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NEOBALLAST: new high-performance and long-lasting ballast for sustainable railway infrastructures

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Abstract

With inherent advantages in environmental performance, land use, energy consumption and safety, railways are an essential component of a competitive and resource-efficient transport system. However, railways have still to face several important drawbacks in order to reinforce its competitiveness against the road mode. Reducing maintenance costs has been appointed as one key goal of Infrastructure Managers (IMs), as Western Europe spends annually between €15 and €25bn to maintain and renew a railway network of about 225,000 km (FP7 Mainline Project, 2011-2014). Future prospects of mobility growth (passenger-km is to be doubled in 40 years) will increase maintenance needs, evincing the need of innovative solutions that downsize maintenance costs.

The increasing demand of higher axle loads and higher speeds has led to the improvement of track components (e.g. harder and heavier rails, pre-stressed sleepers, etc.). However, there has not been a significant change in ballast aggregates, even though it is the main cost-driver of maintenance costs.

In this context, NEOBALLAST emerges as a high-performing, long-lasting and eco-friendly ballast aggregate solution designed to overcome two of the most important drawbacks of railway tracks: track degradation and noise and vibrations (N&V). Whilst the former is the main trigger of maintenance and eventually renewal works, thus representing one of the main cost drivers for IMs, the latter has become an issue of paramount importance not only to IMs but the whole EU, since according to the European Environment Agency rail noise affects around 12 million people during day time (55dBA) and 9 million at night (50dBA). NEOBALLAST is a research project funded by MINECO (Spanish Ministry of Economy and Competitiveness) carried out by COMSA, MAPEI, UPC and ADIF.
NEOBALLAST benefits have been proven in an extensive laboratory campaign involving both reduced and large-scale testing. This paper will summarize the results obtained in terms of mechanical and vibration mitigation performance of NEOBALLAST aggregates itself and their behaviour as a whole.

Keywords: Ballast; noise and vibrations; maintenance; sustainable infrastructures

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1. Introduction

During the last decades a lot of research/design/construction/monitoring concerning slab track solutions have been done. In almost each study a comparison with ballasted track appeared as one of the key points leading to interesting conclusions about what should be "the track of the future".

What it seems logical is that the last goal of railways engineers should be to combine the main advantages of the ballasted track and those from the slab track in order to develop an innovative new track system providing the best possible performance (CENIT, 2005). A decade ago the ballast-less track was seen as a far better solution than ballasted track, yet much more expensive, but time and real tests have proved that it is not exactly this way and ballasted track still has big chances for the future.

Thus, ballasted track properties –such as high maintainability at relatively low cost, convenient values of elasticity, high drainage capacity, adequate Noise &Vibrations (N&V) behaviour, etc.- should be merged with slab track strengths - low maintenance requirements and hence, high availability, high durability, etc. - to obtain the best possible solution.

Furthermore, new challenges have arisen in the time being as high quality ballast - as a natural resource it is - has started to be scarce and not always an available material. As a result, in some specific locations and projects, long transport routes must be done in order to get the right material, which results in an increase of not only cost, but of the environmental burdens associated to track construction.

This occurs in a context where EC policies have increased its strictness in environmental issues, whereas sustainable and durable solutions are each time more encouraged by the EC. In this sense, there has been an increasing awareness of noise and vibration related problems in the last years. For this reason, there should be a migration for the existing situation -mitigation- where countermeasures are adopted to comply with the new N&V demands to a new scenario - prevention- where the track system is designed to cope with N&V future demands.

Solutions like precast ballast, modified ballast with in-situ polymers (Woodward, P.K., Kennedy J. and Medero G., 2009) or geo-grids (Fischer, Sz. And Horvat, F., 2011), (Indraratna, B., Khabbaz, H. Salim, W. and Christie,D., 2006) have been developed to improve both LCC (Life Cycle Cost) and LCA (Life Cycle Assessment) and performance. Nevertheless, further tests should be carried out to demonstrate that these new solutions are feasible from a technical-economical-environmental point of view.

NEOBALLAST is an innovative project with a focus on developing the “ballast of the future”, as the believe that there is much room for improvement in ballasted track is shared, but at the same time ballasted track still has a long and brilliant future.

It results from the applying of a special coating made of recycled rubber coming from end-of-life tyres to natural and recycled aggregates. The technical upgrades of this new ballast aggregate involves reducing the stiffness of the track (ratio of the load applied to the rail to vertical rail deflection), high abrasion resistance (i.e. less fines) and more energy dissipated through contact with the rubber coating. Also, the inclusion of recycled rubber in the coating provides the new aggregates with better vibration and acoustical properties, which tackles an increasing problem in urban railways.

Fig. 1. NEOBALLAST aggregates.

2. Main project results and findings

2.1. Project objectives and structure

The overall aim of the NEOBALLAST project is to develop an enhanced and cost-efficient ballast technology able to drastically increase the service life of railway tracks as well as to minimize annoyance caused by noise and vibration.

Ballast durability, and so that of the overall track superstructure, is strongly related to the generation of fines caused by the friction between ballast aggregates, which wears their contact surfaces. In some countries, the amount of fines in the ballast layer is main decision parameter for undertaking renewal works (e.g. Infrabel –Belgian IM- carries out ballast renewal when fines exceeds 30%) (Godart, P., 2013). NEOBALLAST aggregates seek to improve wear resistance of aggregates by means of an advanced coating that includes rubber particles, which at the same time is able to increase the elasticity of the ballast layer. According to recent studies conducted by Deutsche Bahn (Fonseca, P., 2005), reducing vertical stiffness of ballast aggregates results in reduced velocity of vibration, proving the potential of vibration mitigation of NEOBALLAST aggregates.

The project has been structured in three stages, according to the level of technology validation. The first two stages are related to the laboratory characterization of NEOBALLAST aggregates, whilst the third one is related to a field test demonstration. Only the two first stages are described in this field, as the third one is still under development.

2.2. First stage of validation

The first stage consisted on undertaking the following laboratory test in order to characterize the enhanced performance of NEOBALLAST:

- Abrasion and impact resistance tests (Los Angeles)
- Test of density and water absorption
- Resistance to degradation by abrasion in the Micro-Deval apparatus
- Magnesium sulphate soundness test
- Vibration mitigation test

This first phase of development analysed four different types of coatings in order to identify the more performing solutions. The following figures show two examples of ballast with different coatings.

(a) (b)

Fig. 2. (a) NEOBALLAST coating with large rubber particles; (b) NEOBALLAST coating with small rubber particles.

The tests have been conducted by the Laboratory of the Polytechnic University of Catalonia, under the supervision of Prof. Andrés Lopez Pita.

Los Angeles and Micro-Deval tests are the reference tests worldwide to assess the abrasion resistance of ballast aggregates. Most of railway technical standards establish minimum LA and Micro-Deval values for aggregates to be used in railways, taking into account the correlation of these tests with ballast durability.

Both tests have been carried out comparing NEOBALLAST (the four variants) and conventional granite ballast aggregates (classified as A class according to ADIF, which is the category required for high-speed lines).

The figures relate to the execution of the Los Angeles test. It consists in placing 10 kg of aggregate in a metal drum next to 12 steel balls and then exposing it to 1000 turns, to quantify the amount of fines that have been generated.

(a) (b)

Fig. 3. (a) Los Angeles test material; (b) NEOBALLAST sample inside the drum.

The results of the Los Angeles tests are shown in Figure 4, proving that NEOBALLAST aggregates generate fewer fines that granite ballast aggregates in all cases. The most performance NEOBALLAST configuration is able to reduce fines twelve times in comparison with high quality ballast aggregates.

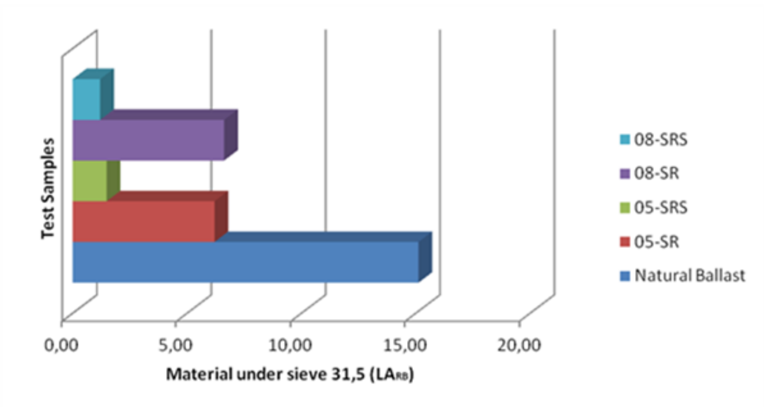


Fig. 4. Results of LA test for NEOBALLAST and granite ballast aggregates.

Another factor that must be highlighted after concluding the testing is the final geometry of the particles. As it can be observed in Figures 5.a and 5.b, the particles of natural ballast present all their edges rounded after the test, while the particles of NEOBALLAST remain angular and sharp. Maintaining angularity of ballast particles is crucial for assuring a good interlocking and load transfer of the ballast layer as well as adequate lateral resistance.

(a) (b)

Fig. 5. (a) Natural ballast after the LA test; (b) Two samples of NEOBALLAST after the tests.

A significant increase of abrasion resistance of NEOBALLAST aggregates with respect to natural ballast is also demonstrated by the Micro-Deval tests. In the light of the results shown in Figure 6, the effect of water in the degradation process is clearly more detrimental for natural aggregates than for NEOBALLAST aggregates.

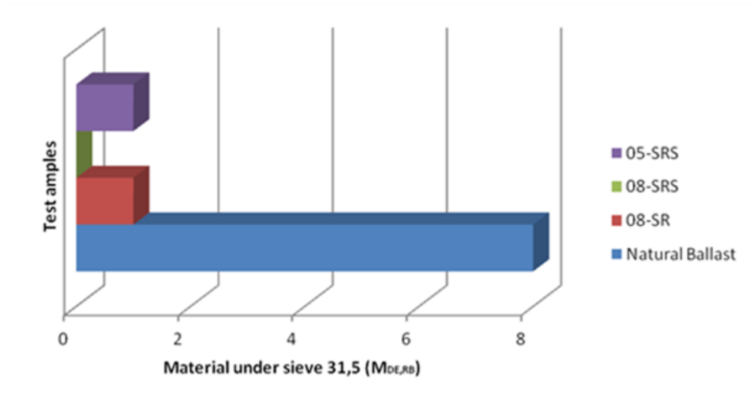


Fig. 6. Results of Micro-Deval tests for NEOBALLAST (four configurations) and natural ballast.

With regards to the water absorption tests, the results obtained are practically the same for both types of aggregates. Nonetheless, it is noteworthy to stress out that the isolation provided by the coating can result in an improved durability of the aggregate. In effect, according to the work conducted by Oldecop and Alonso (2003), changes in relative humidity can affect the formation of small meniscus in the cracks present in the aggregates, which contributes towards the proliferation of cracks and hence, the degradation of the ballast aggregates.

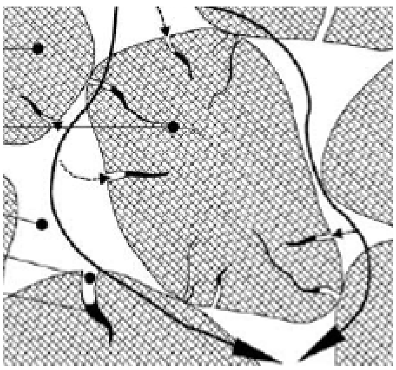


Fig. 7. Scheme showing how water transport occurs within the rockfill specimen.

On the other hand, the Magnesium sulphate soundness tests demonstrated that coating provides NEOBALLAST with a much higher resistance to weathering than natural ballast. This test is aimed at showing how well the aggregates are able to cope with extreme temperatures and external conditions. As shown in Figure 8, ballast aggregates generated about 1% of fines, while NEOBALLAST aggregates produced ten times less.

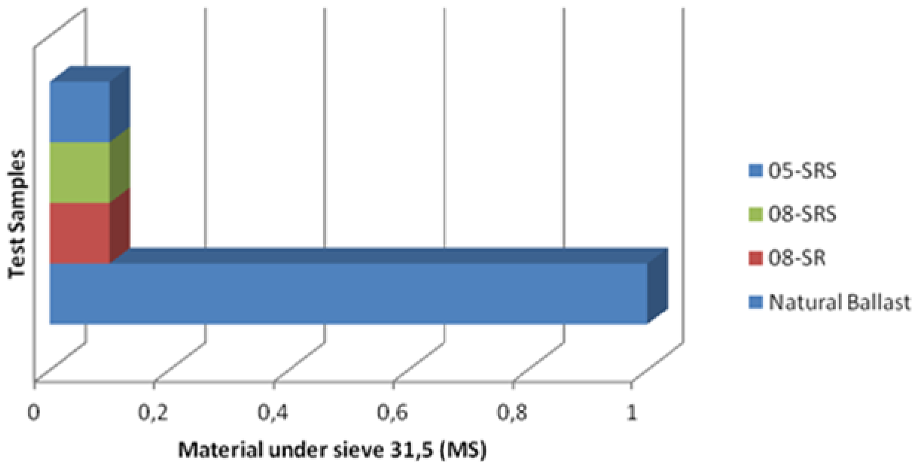
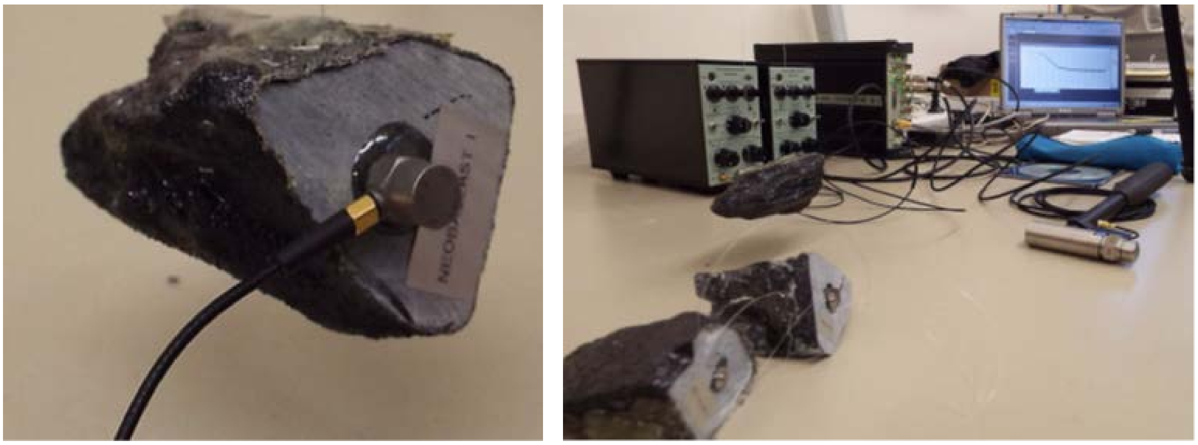


Fig. 8. Magnesium sulphate test results for NEOBALLAST and natural ballast aggregates.

The first stage concludes with the characterisation of NEOBALLAST vibration mitigation capacity. The tests were carried out by the Applied Geophysics of the Polytechnic University of Catalonia. Accelerometers were installed in the core of the aggregates and a hammer was used to generate the vibration impact. The results confirmed that better performance of NEOBALLAST in terms of vibration mitigation.



(a) (b)

Fig. 9 (a) Accelerometer inside a NEOBALLAST aggregate; (b) Equipment required for the vibration mitigation test.

2.3. Second stage of validation

The second stage of validation refers to the assessment of the NEOBALLAST aggregates, not as individual aggregates, but as a whole. This stage involves the testing of NEOBALLAST in large-scale tests, namely:

- Large scale direct shear tests
- Cyclic loading tests

The large scale direct shear test has been adapted from a similar test for soils since there was no specific test for aggregates to assess this characteristic. The test consists in filling a metallic box with the aggregates, onto which a normal load is applied as a confinement while the horizontal load required for the box to move horizontally is registered (Figure 10). The equipment required is a load cell dynamometer (ring type) and 3 LVDT, which are connected to a computer recording stress and displacements. The tests were carried out in the Geotechnical Laboratory of the Polytechnic University of Catalonia under the supervision of Prof. Jean Vaunat.

(a) (b)

Fig. 10 (a) Large size direct shear test before carrying out the test (b) during test.

Regarding the cyclic loading tests, they have been performed by the renowned Laboratory of Materials of the University of Cantabria (LADICIM). The test measured the stiffness offered by NEOBALLAST and natural aggregates before and after the application of one million cycles. The results of the test will be ready soon; however, initial measurements show that the overall stiffness of the ballast layer made of NEOBALLAST can be reduced by 90% with respect to conventional ballast.

Fig. 11. Cyclic loading tests carried out on NEOBALLAST and conventional ballast.

4. Conclusions

The ambitious laboratory campaign carried out by the Polytechnic University of Catalonia have evinced the enhanced performance of NEOBALLAST aggregates, which have shown abrasion resistance ten times higher than granite ballast aggregates used for high speed lines. Improved performance against weathering and higher capacity for vibration mitigation are other benefits demonstrated in the first stage of the project.

Further validation is undergoing, but the promising results obtained so far are encouraging and show a huge potential for the European railways, taking into account the urgent need of increasing cost-effectiveness of rail assets.

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