Resources, Conservation and Recycling 117 (2017) 204–212

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Full length article

Life cycle assessment applied to bituminous mixtures containing recycled materials: Crumb rubber and reclaimed asphalt pavement

Angela Farina, Maria Chiara Zanetti*, Ezio Santagata, Gian Andrea Blengini

Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy

ARTICLE INFO

Article history:
Received 1 May 2016
Received in revised form 3 September 2016
Accepted 30 October 2016
Available online 4 November 2016

Keywords:
Life cycle assessment
Road pavements
Bituminous mixtures
Crumb rubber
End-of-life tires
Reclaimed asphalt pavement

ABSTRACT

This paper focuses on Life Cycle Assessment (LCA) of different types of road paving technologies based on the use of bituminous mixtures containing recycled materials such as crumb rubber from end-of-life tires and reclaimed asphalt pavement. Analyses were carried out by considering different scenarios which stem from the combination of production, construction and maintenance operations, and by comparing them with a reference case involving use of standard paving materials. LCA results, expressed in terms of gross energy requirement and global warming potential, showed that the use of rubberized bituminous mixtures produced by means of the so-called wet technology leads to significant benefits in comparison with standard paving solutions. This was proven by the reduction of both considered environmental indicators, ranging between 36% and 45%. However, these improvements are only slightly enhanced by making use in the same type of mixture of reclaimed asphalt pavement material in partial substitution of virgin aggregates. In the case of materials deriving from the alternative dry technology, no significant differences can be identified, with results that are very close to those of the standard scenario. Finally, the LCA also considered effects caused by variations of thickness and maintenance frequency for the wet technology scenarios, thus showing that their environmental effectiveness is guaranteed only by ensuring an adequate durability of the mixtures in service.

1. Introduction

One of the major challenges of pavement engineering worldwide is to meet the ever-increasing demand of economic and physical resources related to construction and maintenance by means of environmentally sustainable technologies (Santero et al., 2011). In such a context, several studies have shown that Life Cycle Assessment (LCA) methodologies may be extremely useful in supporting the choice of preferred paving solutions, which should not be exclusively analyzed with respect to their economic impact (i.e. through a least-cost approach) or to their expected field performance (i.e. by means of a maximum-durability approach).

Use of LCA tools is especially valuable in the case of innovative materials containing recycled products, which may be attractive for applications as a result of their contribution to the reduction of consumption of raw materials and non-renewable resources (Carpenter et al., 2007; Chiu et al., 2008; Giani et al., 2015; Huang et al., 2007). Among the recycled materials which have gained wider popularity throughout the evolution of paving technology, those which are currently considered more frequently are crumb rubber (CR) from end-of-life tires (ELTs) and reclaimed asphalt pavement (RAP) (Copeland, 2011; McDaniel and Anderson, 2001; Santagata and Zanetti, 2012; Way et al., 2012).

CR is obtained from the mechanical size reduction of end-of-life tires in specialized plants (Zanetti et al., 2015). Following such a preliminary treatment, CR can be included in the preparation of bituminous mixtures by means of the so-called "wet" and "dry" production processes, in which it is respectively added to base bitumen as a modifying agent or in hot mix plants as an additional aggregate fraction (Epps, 1994; Heitzman, 1992; State of California Department of Transportation, 2005a).

The modified asphalt binder produced by means of the wet process, also known as asphalt rubber (AR) (ASTM, 2009), is characterized by a high viscosity and enhanced elasticity and ductility. Production takes place in specialized blenders at approximately 180 °C, with the use of a CR percentage (typically higher than 15% by weight of total binder) which depends upon desired properties of the final product. After preparation and curing, the binder is combined with aggregates in the hot mix plant for the production of bituminous mixtures which are usually of the gap-graded or open-graded type, with a non-continuous particle size distribution that allows the use of very high binder contents (about 8–9%

* Corresponding author.
E-mail address: mariachiara.zanetti@polito.it (M.C. Zanetti).

http://dx.doi.org/10.1016/j.resconrec.2016.10.015
0921-3449/

by weight of dry aggregates) (State of California Department of Transportation, 2006). However, AR can be also used for the production of dense-graded mixtures, characterized by a continuous particle size distribution and by a binder content closer to that of standard paving mixtures (of the order of 5–6% by weight of dry aggregates) (State of California Department of Transportation, 2005b).

Effects of CR on the properties of bituminous mixtures in the case of the dry production process are significantly different from those synthesized above. Rubber particles contribute to the load-bearing function of the aggregate structure in which they are included, with an overall improvement of elastic response (Santagata et al., 2013a,b; Santagata and Zanetti, 2012). Mixtures produced with this technology are usually of the dense-graded type, with typical dosages of CR comprised between 1% and 3% (by weight of dry aggregates). However, since CR particles absorb part of the aromatic fractions of bitumen during mixture production and laying, optimal binder content is often slightly higher than that adopted for standard mixtures containing no recycled rubber (Buncher, 1995).

RAP is the residue which is created when milling damaged pavements for maintenance and rehabilitation purposes. Such a material is constituted by aggregates of selected quality, partially covered by aged bitumen, and can therefore be re-used in the production of bituminous mixtures by means of cold-recycling or hot-recycling technologies (Re-Road, 2013; Santagata and Chiappinelli, 2002, 2003a,b, 2004; Santagata et al., 2007, 2010). In a number of research projects, it has been shown that composite paving materials can include significant RAP quantities while still exhibiting acceptable performance-related properties (Huang et al., 2009; Santero et al., 2011; Yu and Lu, 2012). Moreover, it has been repeatedly pointed out that RAP recycling is especially attractive for Administrations since it offers an effective solution to the efficient use of resources and sustainable waste management, avoiding landfilling and reducing consumption of natural aggregates (Chowdhury et al., 2010; Giani et al., 2015).

2. Objective

This paper presents environmental results deriving from the use of recycled materials in bituminous mixtures for pavement wearing courses. Advantages and disadvantages associated to such materials were investigated by means of a LCA methodology (EC, 2010; ISO 14040, 2006), which was used to measure environmental performance in terms of selected indicators. Evaluations were performed by referring to the case study of an Italian extra-urban road, for which it was hypothesized that five different types of bituminous mixtures could be employed for the formation of the wearing course.

3. Goal and scope

3.1. Methodology

The definition of a sector-specific LCA procedure for road paving applications is still largely under debate (SUSCON, 2006; Carpenter et al., 2007; Huang et al., 2009, 2013; Santero et al., 2011; FHWA, 2014; Farina et al., 2014, 2015). Although it is recognized that in the context of decision-making a consequential approach may be beneficial (Brander et al., 2008; Finnveden and Hauschild, 2009), the LCA method adopted in the study presented in this paper was of the attributional type. This was deemed appropriate given the innovative character of the considered paving materials and technologies, for which a consequential approach may lead to uncertainties that prevent a full understanding of their main characteristics (Lundie et al., 2007). As a result of such a choice, marginal data were excluded and the analysis relied entirely upon average data for all subsystems, avoiding any consideration of marginal effects (Tillman, 2000).

The adopted methodology entailed the use of two environmental indicators: Gross Energy Requirement (GER) and Global Warming Potential (GWP). GER provides an estimate of the life cycle energy extracted from the earth's crust (Boustead and Hancock, 1979), whereas GWP quantifies climate change expressed in kg of equivalent released CO_2 (IPCC, 2006).

In order to expand the analysis and cover more areas of environmental and resource-use interest, the ReCiPe method was also used in the analysis (Goedkoop et al., 2013). By means of such a method, the list of Life Cycle Inventory results is transformed into a limited number of indicator scores attributed to environmental impact categories.

3.2. Functional unit

The functional unit employed in the analysis and to which results were referred is constituted by 1 m of built pavement layer. Width and thickness of the unit were based on specific project data, which changed depending upon considered paving solution.

3.3. System boundaries

It was assumed that system boundaries of the LCA analysis were to include all processes and activities that encompass raw materials sourcing, composite materials production, construction operations and maintenance works during pavement service life.

Raw materials sourcing included rock blasting, milling and aggregate fraction separation carried out in quarries, bitumen production in refineries, tire processing in specialized plants for the generation of crumb rubber, and milling operations for the recovery of RAP from distressed pavements. Corresponding life cycle inventory data are provided in subparagraph 4.1, while details on transport operations to asphalt rubber or hot mix plants are given in subparagraph 4.3.

Production of composite materials considered handling and processing operations occurring in asphalt rubber and hot mix plants. In the first case, activities included in the analysis were bitumen heating and pumping, crumb rubber feeding and prolonged mixing of the two components. In the case of hot mix plants, phases which were taken into account were binder heating and pumping, aggregate feeding and drying, and batch-tuype mixing in the pugmill. Transportation to production and construction sites of these materials was also considered in this phase. Related quantitative analyses are described in subparagraphs 4.2 and 4.3.

Finally, laying operations, involving the use of standard pavers and rollers, were considered by including in the analysis both initial construction and maintenance. In the latter case, activities comprised within the system boundaries were those of damaged wearing course removal, its transportation to landfills, and repaving. Assumptions and reference data on which the analysis of this portion of the system was based are illustrated in subparagraph 4.4. Consumptions and impacts related to the overall management of working sites and to their traffic disturbance were neglected.

Due to the unavailability of reliable data for the innovative materials considered in the investigation, the use phase, which may be of premium interest in LCA studies, was not included in the analysis.

3.4. Models

Models employed for life cycle analyses were those available as part of SimaPro 7.3 (SimaPro7, 2006), a software developed by Prè Consultant.