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SHEAR RESISTANCE OF RUBBER-BALLAST COMPOSITES IN SIMULATED WATER AND ACID SOAKED CONDITIONS

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ABSTRACT

Ballast is one of the main structures for the railway tracks. It can resist the lateral movement under dynamic loading transferred by the passing trains with repeatedly. Under some circumstances, ballast can suffer degradation or breakdown due to the repeated loading and maintenance. Ballast is easily exposed to the weather because it is laid on the track. Acid rain affects the performance of the railway track near the industrial and urban area. As a result, it starts to foul and the small chips from ballast filled the void, as well as reduce the shear strength of ballast particles. This situation can contribute into the increasing of maintenance frequency and costing. This paper examines the potential of rubber inclusions in increasing the shear resistance of rubber-ballast composites in simulated water and acid soaked conditions with several configuration. This lab-based exploratory work is only static load simulation in conventional shear box setup measuring 60 mm × 60 mm. The aggregates size is 10 times smaller than actual size of ballast. In order to identify the shear resistance deterioration of rubber-aggregates mixture under poor drainage conditions by soaked a batch of aggregates in water and acid solution for 2 weeks to simulate accelerated weathering effects. The shear resistance did not rise dramatically with the rubber reinforcement. This susceptible shear strain plots indicate ductile behaviour on the aggregates-rubber composites. This is evident by the linear rise of shear stress with strain up to approximately 10% for the control samples (CS) until it reaches a constant value. Note that all the specimens including CS are in a loose state during the testing because there were no tamping been applied on the samples. Overall the circular patch (CP) specimen was the most favourable than the other configurations. Both mechanisms contributed to the reduced overall subsistence, accompanied by an increase in the shear resistance. The inclusion of rubber elements apparently prevented the dilation of the granular material when approaching the shear failure and the reducing the settlement.

Keywords: Acid hydrochloric; Ballast; Railway tracks; Rubber; Shear box

1. INTRODUCTION

Railway tracks have a flexible support which is known as ballasted track (Figure 1). Ballast usually consists of crushed stones (gravel) that have some damping affect for the vibrations. The shape of stones should have angular shape in order to achieve the best interlocking and resist the lateral movement under dynamic loading. Ballast also can distribute the load until the subgrade layer and act as drainage by allowing the rainwater through ballast. Under some

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circumstances, ballast can suffer degradation or breakdown due to the repeated loading and maintenance. Bonnett (2005) stated that the edges of stones (gravel) will become rounded after receive loading and vibration with repeatedly from the trains. In addition, the layer of ballast is designed to have free drainage. If the voids are fully or partially fill the ballast layer with the small particles, the fouled can be occur during the operation (Indraratna et al., 2014). When the ballast ‘fouled’, the angular shape of ballast also changes into rounded and has low shear strength. Therefore, this problem also contributes into the increasing of maintenance frequency and rehabilitation costing. Raymond et al. (1975) and Shenton (1975) also mentioned that the cost of maintenance for the rail track had taken the major portion of budget cost just for the geotechnical problems. Therefore, it is necessary to have some measures to reduce maintenance track but still need to provide good track performance and comfort to the train passengers. Ballast is easily exposed to the weather because it is laid on the track. For example, Malaysia as tropical country is hot and humid throughout the year. Khabbaz and Indraratna (2009) reported that the presences of water or ballast moisture are one of factors ballast breakage. Acid rain affects the performance of the railway track, near industrial area. EPA (Environmental Protection Agency) attributes the main sources of acid rain deposition to factories with large “smoke channel” facilities which releasing the smoke to the air. Nordberg et al. (1985) and Spengler et al. (1990) also found the contamination of toxic gas as the main cause of acid rain, especially in urban and industrial areas. In addition, ballast breakdown and fouling can occur during transportation and handling or over time due to chemical interactions (Selig and Waters, 1994). However, Ashadi et al. (2015) showed that the negative effect of acid rain on gravel or aggregates in term of corrosion or crack is low.

Kim and Ha (2014) defined strain as the deformation of a solid due to stress as a percentage of the quotient of shear strain divided by the length of shear box. The higher the stresses applied, the more strain takes place on the material. When the stress is removed, the gravels would still remain permanently deformed into new shape. Zornberg et al. (2004) and Xiao et al. (2013) examined the behaviour of tyre shreds-sand mixtures and found shear strength improvement with tyre shreds inclusions sustain with greater elastic deformation. The mechanical properties aggregates will enhanced with rubber inclusions, as mentioned by Edincliler et al. (2010). This paper examines the potential of rubber inclusions in increasing the shear resistance of rubber-ballast composites in simulated water and acid solution soaked conditions with several configurations. This lab-based exploratory work is only static load simulation in conventional shear box setup.

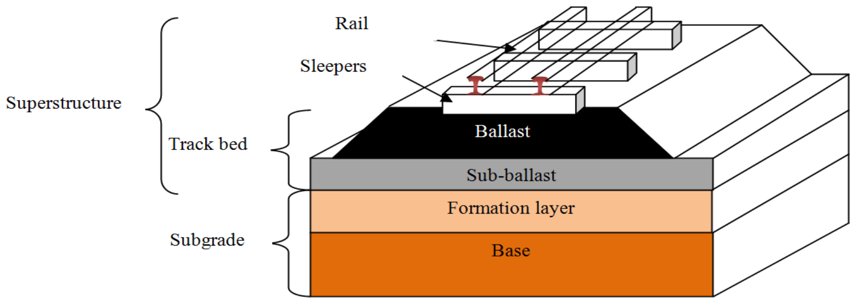

Figure 1 Cross-section of typical railway track system

2. EXPERIMENTAL WORK

2.1. Materials

Aggregates used in this study are gravels meant to represent ballast particles. The particle size distribution plot is shown in Figure 2. The particles are aggregates with angular shapes, which physical properties were evaluated using standard test procedures based on BS 1377(1990). The particles size of the gravels were sieved to smaller sizes suitable for the shear box condition, i.e. scale down to 10 times from the original size of ballast found in rail tracks, which are generally 300–500 mm. Gravels of suitable sizes were sieved and used as representative samples of the ballast. Prior to the test, the gravels were soaked with acid solution for 14 days. The rubber strip, circular patch and shreds were derived from inner tyre tubes used for motorcycles. The thickness of the inner tube was approximately 1.5 mm. Rubber tube was cut accordingly to produce various configurations as in Figure 3. The concentration of hydrochloric acid used was 0.05 mol/l, prepared by dilution with distilled water to obtain similar acidity as acid rain. To prepare the acid, a 1000 ml of distilled water has been used with molarities of concentrated 0.1M of hydrochloric acid (HCL). Thus, the volume of concentrated HCL needed is approximately 500 ml. For the next step, distilled water was added to the volumetric flask before adding concentrated HCL. This was to avoid explosion or broken volumetric flask as the chemical process involved excessive heat. Note that, the purpose of acid solution for this experiment was to determine the environment effect on the ballast aggregates, especially rail tracks near with the industrial areas.

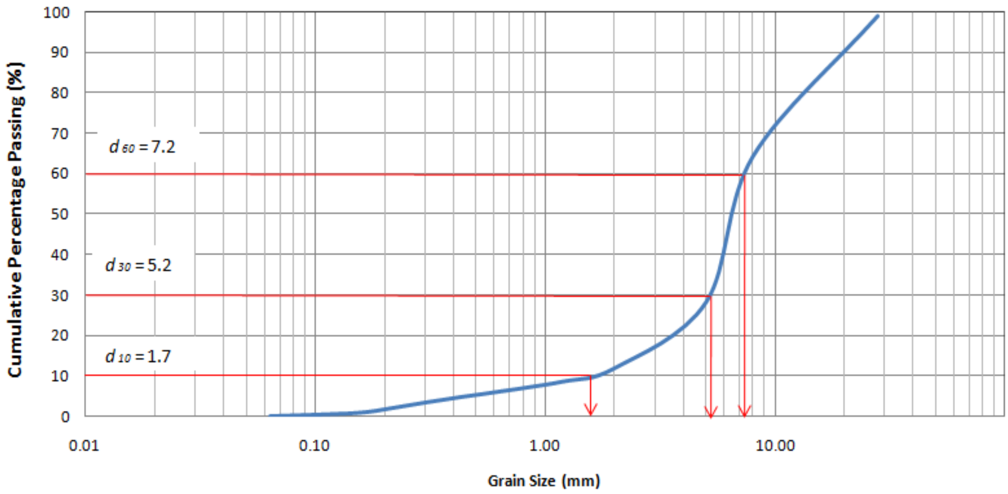

Figure 2 Particle size distribution of ballast aggregates

2.2. Methods

The lab-based experimental work used was standard direct shear box. The 3 vertical stresses applied for each test was 5 kPa, 7 kPa and 9 kPa. The stress applied until it reached constant with 1.6% horizontal strain per minute. The direct shear test was performed to obtain shear resistance of the ballast aggregates with rubber inclusions in various predetermined configurations. Figure 3 showed the cross section position of rubber with each configurations (i.e. SH as shreds, ST as strips and CP as circular patch). The configurations of rubber tube had been shaped for 3 configurations such as strips, shreds and circular patch. The contact area between rubber-aggregates was 40% of rubber and the aggregates with 60%. The rubber shreds were then mixed equally with aggregates manually before put into shear box. However, both rubber strips and circular patch were only placed it between the aggregates inside the shear box. The weight of aggregates sample was 20 g. Each of the configurations has difference contact area with the ballast. The circular patch more wide surface area than the strips and shreds, respectively. Note that the samples are in loose particles because no tamping been applied in this study.

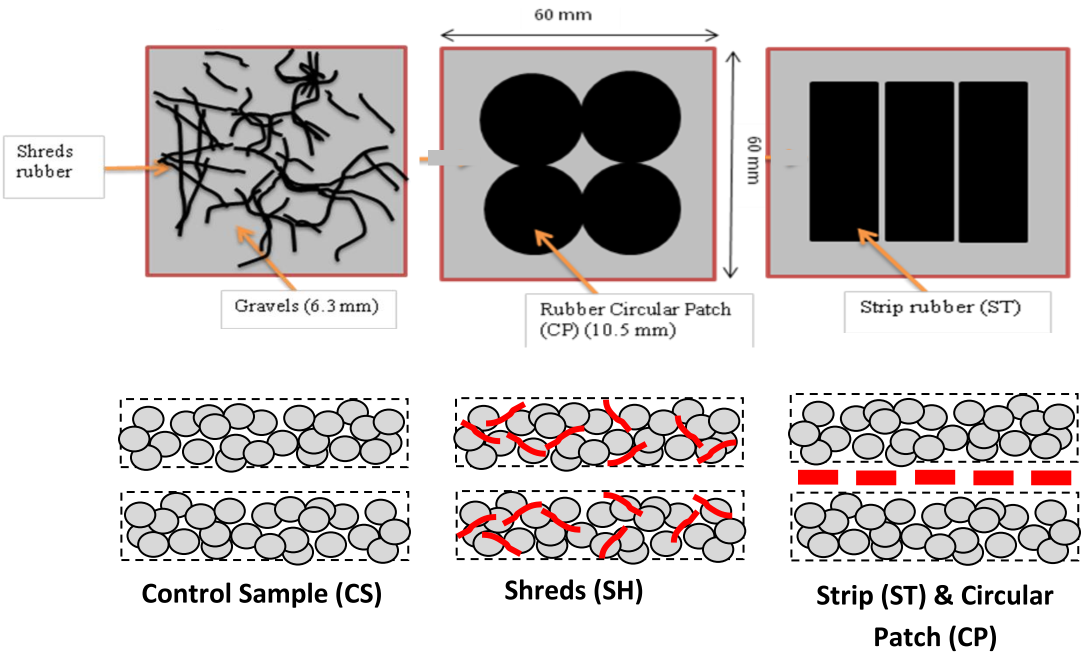

Figure 3 Illustration for rubber configurations with gravels in shear box

3. RESULTS

Characteristics of the shear strength for rubber-ballast composite were tested with respect to the configurations as shown in Figure 4. Again, the acid solution and water specimens were derived by plots the shear-strain ($\tau - \varepsilon$), vertical-horizontal displacement ($\Delta v - \Delta_H$) and the shear strength envelope ($\tau - \sigma_v$). Note that the relationship for each sample between shearing stress, horizontal strain and vertical-horizontal displacement curves for gravels performed under different vertical stresses. Roughly, it can be seen from the graph curve in Figure 4 shows all the specimens increase until it reached the constant values at the end. This would prove that highest stress been applied on the specimens, the longest the strain take for the particles until it shows a constant value. It does not seem give much different result for both specimens, although 2 weeks soaked with acid solution and water. However, the water condition was found to be better with the rubber strips for ST (W) with recorded result as high as 240 kPa. Both specimens for circular patch at the end were almost slightly in the same peak with the ST (W).

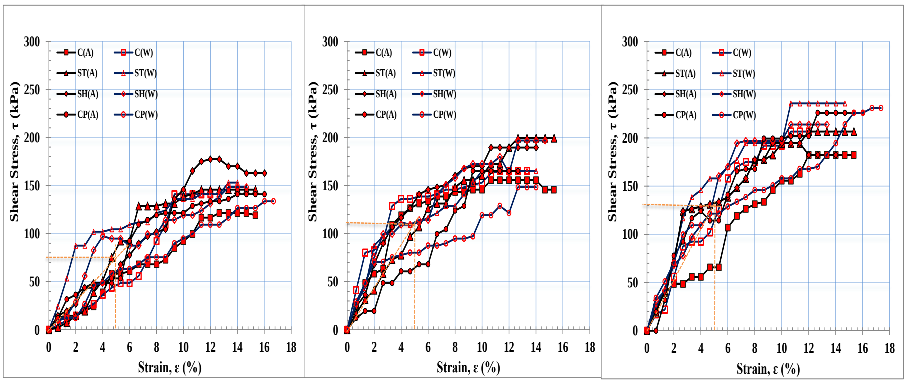

Figure 4 Shear stress (τ)-strain (ε) for all configurations (water-acid specimens)

Meanwhile, for the shreds reinforcement, the water conditions seem to be more promising for the shear resistance when it in higher stresses. Even though the shear resistance for all configurations did not increased dramatically with the aggregates-rubber composites, but it show the behaviour of ductility. This can be prove at Ɛ = 5%, the τ_{avg} for ST, SH and CP was about 110 kPa, while for control with 90 kPa. The influence of lubricating the aggregates because the water and acid specimens had filled the void between the particles. Figure 5 plots for vertical (Δ_v) and horizontal (Δ_H) displacements. All specimens indicate that the settlement was slowly increased. As the specimens were initially loose aggregates, hence it does not dilate except for CP (W) at 9 kPa. This happened due to the slippage or movement between the rubber and aggregates throughout the shearing because of poor contact with each other due to the condition of aggregates were in wet state.

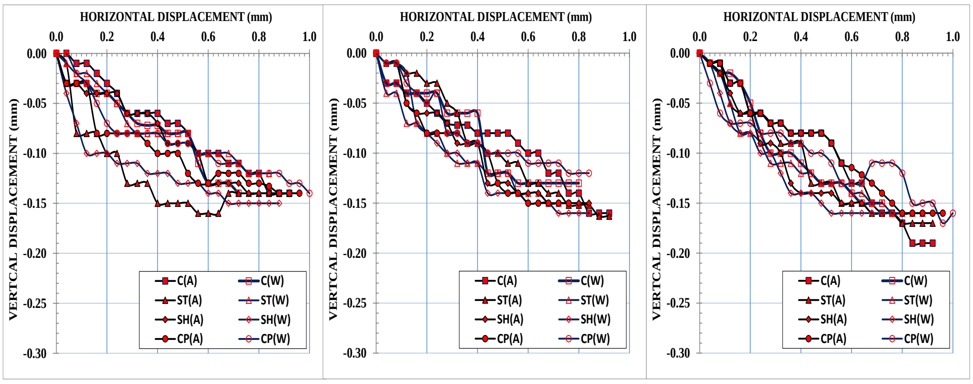

Figure 5 Vertical-horizontal displacements for all configurations with both specimens condition

Figure 6 shown the movement of aggregates during shearing. The dilation or expand occurs where the aggregates rolled from the bottom to the top of A and this means that the vertical displacement (ε_v) is reducing. In addition, when the aggregates at x roll over and down from A, means that vertical displacement increasing and this behaviour was referred as contraction or settlement.

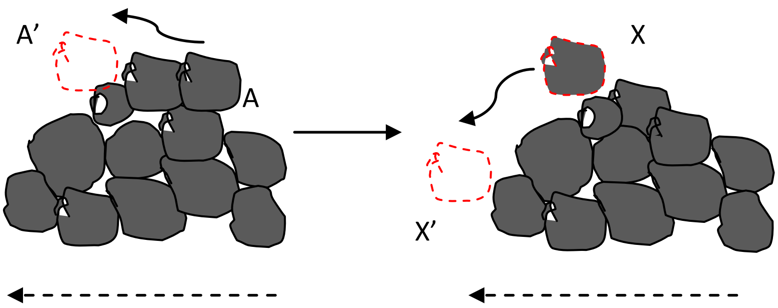

Figure 6 Sketches of the aggregates rolls over during shearing

Figure 7 shows the shear strength envelope for acid and water specimens. The friction angle for all aggregates-rubber composites as summarize in Table 1 were in the range between 87°–88°. CP and ST position better than the C and SH for both conditions specimens. Surface or size of rubber plays an important role in the shear resistance between the rubber-ballast composites.

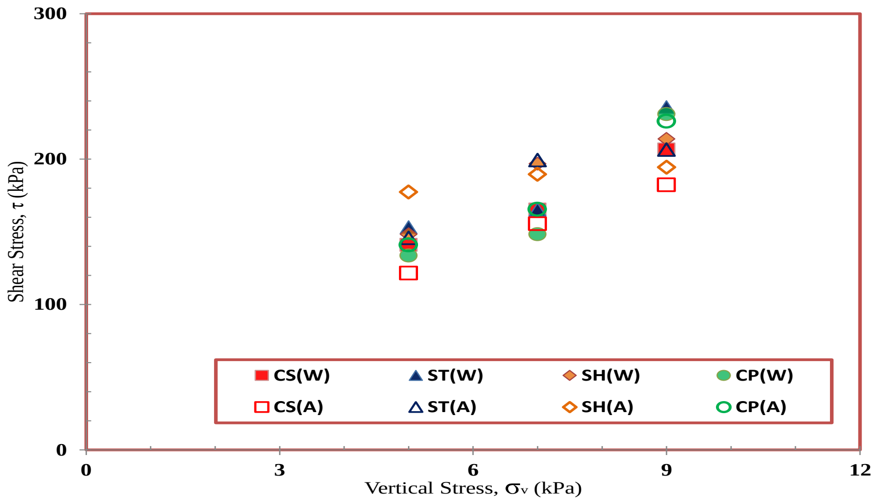

Figure 7 Failure envelopes for all configurations

Table 1 Summary of friction angle (ϕ)

Specimens	tan ϕ		ϕ (°)	
	Water (W)	Acid (A)	Water (W)	Acid (A)
Control (C)	26.76	21.53	88	87
Strips (ST)	25.82	26.45	88	88
Circular Patch (CP)	26.83	25.14	88	88
Shreds (SH)	28.11	25.58	88	88

4. CONCLUSION

This experimental study has shown that the preliminary work give some improvement of the shear resistance between rubber-aggregates inclusions within wet state (weather effect). Overall, the role of rubber tube content is very clear that the bigger the area of rubber tube content, the greater is the shear stress can be generate. The shear stress-vertical stress relationships do not differ much among the specimens tested, except in the case of strips and circular patch. Even though the shear resistance for all configurations did not increased dramatically with the rubber inclusions, but it did show the behaviour of ductility in aggregates-rubber composites. This summarize that the most preferable configurations by using rubber tube were the circular patch (CP) and strips (ST). The improvement of shear resistance is due to the increased ductility of composite and breakage control. It is nothing worth that the present study conduct is static in a scaled down model. Future work will be necessary for the research to be conducted with full-scale test under dynamic loading simulations to create the actual rail traffic.

5. ACKNOWLEDGEMENT

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6. REFERENCES

Ashadi, H.W., Aprilando, B.A., Astutiningsih, S., 2015. Effect of Steel Slag Substitution in Geopolymer Concrete on Compressive Strength and Corrosion Rate of Steel

Reinforcement in Seawater and an Acid Rain Environmental. *International Journal of Technology*, Volume 6(2), pp. 227–235

Bonnett, C.F., 2005. *Practical Railway Engineering*, 2nd Edition, Published by Imperial College Press

British Standards Institution, 1990. *Methods of Tests for Soils for Civil Engineering Purposes*, Part 7, BSI, London

Edincliler, A., Baykal, G., Saygili, A., 2010. Influence of Different Processing Techniques on Mechanical Properties of Used Tires in Embankment Construction. *Waste Management*, Volume 30, pp. 1073–1080

Indraratna, B., Ngo, N.T., Rujikiatkamjorn, C., Vinod, J.S., 2014. Behaviour of Fresh and Fouled Railway Ballast Subjected to Direct Shear Testing: Discrete Element Simulation. *International Journal of Geomechanics*, Volume 14, pp 34–44

Khabbaz, H., Indraratna, B., 2009. Development of a Smart Tool for Capturing Novel Advancement in Ballasted Rail Track Substructure. *In*: 8th International Congress on Civil Engineering

Kim, D., Ha, S. 2014. Effects of Particle Size on the Shear Behavior of Coarse Grained Soils Reinforced with Geogrid. *Materials*, Volume 7(2), pp. 963–979

Nordberg, G.F., Goyer, R.A., Clarkson, T.W., 1985. Impact of Effects of Acid Precipitation on Toxidity Metals. *Environmental Health Perspectives*, Volume 63, pp. 169–180

Raymond, G.P., Gaskin, P.N., Svec, O., 1975. Selection and Performance of Railroad Ballast. *In*: Ker (ed): Railroad Track Mechanics and Technology, Proceedings of a symposium held at Princeton University, pp. 369–385

Selig, E.T., Waters, J.M., 1994. *Track Geotechnology and Substructure Management*. Thomas Telford, London

Shenton, M.J., 1975. Deformation of Railway Ballast under Repeated Loading Conditions. *In:* Railroad Track Mechanics and Technology, Proceedings of a symposium held at Princeton University, pp.387–404

Spengler, J.D., Brauer, M., Koutrakis, P., 1990. Acid, Air and Health. *Environmental Science and Technology*, Volume 24(7), pp. 946–956

Xiao, M., Ledezma, M., Hartman, C., 2013. Shear Resistance of Tire-derived Aggregates using Large-scale Direct Shear Tests. *J. Mater. Civ. Eng.*, Volume 27(1), pp. 1–8

Zornberg, J.G., Cabral, A.R., Viratjandr, C., 2004. Behaviour of Tire Shred – Sand Mixtures. *Canadian Geotechnical Journal*, Volume 41(2), pp. 227–241