Journal of Cleaner Production 121 (2016) 45–55

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Environmental comparison of two alternative road pavement rehabilitation techniques: cold-in-place-recycling versus traditional reconstruction

Janez Turk [a,*], Alenka Mauko Pranjić [a], Ana Mladenovič [a], Zvonko Cotič [b], Primož Jurjavčič [b]

[a] Slovenian National Building and Civil Engineering Institute, Dimičeva ulica 12, 1000 Ljubljana, Slovenia
[b] Structum d.o.o., Tovarniška cesta 26, 5270 Ajdovščina, Slovenia

ARTICLE INFO

Article history:
Received 7 September 2015
Received in revised form
2 February 2016
Accepted 7 February 2016
Available online 13 February 2016

Keywords:
LCA
Road reconstruction
Cold in place recycling
Sensitivity analysis

ABSTRACT

Based on a road reconstruction case study, the advantages and disadvantages of two alternative road pavement rehabilitation techniques, a hypothetically defined comparable traditional approach and an actually used cold-in-place-recycling approach, both of which enable a comparable extension of road service life of about 20 years, were investigated by means of Life Cycle Assessment. The results showed that the considered environmental impacts of the traditional approach exceeded those of the cold-in-place-recycling approach: by only 1% with regard to Global Warming, by 18% with regard to Acidification, by 15% with regard to the Abiotic Depletion of Fossil Fuels, and by 16% with regard to primary energy consumption. In the case of the traditional approach, the use of larger amounts of natural aggregate and the transportation of materials significantly contributed to emissions and the consumption of fossil fuels and energy, whereas the cold-in-place-recycling approach was sensitive to the use of cement, whose production results in relatively high emissions, especially of greenhouse gasses. In the case of the traditional approach, sensitivity analyses were carried out with regard to the use of aggregate from a quarry instead of a gravel pit, and to the delivery distance of material hauled away from the distressed road during rehabilitation works (extending the one-way delivery distances from 20 to 100 km). It was found that, if aggregate from a quarry is used instead of from a gravel pit, then the various environmental impacts of the traditional approach would exceed those of the cold-in-place-recycling approach by factors which range between 1.3 and 1.7. Increasing the transportation distance of hauled-away materials from 20 km to 100 km, the impacts of the traditional approach would exceed the impacts of the cold-in-place-recycling approach by a factor of 1.4 (Global Warming) and 1.6 (Acidification and Abiotic Depletion of Fossil Fuels). A further sensitivity analysis was carried out in the case of the cold-in-place-recycling approach, with regard to the use of Portland cements containing different amounts of clinker. It was found that the use of cements with a higher clinker content results in an increase in the Global Warming impact to a level significantly higher than that of the traditional approach.

1. Introduction

Representing an important part of the European and world economy, modern transport systems have given both Europe and the world a high degree of mobility, with ever-increasing performance in terms of speed, comfort, safety and convenience. During recent decades this improved mobility has developed within a context of generally cheap oil, expanding infrastructure, and relatively loose environmental constraints (European Commission, 2011). Today, road transport dominates in comparison with other transport modes. Fuel consumption in road transport generates almost one fifth of global carbon dioxide emissions (Uherek et al., 2010). Moreover, the emissions related to construction, maintenance, operation, and end-of-life of the road infrastructure, as well

* Corresponding author. Tel.: + 386 1 2804 250; fax: + 386 1 2804 484.
E-mail addresses: janez.turk@zag.si (J. Turk), alenka.mauko@zag.si (A. Mauko Pranjić), ana.mladenovic@zag.si (A. Mladenovič), zvonko.cotic@structum.si (Z. Cotič), primoz.jurjavcic@structum.si (P. Jurjavčič).

http://dx.doi.org/10.1016/j.jclepro.2016.02.040
0959-6526/

as vehicle production and use, contribute up to 40% of global greenhouse gas emissions (Hill et al., 2011).

The intensity of road traffic influences not only direct greenhouse gas emissions (due to fuel combustion), but also road durability, which is again indirectly associated with emissions owing to more frequent rehabilitation and maintenance works. Slovenia is one of those countries with the highest road traffic intensity per unit of Gross Domestic Product (OECD, 2013). For instance, in Slovenia, over the last ten years, transit transport by road (82% of all goods are transported using the national road network) has increased by more than 100% (DRSC, 2011), with an annual increase, over the last few years, of 3–4% (Kranjc, 2010). This means that the sustainable construction, maintenance, and rehabilitation of road pavements is a matter of ever increasing importance in Slovenia, and elsewhere in the world.

Besides the intensity of traffic loads, some other factors such as road design and construction, the quality and performance characteristics of input materials, and local weather conditions, are crucial for road durability, and thus also the lifespan of roads. All these parameters are also of key importance when determining the causes of failure or damage in older, distressed road pavements, and preparing corresponding maintenance and reconstruction plans (Fwa, 2006; Adlinge and Gupta, 2013; Gransberg et al., 2014). In the EU several different road rehabilitation techniques are used for the extension of the service life of roads. The disadvantages of the traditional approach to road rehabilitation, based on the hauling away of materials from the distressed road, and their replacement with virgin materials, are related to a lack of efficiency. In order to reduce costs and an excessive consumption of natural resources, different recycling techniques in which materials in distressed pavements are recycled and reused during the rehabilitation of pavements are increasingly preferred (Miller and Bahia, 2009; Giustozzi et al., 2012; Butt et al., 2014). Some maintenance treatments involve the cold-in-place-recycling technique, which enables the recycling of materials and reduces energy consumption due to decreased transportation distances of materials to or from the work site (Lewis and Collings, 1999), as well as faster rehabilitation times. Decisions on the selection of appropriate rehabilitation techniques are, today, more and more based on foreseen environmental impacts, where Life Cycle Assessment (LCA) can act as a powerful tool for the quantification of environmental burdens and possible achievable improvements.

A number of environmental studies, some of which make use of LCA, refer to road construction (Chappat and Bilal, 2003; Muench, 2010; Barandica et al., 2013), and to the processes which are related to the recycling and reuse of materials from distressed roads (Miliutenko et al., 2013; Aurangzeb et al., 2014). The complete life cycle of roads has also been studied by different authors (e.g. Santero et al., 2011; Loijos et al., 2013). In several LCA studies comparisons have been made of different road rehabilitation techniques. For example, Thenoux et al. (2007) compared three such techniques, i.e. asphalt overlay, traditional reconstruction, and cold-in-place-recycling with foamed bitumen, with regard to energy consumption, and found the last-mentioned technique to be the most beneficial. Similar results were obtained by Santos et al. (2014), who demonstrated that the cold-in-place-recycling technique can reduce environmental impacts related to the extraction of raw materials and the production of various mixtures by about 75% compared to the traditional road pavement reconstruction technique. The results refer to a specific highway rehabilitation project. Giustozzi et al. (2012) studied the carbon footprint of the reconstruction of an airfield pavement. Two scenarios were compared: rehabilitation of the existing pavement by (1) using only virgin aggregates and bitumen, and (2) by using 85% of recycled materials. In the latter case the greenhouse gas emissions were reduced by 35%. The energy consumption and greenhouse gas emissions corresponding to different types of road pavement rehabilitation and maintenance works have also been studied by Chappat and Bilal (2003), Chehovits and Galehouse (2010), and Cross and Chesner (2011).

In this study, two different road pavement rehabilitation techniques have been compared by means of LCA, both with a comparable extension of road service life of 20 years (CTRE, 2007): (1) the traditional pavement reconstruction technique: using, for the sub-base, crushed virgin carbonate aggregate from a gravel pit, crushed virgin carbonate aggregate for the base course, crushed virgin volcanic aggregate for the wearing course, and fresh bitumen (abbreviated: "the traditional approach"), and (2) the cold-in-place-recycling pavement reconstruction technique: recycling the original sub-base material and reclaimed asphalt concrete (also known as "full depth reclamation"), including stabilization by cement, followed by the placing of an asphalt base course made from crushed virgin carbonate aggregate, and an asphalt wearing course made from crushed virgin volcanic aggregate, using fresh bitumen (abbreviated: "the cold-in-place-recycling approach"). Unlike in other similar studies, sensitivity analyses were additionally carried out with regard to the use of two different types of virgin aggregate for the sub-base and their corresponding delivery distances (in the case of the traditional approach), and with regard to the use of Portland cement containing different amounts of clinker as a hydraulic binder (in the case of the cold-in-place-recycling approach).

2. Materials and methods

The study refers to actual rehabilitation works which were performed on the regional road G2-102/1038 between the villages of Bača and Dolenja Trebuša (Slovenia), where the average daily traffic load amounts to about 2500 vehicles per day (85% of them being cars). The length of the rehabilitated two-lane road section, which had not been reconstructed for 30 years, was 6400 m, and the average road width was 6.25 m. The existing pavement consisted of an asphalt base + wearing course with a total thickness of about 10 cm, and an unbound aggregate sub-base with a total thickness of about 42 cm, resulting in a total pavement thickness of about 52 cm. According to the local climatic conditions, this is the minimum thickness of pavement needed in order to prevent freezing of the sub-grade material. The upper part of the sub-base consisted of crushed carbonate aggregate, with a total thickness of about 22 cm, whereas the lower part consisted of silty screen which was obtained from local sources, with a thickness of about 20 cm. By means of laboratory tests, it was found that the sub-base material contained more than 8% of particles smaller than 0.063 mm, which meant that it was, in fact, susceptible to frost heave and consequent damage due to severe conditions in winter. For this reason, the pavement was structurally severely deteriorated, significant fatigue cracking being visible on the road surface.

The functional unit for the performed LCA was defined as the rehabilitation of approximately 40,000 m^2 of pavement, with a design life of 20 years. The environmental burdens of the two investigated rehabilitation techniques were compared with regard to Global Warming Potential over 100 years (GWP in kg CO_2 equivalent), Acidification Potential (AP in kg SO_2 equivalent), and the Abiotic Depletion Potential of Fossil Fuels (ADP_f in MJ). These environmental indicators are based on the midpoint CML 2001 model (see Hauschild et al., 2013). Energy consumption, i.e. the total consumption of renewable and non-renewable energy resources, was also estimated.