Proceedings of the Sixth International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 7, Paper 13.7
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.7.13.7

Rubber Modified Ballasted Track Systems for Low Noise and Low Vibration

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Abstract

Ballasted railways are among the most commonly used forms of track infrastructure. However, their primary drawbacks include track stability issues due to ballast degradation over time, as well as increased noise levels and high maintenance costs. A novel low-noise and vibration railway ballast track design is needed to address these concerns. This paper presents an innovative solution developed within the European project LIAISON-HORIZON-CL5-2022-D6-02-06 framework that combines modified railway ballasted track systems with recycled tires, geosynthetics, low-height ballast walls, and noise barriers. The study investigates the use of recycled waste tire rubber chips to enhance shear modulus and mitigate vibrations within the ballast layer. Large-scale cyclic simple shear tests conducted on the rubber-mixed ballast material demonstrate improved shear modulus and damping ratio. Additionally, the paper briefly examines prototype testing and performance evaluations of the modified ballast wall arrangement in conjunction with geosynthetics. The inclusion of geosynthetic materials enhances lateral confinement by facilitating particle interlocking and providing better confinement through end-to-end connections with ballast walls.

Keywords: rubber, ballast, cyclic simple shear tests, geosynthetics, noise barriers, prototype testing.

1 Introduction

Railway networks are pivotal in facilitating connectivity and accessibility, particularly across European regions. Railway infrastructure commonly relies on ballasted tracks, serving three essential functions: i) uniformly transmitting the trainload to the underlying subgrade, ii) maintaining track geometry and alignment, and iii) serving as a drainage barrier. The ballasted tracks deteriorate faster due to ballast breakage, differential settlement, reduction in confinement, and track bulking. These issues lead to excessive vertical and lateral settlements, resulting in costly and frequent track maintenance [1]. To address these challenges, several railway organizations have adopted various track stabilization techniques. These include introducing geosynthetics into the track substructure and treating ballast with substances like bitumen and polyurethane using recycled tire-mixed ballast systems [1]. Over the past three decades, igneous or metamorphic rocks, particularly granite, have been the preferred choice for ballast material due to their exceptional durability compared to sedimentary rocks. However, countries like Slovenia, Croatia, and the Netherlands face challenges due to the limited availability of high-quality ballast material. Consequently, they are compelled to utilize sedimentary rocks with lower abrasion resistance as a substitute [2]. Therefore, there is a growing demand to explore innovative solutions to uphold track stability and reduce maintenance costs. Recently, there has been an increasing trend to conserve high-quality raw materials by incorporating secondary or waste materials. Extensive research efforts[1,3,4] have been dedicated to exploring various innovative approaches aimed at utilizing recycled industrial wastes, such as tire derivatives, coal wash, plastics, glass, and others, to address track degradation and enhance overall performance. These studies indicate that integrating rubber granules into ballast consistently enhances its performance. Laboratory experiments, including small-scale physical tests, direct shear tests, and triaxial tests, demonstrate improved dynamic properties of the modified ballast material. In particular, including waste tire chips reduces particle breakage compared to pure ballast [5,6]. Nonetheless, although certain dynamic properties improve and particle breakage is reduced, there is a slight decrease in certain geotechnical characteristics, such as the friction angle and dilation angle, while others, like modulus degradation, display enhancement. Nevertheless, reducing specific geotechnical properties of the modified ballast material aggravates confinement issues on the tracks.

The utilization of geosynthetics can effectively enhance the performance of granular media in road and railway infrastructure [7–9]. Numerous approaches utilizing planar geosynthetics, including geogrids, geotextiles, and geocomposites, have been implemented to mitigate excessive settlement and lateral displacement of tracks under cyclic loading [4,10]. Nevertheless, more attention should be directed towards assessing the performance of modified ballast track systems. While the utilization of concrete walls, recycled tire rubber mixed ballast materials for enhancement of ballast confinement may lead to increased costs compared to traditional methods of reinforcing the ballast layer, their specific advantages include enhanced confinement, minimal space utilization, elevated lateral strength, and decreased maintenance expenses for railway tracks. This paper outlines a unique solution developed within the European project LIAISON - HORIZON-CL5-2022-D6-02-06 framework to tackle vibrations, noise, confinement issues, and lateral displacements in railway tracks. This entails integrating low-height ballast walls with rubber, reused ballast, and planar geogrids, as depicted in Fig. 1, referred to herein as low-noise rubber-modified ballasted track systems. Concrete elements placed at the track shoulder will serve as a noise barrier near the source. Combined with a horizontal geosynthetic layer, they will also act as ballast confinement simultaneously. Reused ballast material is mixed with rubber chips from recycled waste tires to improve the stress distribution within the layer and, on the other hand, to dampen the vibrations. At least 80% re-utilization of construction materials within or across transport modes will be achieved from the developed LIAISON holistic approach in the construction of the ballast layer. In addition, the rubber-modified reused ballast material improves the mechanical performance of the track compared to the conventional one. New low-noise & vibration railway ballasted track will reduce airborne noise by 3-6 dB (depending on the network's topography) and decrease ground vibrations by at least 50%. Reduction in track maintenance costs by at least 30%. Additional confinement from the geosynthetics and ballast wall arrangement (BWA) significantly decreases ballast degradation, improves the mechanical characteristics of railway tracks, reduces maintenance costs, and improves the damping characteristics of ballast. The cyclic behaviour of these modified ballast materials is investigated from cyclic simple shear tests evaluating the shear modulus and damping ratio. In addition, a small-scale laboratory apparatus was employed to examine the lateral displacements of a confined ballast arrangement.

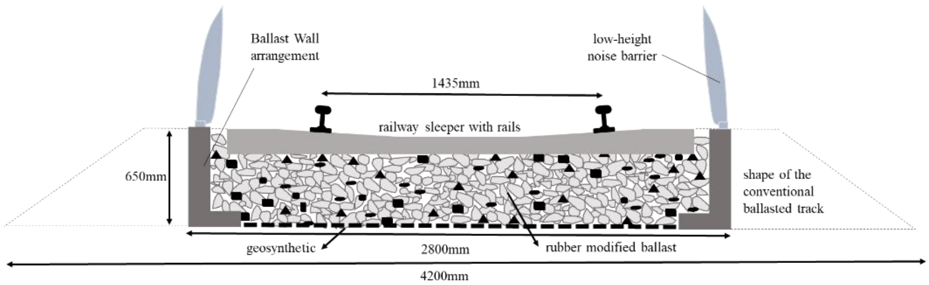

Figure 1: Illustration of field Ballast wall arrangement

2 Materials and Methods

The reused ballast material is sourced from the Ljubljana train station, where track modifications are currently being done, and recycled tire chips, mainly from heavy truck tires, are produced by a company in Slovenia. The gradation curves of the waste materials and the mixtures are shown in Fig. 2(a). Note that the particle size distribution curves of the mixtures align with the suggested gradation (EN 13450). The cyclic simple shear tests were conducted to investigate the shear modulus, and damping ratio of reused ballast material (RBA)+ recycled tire chip (RT) mixtures with varying percentages of RTs (0, 3,5,7,10, by mass). The cyclic shear tests (sample size: 400mmx400mmx500mm, length x width x height) were conducted under average load = 50, 200, and 300 kPa with varying shearing speeds ranging from 0.000125mm/sec to 1.02 mm/sec. These shearing tests were controlled by strains, and shear stresses were measured accordingly. These applied normal loads covered the railway ballast's low to medium confinement range. The test-setup arrangement is illustrated in Fig 2(b). Based on the previous observations, 3 shearing cycles were adopted for each loading speed. The RBA samples underwent cleaning, oven, and air-drying to ensure dryness before preparing the test specimens. The samples were prepared to maintain falling height and compaction effort, ensuring a desired 2 g/cm3 density.

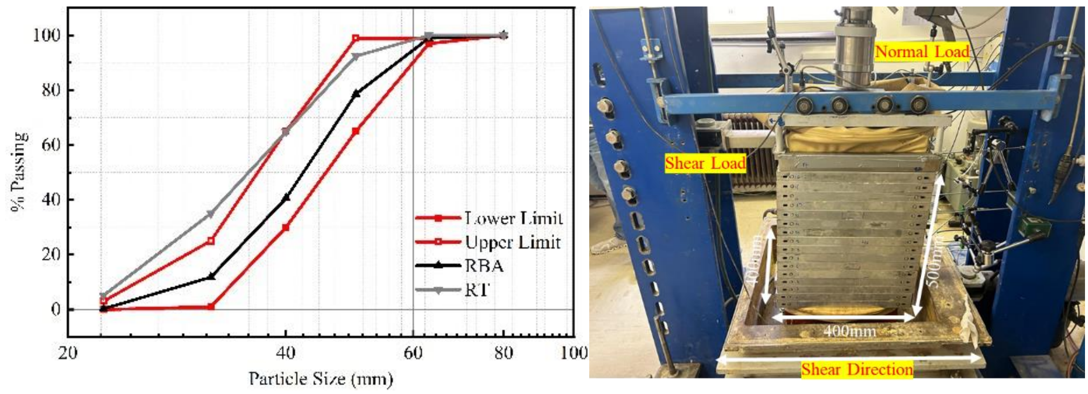

Figure 2: (a). Particle gradation curves (b) Illustration of cyclic simple shear test

Fig. 3(a-c) shows the variation of shear modulus with respect to strain for RBA+RT mixtures with varying RT percentages (0 %, 5 %, 10 %, and 15 %) at normal loads of 300kPa, 200kPa, and 50 kPa. The results indicate that mixtures with RT =5% exhibited higher shear modulus at all applied normal loads. Hence, RBA with no mixtures has shown a lower shear modulus compared to RT=5%. Fig. 4 shows the damping ratio of various mixtures at a shear strain of 4%. The results indicate similar behavior, showing higher performance at RT=5%. Usually, the shear modulus for the clean ballast should be higher; however, in this case, RBA is the ballast with high degradation sourced from a railway track, resulting in lower properties.

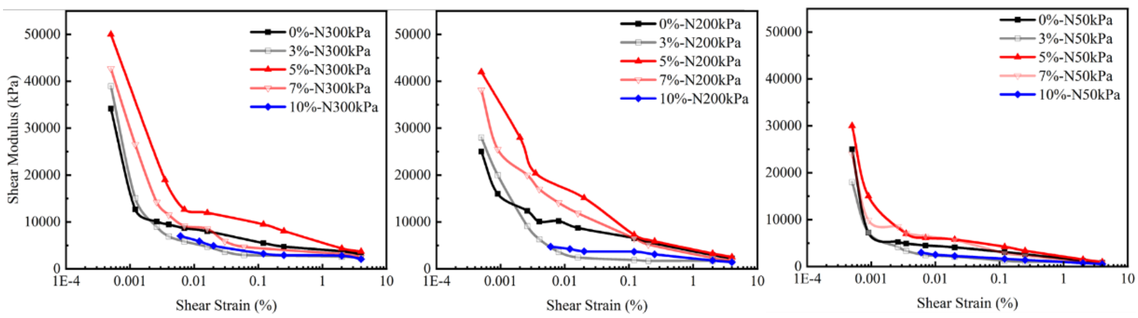

Figure 3: Results of shear modulus for various RT mixes 2 (a) Variation of shear modulus with shear strain for applied Normal Load 300kPa (b) Variation of shear modulus with shear strain for applied Normal load 200kPa (c) Variation of shear modulus with shear strain for applied Normal load 300kPa

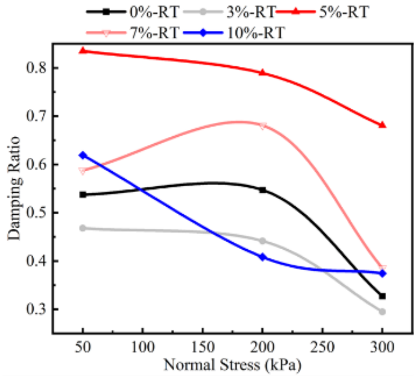

Figure 4: Variation of damping Ratio with normal Stress at a shear strain of 4%

3 Prototype testing and results

Reduced-scale model tests were conducted using a test setup developed at ZAG, Ljubljana. The setup was designed to accommodate the ballast track scaled to 8. On the front side of the setup, a thick plexiglass sheet was installed to visualize the corresponding displacements from the applied load. Moreover, in reduced model tests, scale effects are indeed critical, and their role in geotechnical model tests (1g and centrifuge model tests) has been documented by Wood (2004) [11]. Accordingly, the setup length was adjusted to 800mm to prevent boundary effects. In reduced model tests, the dry gravel samples of particle size 4-8mm obtained from the Sava river basin were used to represent 30-50mm particle size in the field scale. The gravel samples underwent oven and air-drying to ensure dryness before preparing the test specimens. The foundation soil was prepared under dense conditions for considerable rigidity. The end-to-end reinforcement was connected to the L-shaped walls with small pins to ensure connectivity. The test specimens were arranged using the rainfall technique as a layered system with a known quantity of dry gravel layered at 40mm thickness. Maintaining falling height and compaction effort ensured a desired 2 g/cm3 density. The L-shaped BWA (LSBWA) with scaled reinforcement material of lesser stiffness was initially prepared based on testing requirements. Fig. 5 illustrates all model tests as a part of the LIAISON framework on LSBWA made of dry gravel with scaled railway embankment dimensions 125x500x200 (height, mm x length, mm x width, mm). The model test LSBWA 2, shown in Fig. 6(a), was conducted with a reduced size of 350m (representing the BWA near the sleepers). The length of the connected reinforcement was ensured to be long and stiff enough to support the BWA. The model underwent a maximum scaled load of 13kN, considering Wood (2004) [11] scaling laws (representing an 80tonne train axle load). Digital images were captured at regular intervals during testing to visualize the BWA lateral deformation path and corresponding reinforcement strains from the strain gauge placed at the center.

The presentations here include load application details and corresponding lateral deformation mechanisms for LSBWA 2 Fig. 6. The lateral displacement pattern of BWA is obtained from indicative markers in the processed image, as shown in Fig. 6(b). Reinforcement strains and lateral displacements are measured from strain gauges and digital images captured at various applied loads, as illustrated in Fig. 6. This study investigates lateral deformations for the BWA with end-to-end connected reinforcement. Investigations are presented to evaluate the role of reinforcement in holding the BWA against external loads. End-to-end reinforcement plays a role in restricting the probability of the BWA overturning and sliding. Fig. 6(c) illustrates complete loading and unloading data and corresponding strains of reinforcement and lateral displacements of LSBWA 2. The influence of reinforcement and the L-shaped wall is described in Figs. 6(d) & (e), showing the strains and lateral displacement profiles of the scaled LSBWA. The maximum lateral displacement at the right and left walls of LSBWA 2 was 5.46 and 4 mm, respectively. The estimated peak strain for LSBWA 2 is 0.35% at the peak load of 13 kN. Displacements are in the same range for both tests' left and right walls, indicating a stable condition where both walls deform similarly. Additionally, the stiffness of end-to-end connected reinforcement governs the lateral movement of the wall. This indicates that at higher loads, ballast rearrangement occurs, which was observed during the testing process and reflects permanent lateral deformation of BWA. The stability of LSBWA is governed by the stiffness of BWA, reinforcement, and the connection between the reinforcement and BWA, which will be further studied.

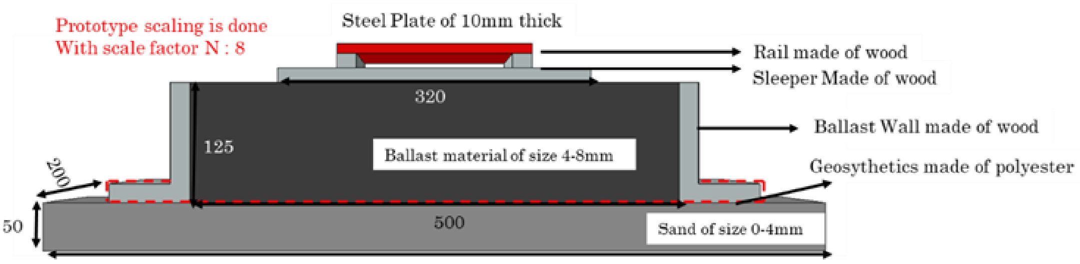

Figure 5: Illustration of the test setup (dimensions in mm)

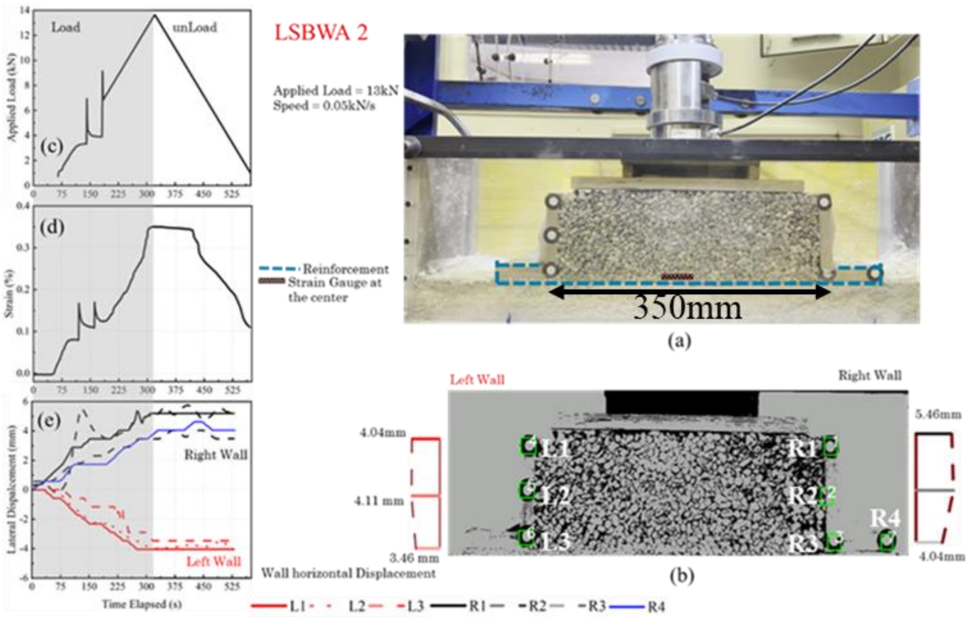

Figure 6: Test results of LSBWA 2 (a) Digital image during testing (b)) Processed image (c) Loading data (d) Strain, % vs. Time elapsed, seconds (e) Lateral displacement, mm vs. Time elapsed, seconds

4 Conclusions and Contributions

The BWA system combined with RBA+RT mixes is a valuable alternative to conventional ballasted embankments subjected to various external loads. The end-to-end reinforcement connections at the bottom connect the BWA, significantly influencing its deformation response and addressing the confinement issues. The key findings from this study include the following:

a) The inclusion of recycled tire chips with the optimum percentage of 5 indicated improved shear modulus and damping ratio.
b) Due to the use of degraded ballast, the mechanical properties of the material are in lower range
c) The positive reinforcement effect is observed for these LSBWA systems, and the stability of the wall depends upon the stiffness of the reinforcement.
d) Further, this research is concentrated on evaluating the behavior of different shapes of BWAs, various percentages of RT mixes, and reinforcement connections when subjected to static and dynamic loads.

Acknowledgments

The authors are grateful for the financial support provided by LIAISON (HORIZON-CL5-2022-D6-02-06) and by the Ministry of Higher Education, Science, and Technology of the Republic of Slovenia - and The Slovenian Research Agency (ARRS) Programme group P2-0273 and Core funding Z1-1858.

References

[1] Prasad KVS, Hussaini SKK. Review of different stabilization techniques adapted in ballasted tracks. Constr Build Mater 2022;340:127747. https://doi.org/10.1016/j.conbuildmat.2022.127747.

[2] Guo Y, Xie J, Fan Z, Markine V, Connolly DP, Jing G. Railway ballast material selection and evaluation: A review. Constr Build Mater 2022;344:128218. https://doi.org/10.1016/j.conbuildmat.2022.128218.

[3] Indraratna B, Sun Q, Grant J. Behaviour of subballast reinforced with used tyre and potential application in rail tracks. Transportation Geotechnics 2017;12:26–36. https://doi.org/10.1016/j.trgeo.2017.08.006.

[4] Indraratna B, Mehmood F, Mishra S, Ngo T, Rujikiatkamjorn C. The role of recycled rubber inclusions on increased confinement in track substructure. Transportation Geotechnics 2022;36. https://doi.org/10.1016/j.trgeo.2022.100829.

[5] Sol-Sánchez M, Moreno-Navarro F, Rubio-Gámez MC. Viability of using end-of-life tire pads as under sleeper pads in railway. Constr Build Mater 2014;64:150–6. https://doi.org/10.1016/j.conbuildmat.2014.04.013.

[6] Gong H, Song W, Huang B, Shu X, Han B, Wu H, et al. Direct shear properties of railway ballast mixed with tire derived aggregates: Experimental and numerical investigations. Constr Build Mater 2019;200:465–73. https://doi.org/10.1016/j.conbuildmat.2018.11.284.

[7] Leshchinsky B, Ling HI. Numerical modeling of behavior of railway ballasted structure with geocell confinement. Geotextiles and Geomembranes 2013;36:33–43. https://doi.org/10.1016/j.geotexmem.2012.10.006.

[8] Indraratna B, Biabani MM, Nimbalkar S. Behavior of Geocell-Reinforced Subballast Subjected to Cyclic Loading in Plane-Strain Condition. Journal of Geotechnical and Geoenvironmental Engineering 2015;141. https://doi.org/10.1061/(asce)gt.1943-5606.0001199.

[9] Biabani MM, Ngo NT, Indraratna B. Performance evaluation of railway subballast stabilised with geocell based on pull-out testing. Geotextiles and Geomembranes 2016;44:579–91. https://doi.org/10.1016/j.geotexmem.2016.03.006.

[10] Indraratna B, Ngo NT, Rujikiatkamjorn C. Deformation of Coal Fouled Ballast Stabilized with Geogrid under Cyclic Load. Journal of Geotechnical and Geoenvironmental Engineering 2013;139:1275–89. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000864.

[11] Wood DM. Geotechnical modelling 2004;Version 2.:488. https://doi.org/10.2208/jscej.2005.780_1.