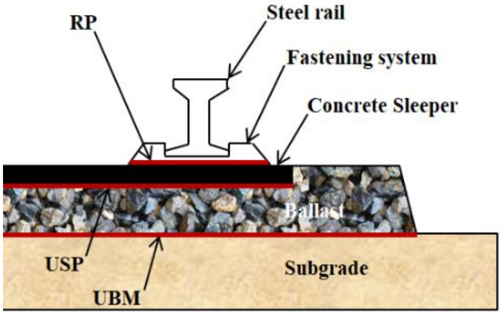


Fig. 1 Various rubber pads used in rail track structure

2.2 *Geogrids*

Geogrids are flexible, tensile elements that are strong in tension. When geogrid is inserted into the ballast layer it acts as reinforcement. It interlocks the ballast aggregates into its open apertures and resists the movement of the aggregates (see Fig. 2). Therefore, the ballast layer experiences lateral confinement after the installation of geogrid. Geogrid also facilitates quicker drainage without any hindrance. And also it leads to an increase in shear strength of the ballast layer (Biabani and Indraratna, 2015, Chen et al., 2012, Horníček et al., 2017, Sweta and Hussaini, 2018). Uniaxial, biaxial, and triaxial geogrids are commercially available but biaxial geogrids are adapted for rail track applications. Geogrid reinforcement gives optimum performance improvement to the tracks on weak subgrade as it provides more compressibility (Chawla and Shahu, 2016, Indraratna et al., 2006, Ngo et al., 2017, Venuja et al., 2020).

Fig. 2 Mechanical interlocking of ballast aggregates into the geogrid apertures

3 EXPERIMENTAL WORK

3.1 *Materials and test apparatus*

Essential materials for this experimentally based study are ballast, USP, UBM, and geogrid. Ballast was collected from the Nawalapitiya railway unit. Ballast was sieved and thoroughly cleaned with water to remove any adhered particles. The mechanical properties of USP and UBM which were used in this study can be found elsewhere (Venuja et al., 2020). Polypropylene extruded biaxial geogrid was obtained from a local supplier.

Large-scale direct shear test apparatus was used to conduct tests on ballast with and without the inclusion of USP, UBM, and geogrid. Unlike the square shear plane of standard direct shear apparatus, this test device is designed with a circular shear area. Thus, the apparatus consists of two equal hollow cylinders with dimensions of 400 mm diameter and 150 mm height each. The upper cylinder is immobile where the lower cylinder is allowed to move in the shearing direction only. Shearing can be applied using a hydraulic jack and normal load can be applied to the sample using a static lever arm system.

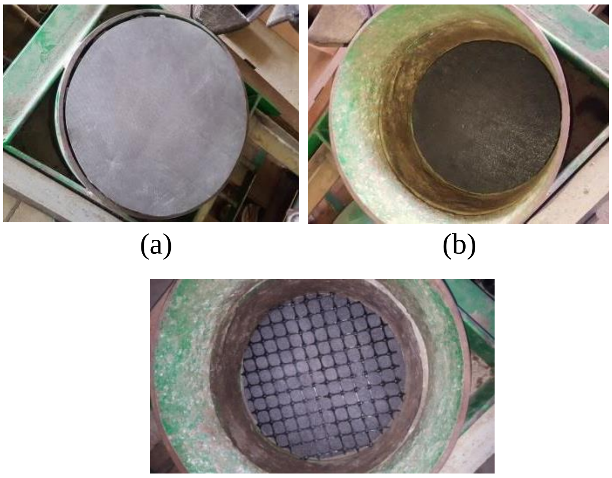
3.2 *Test setup*

Ballast was mixed in the mass proportions as shown in Table 1 to get the particle size distribution that satisfies the standard limits of Indian Railway ballast requirements. After mixing, ballast was filled into the apparatus in three layers and each layer was compacted using a rubber-padded hammer to achieve the field unit weight of 16.1 kN/m^3.

Table 1. The particle size distribution of test specimen

Sieve sizes / (mm)	mass retained (%)
63	0
50	32
37.5	28
25	25
20	15

Tests were conducted on fresh ballast, ballast with single artificial inclusion, and ballast with a combination of artificial inclusions. UBM was laid at the bottom of the apparatus, USP was put on top of the ballast, and geogrid was placed on top of the UBM based on the test requirement (see Fig. 3). All test specimens were tested under 30, 60, and 90 kPa normal stresses with a constant lateral shearing rate of 4 mm/min. Load cell, vertical displacement transducer, and horizontal displacement transducer were connected to the data logger to obtain the readings of shear load, vertical displacement, and horizontal displacement with time, respectively.



(a) (b)

(c)

Fig. 3 Type of artificial inclusions and it's insertion positions; (a) USP; (b) UBM; (c) Geogrid

4 RESULTS ANALYSIS

Shear stresses were calculated using the corrected shear area for the circular-shaped shear plane suggested by Olson and Lai (1989). Fig. 4 shows the shear stress variation with the shear strain of all types of samples under 30, 60, and 90 kPa. Shear stresses of all samples showed an increasing trend and attained maximum values near 13 to 15 % of shear strains. Shear stress increased with applied normal loads irrespective of sample type. This is due to the higher interlocking between aggregates which is induced by higher normal stresses, results improved frictional resistance. Further, as shown in Table 2, friction angles of each type of sample were calculated by developing Mohr-Coulomb failure envelopes. The rubber elements showed a reduction in shearing resistance compared to fresh ballast. This is due to the fact that the rough concrete interface is replaced with a somewhat smooth interface of rubber elements. However, ballast with (USP + UBM + geogrid) showed nearly the same values of friction angle as fresh ballast. This could be a result of the mechanical interlocking provided by geogrid which provides more resistance to shearing.

Table 2. Friction angles of various samples using Mohr-Coulomb criteria

Sample	Friction angle (°)
Fresh ballast	68
Ballast + UBM	61
Ballast + USP	59
Ballast + UBM + USP	62
Ballast + UBM + USP + Geogrid	67

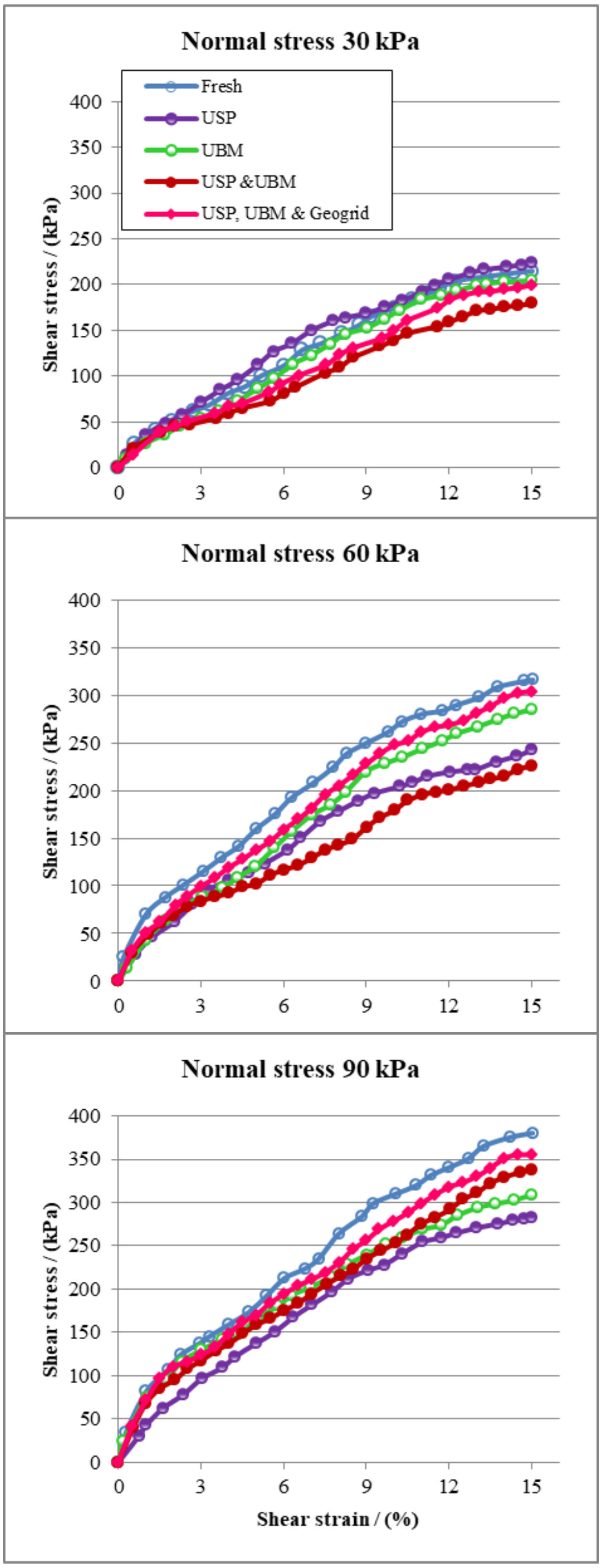


Fig. 4 Shear stress variation of different samples with shear strain under different normal stresses

Fig. 5 shows the dilation behavior of different samples under 60 kPa normal stress with shear strain. All samples showed minimal compression at the initial shear strain and started dilating after that. This is because the normal load application is prominent at the beginning. Dilation is caused by the rolling over of ballast aggregates on top of each other during shearing. A significant change in volumetric behavior with sample types was not observed. But dilation was decreased with high normal stresses for all types of samples.

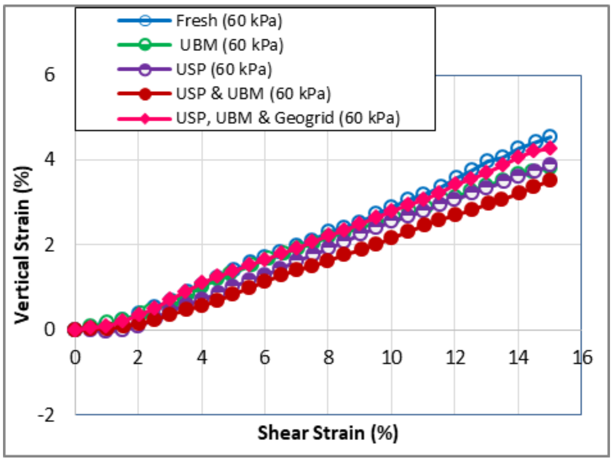


Fig. 5 Vertical strain variation of different samples with shear strain under 60 kPa normal stress

Breakage of ballast particles was observed at the end of each test. Ballast breakage is an important parameter that needs to be quantified which influences the track performance. The well-known method to quantify the breakage is the ballast breakage index (BBI) which was proposed by Indraratna et al. (2005) is used in this study. BBI values were calculated by conducting sieve analysis after each test and plotting the particle size distribution of each sample before and after the test. Calculated BBI values of different samples are tabulated in Table 3.

Table 3. BBI of various samples under different normal loads

Ballast and type of inclusions	Normal Stress		
	30 kPa	60 kPa	90 kPa
Fresh ballast (S1)	0.043	0.052	0.069
Ballast + UBM (S2)	0.033	0.034	0.059
Ballast + USP (S3)	0.024	0.030	0.037
Ballast + UBM + USP (S4)	0.023	0.029	0.035
Ballast + UBM + USP + Geogrid (S5)	0.020	0.030	0.036

When the normal stress increased from 30 kPa to 90 kPa, there is a significant increase in the BBI of each sample. This is because the higher normal stress compresses the ballast sample which leads to higher breakage. Less breakage was observed for the ballast with a combination of USP and UBM as USP distributed normal loads through an extended area and UBM created a softer interface with ballast aggregates. Also, the BBI of all samples under 90 kPa were calculated layers-wise by painting each layer. As the shear band is formed near the shear plane, particles in the shear band were undergone high breakage therefore high BBI was observed in the middle layer of each sample as shown in Fig. 6.

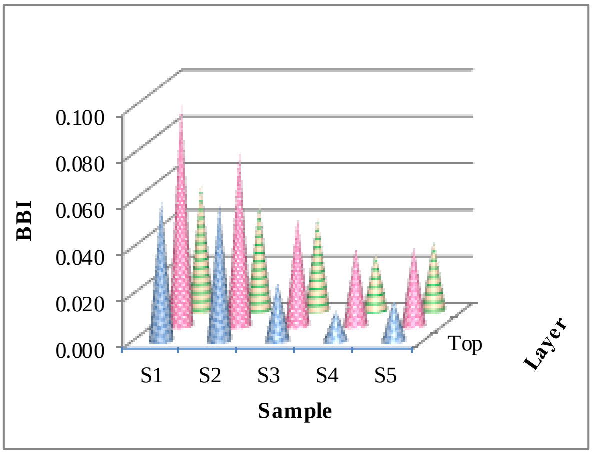


Fig. 6 Layer wise BBI of each type of sample under 90 kPa normal stress

5 CONCLUSIONS

This series of direct shear tests were conducted on ballast to analyze the shear, dilation, and breakage behavior of ballast with artificial inclusions such as USP, UBM, and geogrid. Regardless of the type of inclusions, shear stress increased with normal stress as higher frictional resistance was generated due to improved particle interlocking. Similarly, high breakage was observed with higher normal stress. Ballast with USP and UBM showed a minimum value of BBI. Further, rubber reduces the shear slightly and reduces the breakage considerably high. However, the inclusion of geogrid with the combination of rubber brings back some of the lost shear of ballast. Therefore, based on the finding from this study, it is recommended to use a combination of rubber pads and geogrid in the rail tracks to improve the performance in terms of increasing ballast shear resistance and reducing ballast particle breakage.

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