Performance enhancement of railtrack ballast with rubber inclusions: a laboratory simulation

Chee-Ming Chan i) and Siti Farhana SM Johan ii)

i) Associate Professor, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Johor, Malaysia.
ii) MSc. Student, Railway Engineering Programme, Universiti Tun Hussein Onn Malaysia, 86400 Johor, Malaysia.

ABSTRACT

Railway ballast, which form an integral part of railtracks, is highly susceptible to subsistence due to both vibration transmitted by the passing trains, as well as the breakage of the ballasts themselves with repeated impact. The resulting subsistence necessitates regular monitoring and maintenance, involving cost- and time-consuming remedial actions, such as stone-blowing and ballast renewal. It would therefore be desirable if measures could be taken to minimize the wear and tear effect of the rail traffic, consequently to prolong the lifespan of the ballast layer. This paper describes the exploratory work on rubber inclusions to address this problem. The rubber elements were derived from the inner tubes of motorcycle tyres, cut and shaped accordingly to produce various configurations for the study. Granitic stones of suitable size were sieved and used as representative samples of typical ballast as the tests were mainly carried out with a standard direct shear test setup, i.e. shearbox measuring 60 mm x 60 mm. The rubber tubes were cut and shredded to produce strips and shreds respectively, and the elements were arranged in various pre-determined configurations within the simulated ballast layer. The direct shear test results indicated that rubber inclusion could effectively improve the shear resistance of ballast to various degrees, though the configurations clearly played an important role in the improvement observed. Both strips and shreds were found expedient in deformation control with increased ductility of the composites, with potential to absorb impact and reduce breakages of the ballasts. Both mechanisms contributed to the reduced overall subsistence, accompanied by an increase in the shear resistance. As such, the present study indicates a promising application of the material in improving the performance and longevity of existing ballast layer in railtracks. Nonetheless, considering that the test setup is but a static, scaled down simulation, without dynamic loading which mimics the rail traffic, it is necessary to conduct further investigations in instrumented full-scale setups for verifications prior to filed implementation.

Keywords: railtrack ballasts, rubber inclusions, shear resistance, deformation

1 INTRODUCTION

Railtracks are typically made up of rails, sleepers, railpads, fastenings, ballast, sub-ballast and subgrade. All the components constitute the superstructure of a railtrack while the subgrade consists of a formation layer and the base of the track. Ballast, essentially angular hard stones, could be sourced from granite, limestone, recycled slag or other crushed stones. The ballast layer, with depths of 30-50 cm, functions as a support to the track structure against deformation from dynamic loads transmitted by the passing trains. Considering the cost-effectiveness, availability and practicality of ballast, advancement in railway technology would arguably outrun the material substitution or total replacement in the near future (Eisenmann, 1995).

As summarised by Selig and Waters (1994), vertical and horizontal movements caused by traffic loads are attributed mainly to the deformation and densification of the ballast. Compromised performance of the railtracks leads to poor ride quality, requiring either speed restrictions or maintenance to realign the tracks (Anderson and Key, 2000). Ballast has to be tough, dense, weather-resistant and mechanically stable (Dahlberg, 2004). Based on conventional triaxial tests, Janardhanam and Desai (1983) concluded that the particle size of ballast significantly affect the overall resilient modulus, volumetric and shear behaviour. It follows that track settlement is very much dependent on the ballast quality and its response to traffic load.

Jacobsson and Runesson (2002) attributed track settlement to volume reduction caused by densification and the non-elastic behaviour of ballast-subgade system: the former involves phases of particle rearrangement, penetration into ballast voids, particle breakdown and abrasive wear, the latter encompasses inter-particle microslips as well as movement of ballast and/or sleepers. It was also reported that the initial packing of the ballast has a strong influence on the long term track performance, resulting in greater permanent

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as well as differential deformations (Morgan and Markland, 1981 and Augustin et al., 2003). Excessive track settlement is generally due to the accumulated plastic deformation of ballasts and substructure layers (Li and Selig, 1995). However this gradual accumulation of permanent strains with traffic loads is often overlooked as dynamic records often show negligible elastic deformation of the track support system, where only static measurements reveal the accrued plastic strains (Yoo and Selig, 1979). Furthermore, Dwyer-Joyce et al. (2003) simulated rail-wheel contact with ballast and found that crushed ballast do not only indent and roughen the metal, but inadvertently increase the traction level and reduce the residual fatigue life of the contact.

Referring to the above, it is apparent that prolonged ballast life could effectively enhance the overall performance of railtracks. This paper examines the potential of rubber inclusions in increasing the shear resistance of ballast, hence reducing the wear-and-tear effect of traffic loads. Only static load was applied using a conventional shearbox tests setup in this exploratory work.

2 TEST MATERIALS AND METHODS

The particle size distribution plot of granitic aggregates used to represent ballast in the study is shown in Fig. 1. Note that the downsized particles were necessary to fulfill the shearbox dimensional requirements. The average crushing strength of the aggregates was recorded at 85 kN. In order to identify shear resistance deterioration of the aggregate-rubber mixture under poor drainage conditions in prolonged wet weather, a batch of aggregates only were soaked in water for 7 days prior to mixing and testing.

The rubber inclusions, in strips and shreds, were prepared from new inner tubes of motorcycles (Fig. 2). The thickness of the inner tube was approximately 1 mm. Similar granular material (sand) and rubber mixtures have been reported to demonstrate characteristics of low void ratio and mass density, but high compressibility, friction angle and attenuation (Yanagida et al., 2002, Zornberg et al., 2004 and Pamukcu and Akbulut, 2006). The aggregate-rubber mixtures for the present study were maintained at x:y ratio for all specimens.

The shearbox test was conducted on specimens of 60 mm x 60 mm x 25 mm at a shearing rate of 0.2 mm/minute (BS1377, 1990). The width to thickness ratio of 2.4 gives a large width compared to the thickness, thus eliminating edge effects and ensures shearing on the flat contact surfaces (Olson, 1989). Also, the minimum specimen width and initial thickness should be kept ≥10 times and ≥6 times the maximum particle diameter respectively, while the minimum width should be at least twice the thickness (Cerato and Lutenegger, 2006). The angular-shaped granitic aggregate size which ranged between 63 µm to 0.15 mm clearly fulfilled this criteria. The 3 vertical stresses applied for each test was 5, 7 and 9 kPa.

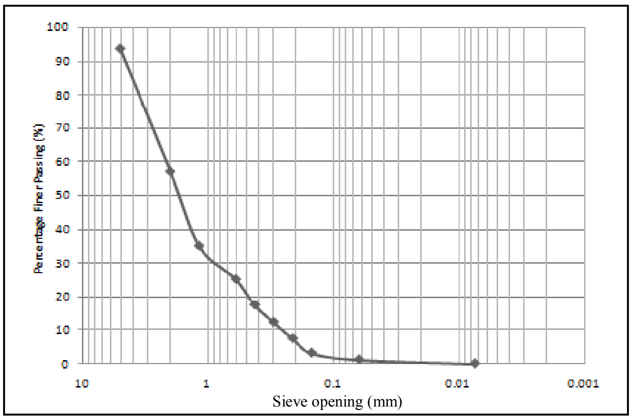

Fig. 1. Aggregates: granitic and angular-shaped.

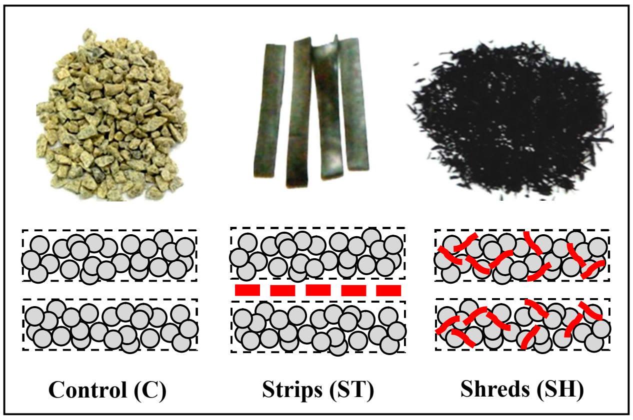

Fig. 2. Rubber inclusions in various configurations.

3 RESULTS AND DISCUSSIONS

Fig. 3 shows the shear stress (τ) – shear strain (ε) plots for all specimens tested. Note that the shear strain was derived from the horizontal displacement measured in the shearbox test. As expected, τ increased with the increased vertical stress (σ_v) applied in all cases, though the 7-day soaking did not seem to have much effect on the results obtained. Nonetheless, the dry condition was found to be expedient in the specimens with rubber strips (ST) inclusions, where τ was recorded as high as 270 kPa. In the case of the rubber shred (SH) reinforcement, dry condition also appeared to be favourable for shear resistance, especially at higher σ_v.

Although the overall shear resistance did not rise dramatically with the rubber reinforcement, the stress-strain plots do suggest a more ductile behaviour in the aggregate-rubber composite. This is evident in the linear rise of τ with ε up to approximately 10 % ε for the Control (C) specimens followed by a sudden decline, compared with the gradual yet continual increment of τ for the ST and SH specimens (Fig. 3). For instance, at $\varepsilon = 5$ %, the corresponding τ_{AVG} for both ST and SH was about 125 kPa, while specimens C recorded approximately 100 kPa. This can be attributed to the water lubricating the aggregate - rubber element interface, and reducing the frictional force developed between the two.

The vertical (ε_v) and horizontal (ε_h) displacements are plotted againts each other in Fig. 4. The inclusion of rubber elements apparently prevented dilation of the granular material when it is approaching shear failure, as indicated by the rather flat ε_v-ε_h plots for ST and SH as compared to C. Settlement was most severe in the unreinforced specimen under high σ_v. Interestingly SH demonstrated distinct ε_v for the dry and wet sepcimens, where the moisture made the rubbershreds less effective in reinforcing the aggregates with approching shear failure.

By relating Fig. 3 and 4, one would notice the less movement required to mobilize maximum shear strength in the composites compared to the Control specimens. Clearly the rubber inclusions contributed to the increased shear resistance. Dry or wet conditions did not seem to make much difference in the ST specimens. Unlike the SH case, the moisture seemed to cause significant slippage among the aggregates despite the rubbershreds addition at ε_h>0.4 mm or 0.67 %. On the other hand, the Control specimens showed markedly suppressed tendency to dilate reaching failure under dry condition. Excessive settlement and dilation were evident in the wet specimens, with the former referring to C_9kPa (W), i.e. overwhelming σ_v effect.

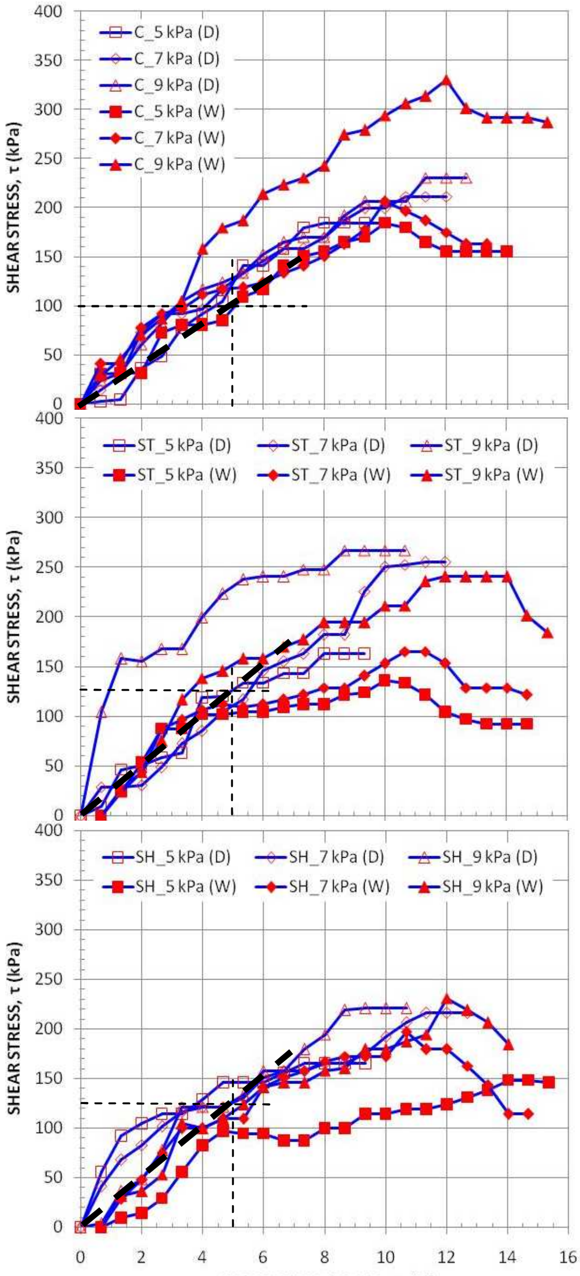

Fig. 3. $\tau - \varepsilon_v$ plots.

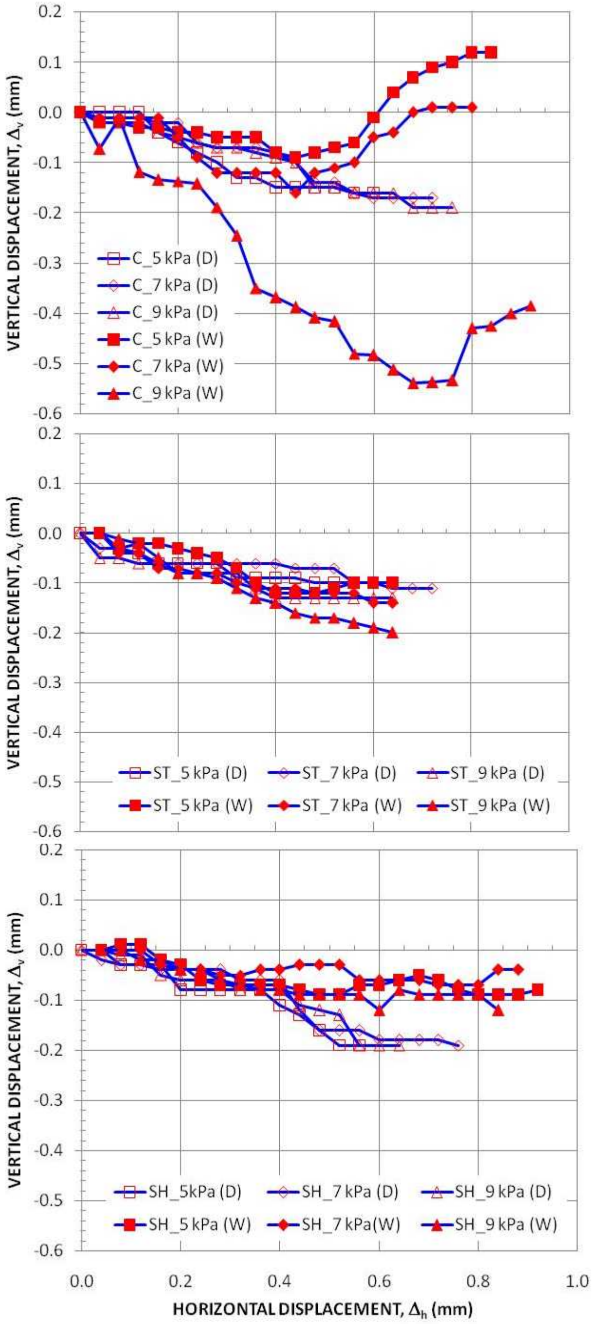

Fig. 4. $\varepsilon_v - \varepsilon_h$ plots.

Table 1. Summary of friction angle (ϕ).

Specimen	tanϕ		ϕ (°)	
	DRY (D)	WET	DRY (D)	WET
Control (C)	26.83	26.76	87.87	87.86
Strip (ST)	32.30	25.82	88.23	87.78
Shred (SH)	27.94	28.11	87.95	87.96

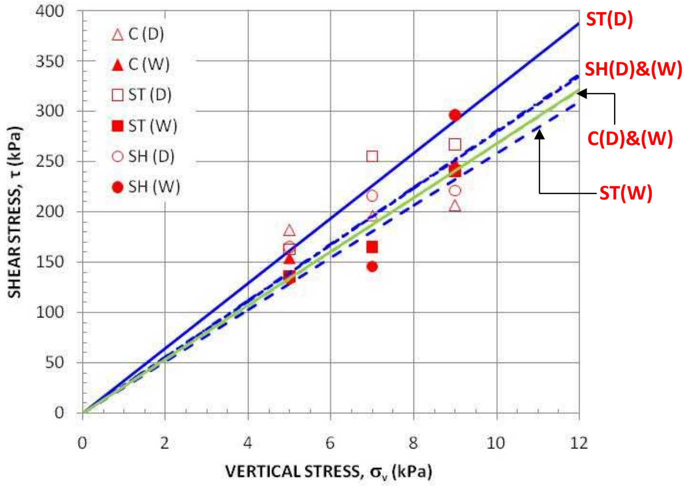

Fig. 5. $\tau - \sigma_v$' plots.

The shear strength envelope is derived in Fig. 5 and the friction angle (ϕ) summarized in Table 1. As there were no fines in the specimens and that the primary assumption made in the test was that the shear resistance was developed entirely from friction alone, there is no y-axis intercept (i.e. cohesion) for all cases. These plots give further insights to the mechanism of shear resistance development in the composites. Overall the τ-σ_v relationships do not differ much among the specimens tested, except in the case of ST. Labels are included in Fig. 5 to indicate the overlapping plots for C and SH. When the SH composite was wet, the rubberstrips required greater σ_v to attain higher shear resistance with the aggregates (see Fig. 3). Moreover, the sudden drop in τ with approaching failure hinted at the poor contact between rubber and aggregates when the composite is inundated with water. Further work could be directed at possible roughened strip surface and larger contact area or closer spacing of the strips.

4 CONCLUSIONS

The paper describes some preliminary work on the shear resistance enhancement of aggregates with rubber elements inclusion. It was found that wet condition somehow impeded the mobilization of shear resistance, but the overall deformation of the composites was reduced compared to the Control specimens, with higher shear resistance mobilized too. Future work could include more detailed rubber-aggregate configurations as well as surface treatment of the rubber elements to improve the frictional contact. Protection of the train's metal wheels with reduced ballast breakage from the cushion effects of the rubber elements should be examined too.

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