Resources, Conservation & Recycling 137 (2018) 76–88

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

A comparative life-cycle assessment of asphalt mixtures for railway sub-ballast containing alternative materials

Sara Bressi[a,*], Joao Santos[b], Marinella Giunta[c], Lavinia Pistonesi[a], Davide Lo Presti[d]

[a] Department of Civil and Industrial Engineering (DICE), University of Pisa, Italy
[b] Department of Construction Management & Engineering, Faculty of Engineering Technology, University of Twente, Enschede, The Netherlands
[c] Department of Civil, Energy, Environmental and Material Engineering (DICEAM), University Mediterranea of Reggio Calabria, Reggio Calabria, Italy
[d] Nottingham Transportation Engineering Centre, University of Nottingham Faculty of Engineering, The University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

ARTICLE INFO

Keywords:
Bituminous mixtures
Crumb rubber
Reclaimed asphalt pavements
Life-cycle assessment
Environmental sustainability

ABSTRACT

Bituminous sub-ballast in railway track-bed can mitigate the variation of the moisture content in the subgrade and reduce vertical stiffness variations of the track leading to a more durable infrastructure. Nevertheless, durability is only one of the aspects that affects the sustainability of an infrastructure. Other relevant aspects are related to the environmental and economic issues. This research work joins the worldwide effort towards a paradigm shift in civil engineering devoted to assess the sustainability of infrastructures at the design stage. With this in mind, in this study different alternative bituminous sub-ballast mixtures containing recycled materials, namely crumb rubber (CR) and reclaimed asphalt pavements (RAP) were compared by means of the results of a Life-Cycle Assessment (LCA). In comparison with a traditional bituminous sub-ballast the Crumb Rubber Modified (CRM) mixtures showed higher impacts due to the treatment of the rubber as well as the higher amount of bitumen employed in the mixture. In turn, when RAP is used, the LCA results report an improvement of all the indicators considered. The reduction of the impacts is even higher when full blending between the aged and the virgin binder is assumed because it allows reducing the amount of virgin bitumen employed. The results are intended to be used by engineering experts and practitioners to make more assertive judgments on the advantages and disadvantages associated with the use of emerging and commonly called sustainable strategies and practices for railway track-bed.

1. Introduction

Railway transport is one of the transport modes responsible for the lowest CO_2 emissions and energy consumption when operational components, such as running vehicles, are considered. However, during the construction and maintenance operations (non-operational components) the CO_2 emission and energy consumption are considerably high comparatively to other transport modes (Chester and Horvath, 2009; Schwarz, 2009). This gap between energy consumption and Greenhouse Gas (GHG) emissions related to operational and non-operational components underline the need for further research efforts dedicated to the improvement of the best practices of construction and maintenance of railway infrastructures, in order to minimize their negative effects on the society and environment. Railway track-bed is typically composed of different layers, namely ballast, sub-ballast and subgrade. Each layer plays an important role for the durability and maintenance of the track geometry. The use of natural aggregates for constructing those layers represents a significant consumption of an important non-renewable resource that is becoming increasingly scarce. Using recycled materials in the construction and maintenance of railway track-bed can significantly reduce the consumption of natural resources and mitigate the need for the disposal of a solid waste.

In the last years, the growing popularity of recycled materials applied in road pavements and railway infrastructures, such as crumb rubber (CR) coming from end-of-life tires (ELTs), and reclaimed asphalt pavement (RAP) has sparked the conduction of several studies aiming at improving the recycling of materials, in which the waste produced by some systems reduces the consumption of primary materials being needed by other ones as for instance the production of asphalt mixtures (Silva et al., 2012; Bressi et al., 2016).

ELTs are among the largest and most problematic sources of waste due to the large volume produced and their durability (Lo Presti, 2013). On one hand, these characteristics are negative if ELTs are considered as waste material, but being very resistant and durable, CR obtained

* Corresponding author.
E-mail addresses: sara.bressi@ing.unipi.it (S. Bressi), j.m.oliveiradossantos@utwente.nl (J. Santos), marinella.giunta@unirc.it (M. Giunta).

https://doi.org/10.1016/j.resconrec.2018.05.028
Received 28 November 2017; Received in revised form 12 April 2018; Accepted 28 May 2018
0921-3449/

from the processing of ELTs has the potential to be an interesting material for use in other products, such as asphalt mixtures. Rubber grains are obtained from crushing scrap tires in specialized plants where they are also separated from steel fibers and textile. These grains can be incorporated into the preparation of asphalt mixtures by the so-called "wet" and "dry" production processes. The *wet process* envisages the dissolution of the CR in the bitumen as a modifying agent. The *dry process* envisages the replacement of a small portion of aggregates with the same fractions of rubber grains (FHWA, 1997).

The dry process became recently a very attractive technology because of its production simplicity compared to the wet process (Feiteira Dias et al., 2014). Indeed, the crumb rubber is added directly to the aggregates during the fabrication as another ingredient in the mix. The bitumen is then modified when it comes in contact with the rubber (CEDEX, 2007). When the rubber is added to the asphalt mixture by means of dry process the grains of rubber swell up because they absorb part of the volatile parts of bitumen (paraffin and maltenes). This process of maturation, called "maceration", led to obtain a stiffer bitumen (Dong et al., 2012), increasing the quantity of bitumen necessary to achieve the mix design optimization of the CR mixtures.

The use of CR in the production of asphalt mixtures by means of both technologies (wet and dry process) has proved to be environmentally beneficial due to: (i) the reduction of the Gross Energy Requirement (GER) and the GHG emissions (Farina et al., 2017); (ii) the reduction of noise, especially when the dry process is used (Paje et al., 2010); and (iii) the improvement of damping properties when CR is mixed as an aggregate as a consequence of the vibrations absorption by the rubber (D'Andrea et al., 2004).

RAP is the milled material coming from the Maintenance and Rehabilitation (M&R) of asphalt pavements. The opportunity for using high amounts of RAP is underscored by the need of reducing the exploitation of quarries and the disposal of wastes resulting from rehabilitation projects of road pavements. Often, these materials can be used to replace virgin materials that are more expensive, provided that they ensure the same performance level as the traditional ones. This aspect seems not to be a practical limitation, given that several research works have proven that significant quantities of RAP can be employed while keeping an acceptable level of performance (Santero et al., 2011; Yu and Lu, 2012; Praticò et al., 2013; Bressi et al., 2016). Moreover, the use of RAP to fully or partially replace virgin and/or manufactured materials, thus avoiding their landfill or stockpile as waste, it is also attractive for highway agencies to the extent that it reduces the cost of purchasing and transporting new aggregate and binder for asphalt mixtures.

2. Objective and methodology

The objective of this paper is to perform a comparative life-cycle assessment (LCA) of traditional bituminous mixtures for sub-ballast, produced following the Italian standard specification of Rete Ferroviarie Italiane (RFI), and bituminous sub-ballast mixtures containing different percentages of recycled materials (i.e., RAP and CR).

In order to ascertain the extent to which the alternative sub-ballast mixtures allow achieving environmental benefits when compared to the traditional sub-ballast mixtures, it is crucial to adopt a Life-Cycle approach able to identify and quantify the potential environmental burdens arising from the use of these solutions. This need can be accomplished with the support of the LCA methodology (ISO, 2006a) and the most recent standard on "Sustainability of Construction works" (EN 15804, 2012). 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 (Matthews et al., 2015). Among other capabilities, LCA assesses the potential impacts of the emissions released to the environment as a consequence of the energy and materials consumed and identifies opportunities for environmental improvements. The assessment includes the entire Life-Cycle of the product, process, or service and encompasses the extraction and processing of raw materials, manufacturing, transportation, maintenance, use, and end-of-life (Consoli et al., 1993). According to the ISO 14040 series the LCA framework is divided into four stages (ISO, 2006a, b): (i) goal and scope definition; (ii) Life-Cycle inventory analysis (LCI); (iii) Life-Cycle impact assessment (LCIA); and (iv) interpretation.

2.1. Goal and scope definition

2.1.1. Goal

The main goal of this research work is to quantify the potential Life-Cycle environmental impacts arising from the use of different types of alternative materials in the bituminous sub-ballast layer, specifically CR obtained from processing ELTs and RAP coming from the demolition of old road pavements. The results are compared with those associated with the use of traditional sub-ballast mixtures. The findings of this study are intended to be used by engineering experts and practitioners to make more assertive judgments on the advantages and disadvantages associated with the use of emerging and commonly called sustainable strategies and practices for railway track-bed construction and M&R.

The ReCiPe method (Goedkoop et al., 2013) was used to assess the potential environmental impacts. This allowed covering several environmental interests because a list of LCI outputs are transformed into values of indicators that are related to environmental impact categories. The analyses were performed by using Gabi Professional Academy LCA software® (GaBi ts, 2017) and its database and processes. Specific processes not available in Gabi (for instance CR production) were purposely created.

2.1.2. System description and boundaries

The system includes within its boundaries all the activities required to construct the bituminous sub-ballast layer. Specifically, the following phases are accounted for: (i) resources extraction and composite materials production; (ii) movement involved in hauling materials between facilities and work site; and (iii) construction equipment operation during the construction of the sub-ballast layer. The system boundaries tailored for the specific application carried out in this research work take into account the existing literature about the durability and performance of bituminous mixtures containing CR (dry process) and/or RAP. In this context, according to several recent studies (Farina et al., 2017; Lee et al., 2008; Fontes et al., 2010; Pinheiro and Soares, 2003; Gowda et al., 1996; Tam et al., 1992; McDaniel et al., 2000), CR dry and RAP mixtures can achieve the same performances of a traditional mixture, while few others instead report higher performance (Olivares et al., 2009; Airey et al., 2003; Sargious and Mushule, 1991; Huang et al., 2004). In particular, the dry technology analyzed in this paper is called RUMAC and usually contains 1–3 percent of rubber by weight of the total aggregate in the mix and target air voids content 2–4 percent (FHWA-RD-97-148). In the 1980's the mix design and the technology was refined achieving the production of a bituminous mixture commercially called PlusRide (Kandhal and Hanson, 1993). This type of mixture has been tested several times in test sections showing contradictory results. For instance, the California Department of Transportation (CalTrans, 2006) has constructed four projects using the dry process technology and the results were that two of the four dry process projects improved the performance of traditional dense-graded asphalt, a third project has performed comparably and the last showed worse results (Kirk and Jack, 1991). Moreover, the two dry process sections constructed by the Minnesota Department of Transportation (MNDOT) have not shown higher performance compared to traditional asphalt (Turgeon and Curtis, 1989).

Therefore, a conservative approach assuming the same durability for all the solutions is considered. That means that the maintenance, dismantling and disposal phases are scheduled at the same time for all the solutions and then are excluded from the system boundaries.