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Environmental performance analysis of bitumen stabilized ballast for railway track-bed using life-cycle assessment

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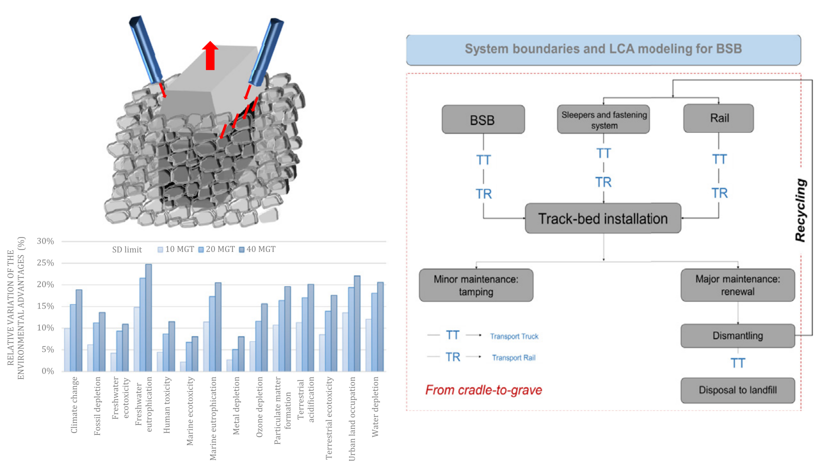
HIGHLIGHTS

- A comparative LCA between bitumen stabilized and traditional ballast is performed.
- BSB does not reduce all the environmental impacts when the single layer is analyzed.
- BSB reduces all the environmental impacts when the complete track-bed is considered.
- Benefits of using BSB are independent of cumulated traffic and track quality level.

GRAPHICAL ABSTRACT



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ABSTRACT

Bitumen stabilized ballast (BSB) is a novel and promising construction or maintenance strategy of traditional ballasted track-bed that consists in the use of bitumen emulsion (BE), which is poured or sprayed at ambient temperature onto the ballast. The bound aggregates show high resistance to degradation and allows increasing intervals between both minor and major maintenance activities.

This paper presents the results of a life cycle assessment (LCA) undertaken to compare the potential environmental impacts associated with the use of bitumen stabilized ballast (bound with BE) with those associated to traditional ballast (unbound aggregates) layers.

Afterwards, for a more comprehensive understanding of the advantages related to the use of BSB, the complete structure of the track-bed, which in addition to the ballast layer also includes other components, such as sleepers, fastening systems and rails, has been considered.

Furthermore, multiple analyses were performed by considering different scenarios involving the comparison of different maintenance timing of BSB and traditional ballast depending on traffic level and/or standard deviation limit (SD) of track irregularities. When the analysis considers the life cycle of the

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complete structure of the track-bed one can conclude that, overall, the use of BSB contributes positively to the reduction of the environmental impacts, independently of the track quality level and the cumulated traffic values considered. Indeed, the higher durability of BSB allows reducing the frequency of replacement of the elements composing the track-bed leading to considerable improvements in the life cycle environmental performance of the entire infrastructure.

1. Introduction

The increasing evidences of the impact of greenhouse gas (GHG) emissions on global warming and its negative effects has urged the international community to strengthen the worldwide commitment to implement far-reaching actions towards low-carbon and climate-resilient growth [1,2].

With the transport sector contributing to around a quarter of the European Union's (EU's) GHG emissions, making it the second-biggest emitting sector after energy, it surely holds the keys to decarbonize the European economy [3]. Although within this sector, road transport is by far the biggest emitter accounting for more than 70% of all GHG emissions from transport in 2014, the role the railway mode, and particularly its infrastructure, can play in the EU's low-emission mobility strategy cannot be neglected [4]. First, the construction of new and the improvement of the existing railway infrastructures is expected to continue its growing trend in the years to come as the EU aims for implementing and completing the Trans-European Transport Network (TEN-T) core network by 2030 and the TEN-T comprehensive network by 2050 [4]. Second, as the EU's answer to the emission reduction challenge in the transport sector comprises the deployment of low-emission alternative energy sources, it is likely that vehicles become more energy-efficient, and then energy use and GHG emissions during the construction, maintenance and disposal of railway infrastructure might increase their share in the environmental impact of the life cycle's railway system. Last, but not the least, as a considerable portion of the Europe's rail network was constructed in a time where the construction methods were not as advanced as those currently available, it is likely that the combined effects of inadequate levels of investment, poor maintenance strategies, and adverse climatic events, result in important elements of the existing rail networks, such as the track-bed structure, requiring frequent maintenance activities [5], thereby increasing the environmental footprint associated with the railway infrastructure's life cycle.

Ballasted track is the most common type of track superstructure supported on a layer of granular material (ballast) [6,7]. Despite the benefits of this track-bed structure and the robustness of experiences in this type of construction, it presents certain limitations and drawbacks, mainly associated with geometry degradation due to ballast settlement [8–10]. Therefore, periodic and costly minor and major maintenance operations are required to provide a granular layer with adequate characteristics, which leads to an important consumption of non-renewable resources and energy while frequent traffic interruptions take place. Thus, for some specific line, ballasted tracks can be considered less convenient from the life cycle standpoint, due to the higher frequency of maintenance and the lower durability, with respect to slab tracks [11–15]. Furthermore, the aggregates used for the ballast must comply with strict requirements. For this reason, when satisfactory quality aggregates are not available nearby the construction/rehabilitation site the environmental and economic burdens increase as a consequence of, for instance, longer hauling distance.

Notwithstanding the facts pointed out above, ballasted track continues to be widely adopted because of the skills acquired by railways authorities in implementing this solution and the relatively low construction costs [6–16].

However, in order to not compromise the global efforts to lower the environmental impacts produced by the transportation sector, and the railway transportation mode in particular, it is of paramount importance to develop new materials and construction technologies that prove to be efficient in reducing the ballasted track-bed maintenance burdens, and thereby attenuating the effects related to the shifting of environmental burdens from one railway system's life cycle phase to another.

In this context, bitumen stabilized ballast (BSB) has been recently proposed as novel and more economical solution [17] to slow down the loss in track quality associated with ballast settlement and particle degradation. It is designed to be used either for reinforcing existing track-beds, reducing the need of both minor and major maintenance, or during the construction of new ones, thus extending the time period between the construction and the first maintenance operation [18–20]. Similarly to stabilization by polymers or resins [21–23], this technology consists of pouring bitumen emulsion (BE) at ambient temperature with an optimum dosage equal to 1.44% by weight of the ballast underlying the sleeper/ballast contact area [19]. Only the ballast subjected to the highest contact pressure [24] is stabilized, therefore it is considered that one third of the sleeper length per sleeper end should be treated by this operation (Fig. 1a). When applied during routine maintenance, it is performed by raising the sleeper (Fig. 1b), whereas during the construction the BE is spread before placing the sleepers [20].

In order to ascertain if the BSB track-bed is indeed better than the traditional ballasted track-bed from the environmental perspective, it is crucial to adopt a life cycle approach to identify and quantify the potential environmental burdens arising from the use of this solution. This need can be accomplished with the support of the Life-Cycle Assessment (LCA) methodology [25]. LCA, which is a data-driven, systematic methodology, has proven to be effective in estimating the environmental burdens caused by a product, process, or service throughout its life cycle [26]. LCA quantifies the environmental impacts of the complete life cycle of products which include processes, or services and encompasses the extraction and processing of raw materials, manufacturing, transportation, maintenance, use, and end-of-life (EOL) [27]. Among other capabilities, LCA assesses the impacts of the emissions released to the environment as a consequence of the energy and material consumed and waste treatment processes and identifies opportunities for environmental improvements and sustainable use of natural resources.

Historically, LCA is not new, as it started being used in the seventies. However, the application of the LCA to railway infrastructures is relatively recent [28–30] and the analysis is often focused on the comparison of different modes of transport [31,32]. In the analyzes of the materials, processes and transport emissions related to construction, maintenance and EOL phases, Milford and Allwood [33] concluded that by maximizing the durability of the track-bed components it is possible to reduce significantly the emissions of CO_2 during the life cycle of the infrastructure. Moreover, by replacing all the components at the