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Development of an alternative maintenance technique for railway ballasted tracks

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Abstract

Currently, ballast tamping is the most common maintenance intervention in ballasted tracks in order to restore original geometry while recovering damping capacity. However, it is wellknown the limited effectiveness of this technique due to the degradation of ballast particles during tamping, and to the memory phenomenon of ballast layer which quickly restores its pre-maintenance geometry. Then, under the need for developing more durable and effective maintenance techniques, this paper proposes an alternative process based on combining the benefits of using Under-Sleeper Pads and the process known as Stoneblowing, by replacing part of the small stones applied during this last technique with rubber particles from wasted tires that act as flexible aggregates under the sleeper. For this purpose, this paper presents an initial laboratory study focused on analysing the viability and effectiveness of this alternative technique while defining the influence of the quantity of rubber as main designing parameter. Results are based on full-scale testing box tests, and they show that this process allows for reducing short and long-term ballast settlement while reducing ballast degradation and the stress transmitted to sub-layers, in comparison to conventional stoneblowing and to the use of under-sleeper pads. Also, it is possible to optimize track deflection and damping capacity by using different quantities of rubber.

Keywords: Stoneblowing, Under-sleeper pads, rubber particles, full-scale testing box, laboratory study.

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1. Introduction

Railway over ballasted tracks plays an essential role in most transportation networks, since it presents a range of benefits in comparison with other alternative systems such as concrete slabs. However, changes in the geometric parameters, associated with differential settlement along ballasted tracks, is one of the major problems in this type of infrastructures for railway transportation. Passing trains generates cyclic movements in ballast particles that cause the recompaction of the granular layer and its accumulative vertical deformation, and therefore, to maintain track geometry within adequate safety and ride quality levels, permanent way maintenance for re-levelling and realignment is necessary. Based on this, automatic tamper is the machine most used from the 1960s, which consists of lifting and laterally squeezing the ballast to fill the void space generated beneath the sleeper (Selig and Waters, 1994; Indraratna et al., 2011). However, this maintenance operation is accompanied by some detrimental effects such as loosening of compacted ballast layer, particles deterioration and reduced track stability (Indraratna et al., 2011).

In light of these problems, alternative solutions are being developed for the improvement of the track quality and the effectiveness of the maintenance tasks. In particular, a process known as stoneblowing is worthy of note since it allows for the reduction of ballast breakage during maintenance whilst simultaneously maintaining the vertical strength of the layer (Hellawell, 1997; Claisse et al., 2003). In addition, using this technique avoids rapid ballast recompaction after maintenance. This process, developed in the U.K., consists of adding small stones (around 14-20 mm) to the existing gap between the sleeper and the ballast surface once the former has been raised to the desired level. However, there are some concerns associated with stoneblowing, such as the stiffening of the granular layer and its retarded capacity to damp loads. Another alternative solution to reduce ballast maintenance, applied primarily in European transition sections (where differential settlements are more probable), consists of using elastic Under-Sleeper pads (USPs) in order to reduce the stress on ballast and the settlement of the granular layer, among other benefits (Plica, 2007; Dahlberg, 2010). Nonetheless, its widespread application is limited due to its high costs (which can reach up to 40% of the final price of each sleeper) and to the need for bonding these elements to the bottom of sleepers.

With a view to considering both alternative measures for reducing ballasted track maintenance, this paper proposes a new method that consists of replacing part of the small stones used in the process of stoneblowing with rubber particles obtained from waste tires, acting as flexible aggregates under the sleeper with capacity to damp loads. Thus, this proposed solution, refereed as "Stone-Rubber Blowing", could replace the incorporation of USPs and would avoid the increase of costs associated with the use of these elements (since the rubber particles are applied at the time of the small stones during the stoneblowing process, without the need of fixing the elastic elements to the bottom of the sleeper) while at the same time an abundant waste material (end-of-life tires) is reused to improve the effectiveness of stoneblowing process. In addition, no bonding agents are needed since the rubber particles are used as aggregates, which also avoids increasing maintenance costs in reference to other solutions (Ho et al., 2013; Fontserè et al., 2016).

For this purpose, this paper analyses the effect of replacing natural small stones with different quantities of rubber particles (used as flexible aggregates), comparing the track section behavior after this process (Stone-Rubber Blowing) to that measured after conventional stoneblowing technique as well as in comparison to the application of different USPs (with various stiffness values) used as reference elastic element in combination with stoneblowing.

2. Methodology

2.1 Materials

In order to analyse the effect of using rubber particles as flexible aggregates during stoneblowing process (mixed with part of natural aggregates used in such conventional technique), these elastic components were obtained by grinding up waste tires primarily composed of rubber (Figure 1). The density of the rubber particles was around 1.15 Mg/m3. The gradation of the elastic granules was as follows: 2% of the particles were between 8 and 12 mm; 61% from 12 to 16 mm; 34% from 16 mm to 22.4 mm; and 2% from 22.4 mm to 25 mm. The rationale for selecting these sizes was to avoid percolation and package (Selig and Waters, 1994; Fair, 2003).

For the same reason, the size of the small natural stones (used to fill the gap between the sleeper bottom and ballast surface after settlement during stoneblowing process) was mainly fixed between 14 mm and 20 mm. These stones were obtained from ophitic rocks, presenting a resistance to fragmentation lower than 8% (EN 1097-2), which is appropriate to limit the fouling of ballast associated with natural aggregates degradation. In Figure 1, the stones are orange painted in order to distinguish them from ballast particles.

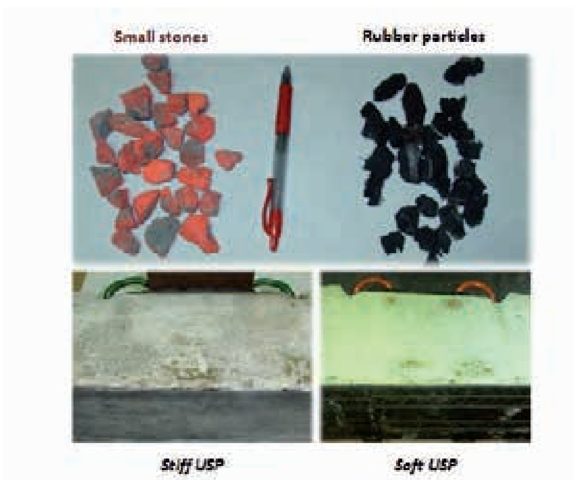

Figure 1. Main materials used for the solutions analysed in this study.

As reference elastic elements to compare the influence of applying rubber particles under sleeper, the USPs used in this study (Figure 1) were manufactured from end-of-life deconstructed tire tread layers (obtained without any need for grinding), which have been shown to be appropriate for application as elastic elements in railway tracks (Sol-Sánchez et al., 2014) These pads were categorized as soft USP (4.5 mm thick) and stiff USP (2.5 mm thick), presenting a static bearing modulus close to 0.20 N/mm3 and 0.40 N/mm3, respectively.

On the other hand, to carry out this study, a conventional track section was reproduced in laboratory by using a testing box that allows for simulating the effect of trains passing, and then, the track settlement due to traffic, which requires maintenance interventions (in this case stoneblowing without and with the combination of the different elastic solutions – rubber particles or USPs) to restore initial position. The box dimensions (1 m x 1 m, and 500 mm in height) allowed for the introduction of a piece of concrete sleeper (250 mm in width and 850 mm in length) with a flexible fastening system and a piece of rail type UIC-54 with a length of 250 mm. The height of the ballast layer was 300 mm under the sleeper, which is a common value found in railway tracks, and allows for maintenance tasks (UIC Code 719-1). The ballast used in this study was composed of ophite, with appropriate size (mainly between 63 mm and 31.5 mm, EN 933-1) and resistance to fragmentation (lower than 8%, EN 1097-2) for its application in railway tracks according to EN 13450, as well as the rest of properties were in consonance with such Standard.

2.2 Test procedure

In order to prove the efficiency of the proposed technique (stone-rubber blowing) to reduce the railway track maintenance, the testing plan included the analysis of the behaviour of a track section reproduced in laboratory when different solutions are carried out as maintenance for re-leveling after ballast settlement. These solutions were: stoneblowing process as conventional maintenance technique; stoneblowing combined with the application of different USPs used as rseference elastic element; and the incorporation of diverse quantities of rubber particles (10%, 25% and 50% over the total volume of the mix of particles blown) used to replace part of the small stones during stoneblowing process (stone-rubber blowing technique). Figure 2 represents the scheme of the different solutions applied.

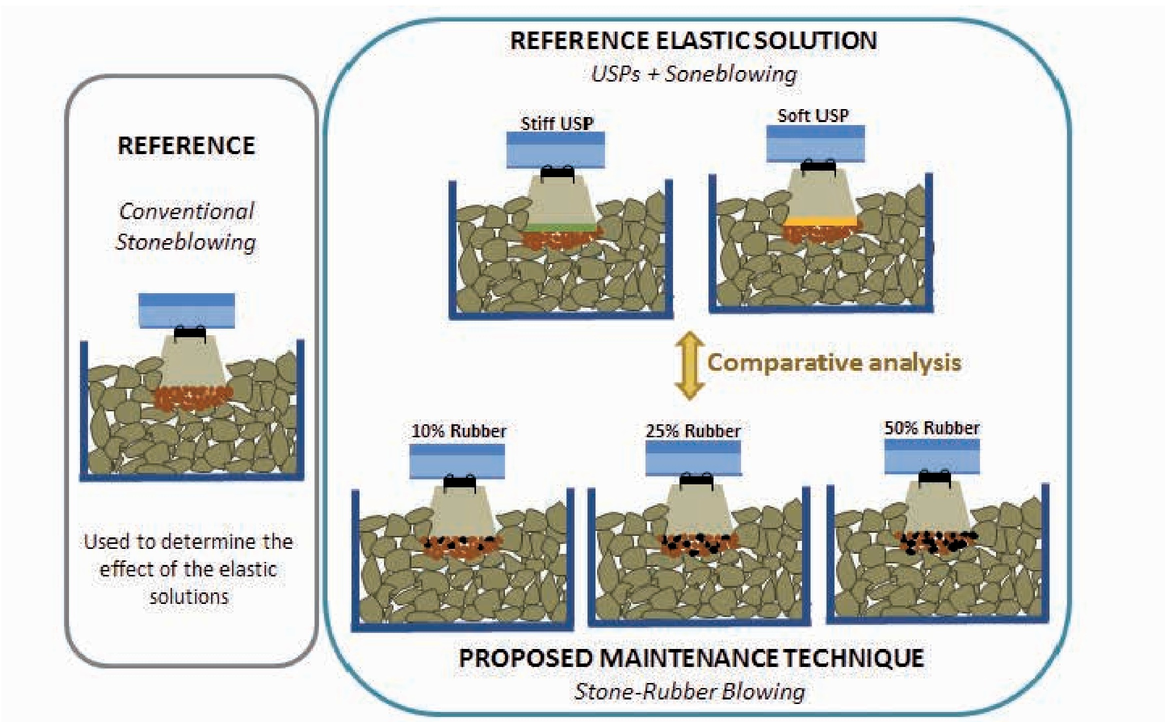

Figure 2. Testing plan.

For this study, a series of dynamic tests were carried out in order to reproduce track section settlement, and then, to simulate maintenance techniques (conventional stoneblowing as well as the combination of this process with the incorporation of elastic elements) for analysing the effect of each solution on track section behavior. The dynamic test consisted of applying 200,000 loading cycles at 4Hz of frequency with a maximum stress over the ballast surface around 250 kPa. These loading conditions are considered appropriate for simulating the effects of passing trains (Indraratna et al., 2006; Bach, 2013; Sol-Sánchez, 2016a). For each maintenance solution, this test began over the conventional section (rail, sleeper, fastenings, rail pad and ballast, without USPs and without blown stones), and it was stopped when the settlement was close to 15 mm and the loading cycles reached approximately 50,000. Following this procedure, a maintenance task was carried out to recover the track geometry, whereupon the test continued until its completion (200,000 cycles). This method was applied twice for all the techniques studied.

The conventional stoneblowing process was conducted after the ballast settlement (up to approximately 15 mm, as indicated previously) by lifting the rail-fastener-sleeper system, and adding the small stones between the sleeper and the ballast surface, which allowed for recovering the original position of the sleeper. In this laboratory work, the process of adding the stones was developed by hand (without compressed air) since the main objective of this initial study was to show the effect of the elastic components, and in particular to examine the feasibility of using rubber particles as flexible stones. The volume of stones and distribution under the sleeper was in agreement with the findings of other authors (Nutbrown and Nicholas, 1999; Tutumluer et al., 2015). Finally, the sleeper piece was returned to its original position (corresponding to its location before ballast settlement), and the dynamic test was continued.

Regarding the combination of stoneblowing with the different elastic elements, in the case of USPs, these components were glued to the bottom of the sleeper by using epoxy resin while the process of stoneblowing was carried out, and then the sleeper with the pad was again placed over the ballast and the stones blown. In reference to the rubber particles (RP) used for stone-rubber blowing process, they were mixed with the natural stones so that both materials were applied at the same time. The quantities of rubber analyzed were 10%, 25% and 50% over the total volume of the mix of elastic particles and natural stones.

3. Analysis of results

Figure 3 analyses the influence of adding different quantities of rubber particles (as replacement of natural small aggregates used during stoneblowing intervention) on the variation in mechanical performance of the global section in comparison to the effect of only apply stoneblowing process (without including innovative elastic solutions). Also, as a referent elastic element to analyse the effect of rubber particles, Figure 3 shows the impact of including USPs in combination with stoneblowing process.

It is possible to understand that the inclusion of USPs and rubber particles during stoneblowing operation, leads to an important reduction in track stiffness while increasing the damping capacity of the section, limiting the negative effect of stiffening of the track when conventional stoneblowing is applied. Also, results show that the use of different percentages of rubber particles allows for gradually varying the track performance, obtaining comparable results to those measured for USPs. Indeed, the replacement of more than 50% of stones with rubber particles presents a comparable reduction in section stiffness to that obtained with soft USPs while a percentage around 10% could be appropriate to use this solution as alternative to stiff USPs. Then, it is seen that the mix of different ratios of rubber particles and stones for track maintenance would allow for the optimization of its vertical stiffness, which is particularly beneficial in transition sections where a gradual change in stiffness is required.

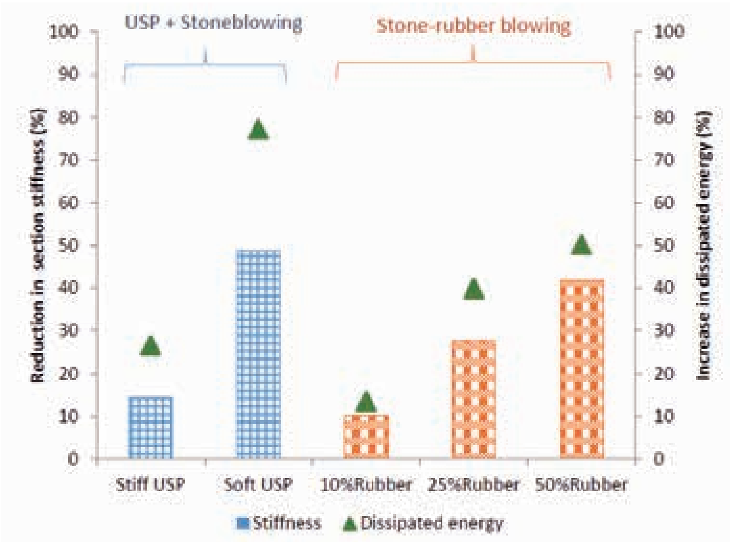

Figure 3. Influence of rubber dosage to modify track performance in reference to conventional stoneblowing, comparing to the effect of USPs.

Regarding the effect of stone-rubber blowing on the settlement trend of the whole track section after maintenance intervention, Figure 4 represents the reduction in total settlement at the end of the test as well as the ratio of settlement per load cycle, in reference to the conventional stoneblowing process. Also, results are compared to those measured when USPs are used as control to analyse the effect of the flexible aggregates.

Results demonstrate that the inclusion of rubber particles during stoneblowing intervention leads to a positive effect on track geometry by reducing cumulative ballast settlement, this fact being more remarkable when increasing the quantity of rubber applied. In comparison to the impact of USPs, it is seen that the quantities of rubber that led to a comparable change in track performance (10% and 50% of rubber in reference to stiff and soft USPs, respectively), allow for a higher reduction in track settlement at the end of the test, and what is more remarkable, a reduction in the long-term trend to settlement. This implies that incorporating rubber particles during stoneblowing seems to be more effective than the application of USPs, which could reduce the need for high-frequency maintenance checks.

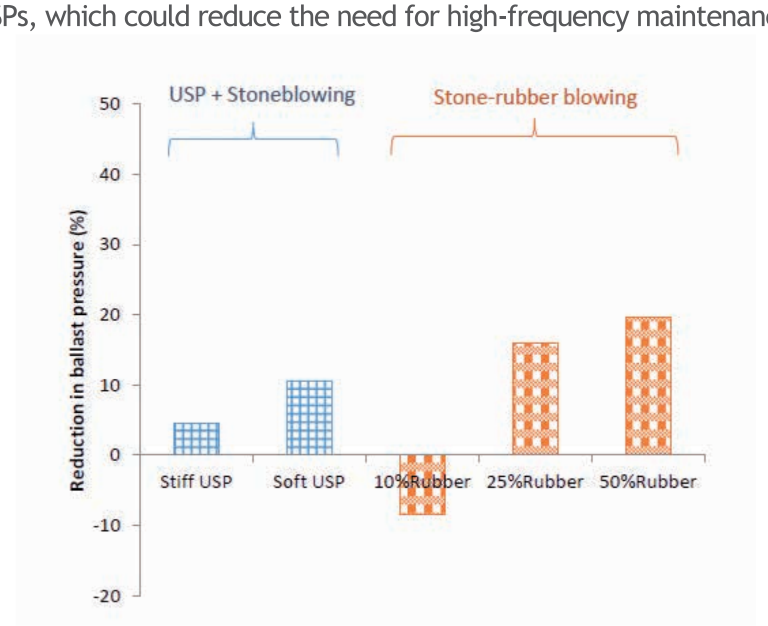

Figure 4. Effect of including elastic solutions to improve the effectiveness of stoneblowing process on reducing track settlement.

On the other hand, Figure 5 compares the effect of rubber particles and USPs on reducing the stress on ballast layer, in reference to the conventional stoneblowing process. Considering that the application of such conventional technique already allows for reducing pressure in the ballast (as a result of the increase of the surfacing contact between sleeper and ballast when smaller stones are added) (Coenraad, 2001; Sol-Sánchez et al., 2016b), results show that the solution with 10% of rubber presented lower reduction than the conventional stoneblowing task, obtaining then a negative decrease in comparison to such reference technique. This is likely to be related to the flexibility of these few particles (having a high capacity to deform under low stress) that cause the concentration of pressure on the natural stones in contact with sleeper.

However, when the quantity of rubber was increased (and there are also rubber particles between the sleeper and the small natural stones), the pressure on the ballast layer was reduced, showing even higher reduction in pressure than that measured for the solutions with USPs. This is due to the strong capacity of the rubber particles to damp loads, associated with their size (up to 20 mm), which is higher than the thickness of the USPs studied.

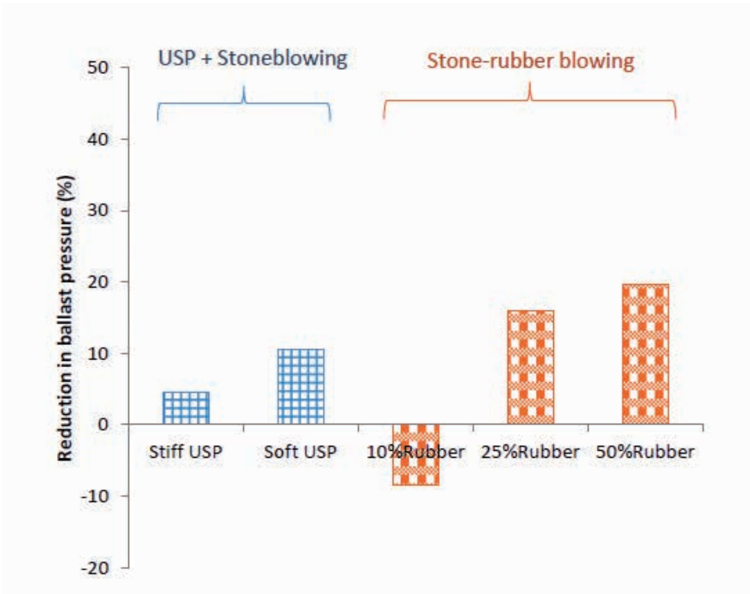

Figure 5. Impact of the elastic solutions on the reduction in ballast pressure, in reference to conventional stoneblowing.

With the aim of analysing ballast degradation after each type of maintenance task based on elastic solutions, Figure 6 displays the effect of combining stoneblowing with USPs and the inclusion of rubber particles as flexible aggregates on two parameters (Index of particle breakage - Bg; Ballast Breakage Index - BBI, %) that have been previously used in other studies to evaluate ballast breakage (Marsal, 1967; Indraratna et al., 2005). As the values recorded for the solutions with the same type of elastic element (USP or RP) were quite similar, Figure 6 shows the mean value recorded for the reduction in degradation when stoneblowing process is combined to both USPs (stiff and soft) and to the different quantities of rubber particles.

The results reflect the fact that both elastic solutions allow for a significant reduction in ballast breakage (regardless of the parameter selected), this fact being more marked when rubber particles were used during the stoneblowing task. This could be related to the better distribution of the stress and lower movement of the ballast stones, which is in accord with the results of ballast settlement and pressure under the granular layer. Thus, it is clear that the use of stone-rubber blowing could lead to an important increase in the durability of ballast, and therefore, in the service life of ballasted tracks.

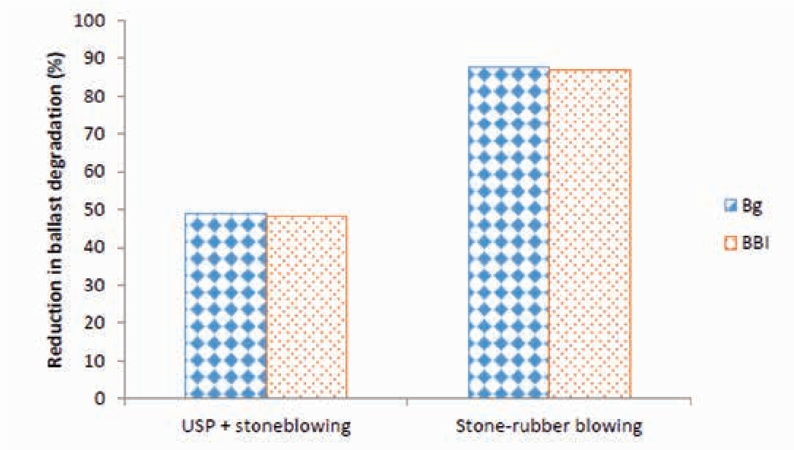

Figure 6. Effectiveness of the elastic solutions to reduce ballast degradation, considering stoneblowing process as a reference.

4. Conclusions

This paper presents a study about the effect of adding rubber particles as flexible stones during the process of stoneblowing, regarded as a new maintenance task (stone-rubber blowing) for railway tracks that combine the benefits of both stoneblowing and USPs (but without the need of bonding such elastic elements) by obtaining an elastic granular layer that fill the gap between the sleepers and the settled ballast layer. With this purpose, this paper shows the influence of adding different quantities of rubber particles as flexible stones at the time that its effect is compared with that recorded when conventional USPs (with different stiffness) are used in combination with the traditional maintenance tasks (tamping and stoneblowing). Based on the results obtained in this study, the following conclusions can be drawn:

- The inclusion of rubber particles during the stoneblowing process improves the effectiveness of this task to reduce ballast settlement and degradation, at the same time that the flexibility and capacity of the granular layer to damp loads is increased, and therefore, longer service life of railway tracks could be obtain.
- The higher the quantity of rubber particles used as flexible stones, the higher the reduction of ballast settlement (at both short and long-term) and vertical stiffness while higher capacity to dissipate the energy transmitted to the ballast is recorded as well as lower stress under such granular layer.
- The use of high quantities of rubber particles (around 50% over the total volume of particles blown) during the process presented as stone-rubber blowing, leads to a comparable (or even better) behaviour of the ballast than that recorded when soft USPs are employed in combination with the conventional stoneblowing process (the most favorable case among the conventional maintenance tasks).
- On the other hand, lower volume of rubber could be comparable to the cases of conventional stoneblowing where stiffer USPs are applied, being able to obtain a gradual behaviour of railway tracks by varying the quantity of rubber employed during the process of blowing. This would allow for smooth stiffness transitions along the track.

Based on the results, it is possible to say that the proposed technique of adding rubber particles to partially replace the stones leads to similar or enhanced benefits in comparison with those obtained when other elastic components such as USPs are applied. Moreover, use of this technique could yield a substantial reduction in maintenance costs, since these rubber particles could be combined with the small stones during the stoneblowing process. Nonetheless, further studies are required to demonstrate the effectiveness of this solution, analysing some issues such as the expected longevity of rubber particles, possible impact on track drainage, and its real-scale application using a stoneblower to assess any possible segregation of the stones and rubber particles.

5. References

- Bach, H. (2013) Evaluation of attrition tests for railway ballast. PhD Dissertation, Graz University of Technology, Austria, 2013.
- Claisse, P. A.; Keedwell, M.; Calla, C. (2003) Tests on a two layered ballast system. Procedings of the ICE - Transport, vol. 156, pp. 93-101.
- Dahlberg, T. (2010) Railway Track Stiffness Variations-Consequences and Countermeasures. International Journal of Civil Engineering, Vol. 8, pp. 1–12.
- Fair, P. (2003) The geotechnical behaviour of ballast materials for railway maintenance. University of Sheffield, PhD Dissertation.
- Fontserè, V.; López Pita, A.; Manzo, N.; Ausilio, A. (2016) NEOBALLAST: New high-performance and long-lasting ballast for sustainable railway infrastructures. Transportation Research Procedia 14, 1847-1854.
- Hellawell, A. (1997) Stoneblower provides ballast maintenance solution. Railway Gazette International(September), pp. 595-596.
- Indraratna, B.; Khabbaz, H.; Salim, W.; Christie, D. (2006) Geotechnical properties of ballast and the role of geosynthetics. Journal of Ground Improvement, Vol. 19, pp. 91-102.
- Indraratna, B.; Lackenby, J.; Christie, D. (2005) Effect of confining pressure on the degradation of ballast under cyclic loading. Geotechnique, Vol. 55, pp. 325–328.
- Indraratna, B.; Salim, W.; Rujikiatkamjorn, C. (2011) Advanced Rail Geotechnology - Ballasted Track.
- Marsal, R.J. (1967) Large scale testing of rockfill materials. Journal of Soil Mechanics and Foundation Engineering. ASCE, Vol. 93, No. SM2, pp. 27-43.
- Nutbrown, D.; Nicholas, R. (1999) Stoneblower experiences. PWI Autumn Technical Seminar.
- Plica, P. (2007) Sleeper Solicitation/Sleeper design. Work Package number 2b of UIC Project Under Sleeper Pads.
- Selig, E.T.; Waters, J.M. (1994) Track Geotechnology and Substructure Management, T. Telford.
- Sol-Sánchez, M.; Moreno-Navarro, F.; Rubio-Gámez, M.C. (2014) Viability of using end-of-life tire pads as under sleeper pads in railway. Construction and Building Materials, Vol. 64, pp. 150-156.
- Sol-Sánchez, M.; Pirozzolo, L.; Moreno-Navarro, F.; Rubio-Gámez, M.C. (2016a) A study into the mechanical performance of different configurations for the railway track section : A laboratory approach, Eng. Struct. 119, pp. 13–23.
- Sol-Sánchez, M.; Moreno-Navarro, F.; Rubio-Gámez, M.C. (2016b) Analysis of ballast tamping and stone-blowing processes on railway track behaviour: the infuence of using UPS's, Geotechnique.
- Tutumluer, E.; Staplin, D.; Trosino, M.; Smak, J.; Tomas, M. (2015) Stone blowing as a remedial measure mitigation differential settlement at bridge approaches. Presented at 94th Annual Meeting of the Transortation Research Board, Washington, D.C.
- UIC (Union International of Railway) (2011) Recommendations for the use of Under Ballast Mats, UIC Code 719-1.