Resources, Conservation and Recycling 104 (2015) 224–238

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Comparative life cycle assessment of asphalt pavements using reclaimed asphalt, warm mix technology and cold in-place recycling

Martina Irene Giani*, Giovanni Dotelli, Nicolò Brandini, Luca Zampori

Politecnico di Milano, Dipartimento di Chimica, Materiali e Ingegneria Chimica "G.Natta", Piazza Leonardo da Vinci 32, Milano 20133 Italy

ARTICLE INFO

Article history:
Received 30 June 2014
Received in revised form 8 August 2015
Accepted 11 August 2015
Available online 11 September 2015

Keywords:
Road pavement
Life Cycle Assessment (LCA)
Asphalt
Bitumen
Reclaimed Asphalt Pavement (RAP)
Cold In-Place Recycling (CIR)

ABSTRACT

In this work the environmental sustainability of asphalt pavement is analyzed, from material production and maintenance strategy point of view. The work consists of an analysis of the life cycle of 1 km of road pavement and includes all stages of the life cycle: from extraction of virgin materials to end of life. Three types of pavements are compared, among which one produced with virgin materials and traditional technologies in plant, which is used as a reference, and two in which the use of Reclaimed Asphalt Pavement (RAP) and Warm Mix Asphalt (WMA) technology are combined. Also the implementation of the practice of Cold In-Place Recycling (CIR) at the end of life is considered from an environmental point of view: after the first 15 years of life the comparison is made between traditional recycling in plant and CIR. The impacts are evaluated using different methods. Decrease in environmental impacts are found for the options that combine the use of RAP and WMA reaching up to a percentage of reduction of 12% for CO_{2eq}, 15% for energy consumptions, 15% for water used during the lifecycle, and 10–15% for the three macro-categories of damage evaluated in the ReCiPe endpoint method. Additional reductions could be achieved by applying also CIR technology especially for greenhouse gas emissions (−9%).

1. Introduction

Large quantity of aggregates and asphalt are produced all over the world to fulfill the material requirements for the construction of the roads: about 400 million tons of asphalt are produced annually in Europe (EAPA and NAPA, 2011) while about 5.2 million kilometers of roads are covered with asphalt.

Today, public agencies and asphalt producers responsible for roads are experiencing limited available funds together with significant increases in the price of construction operations and asphalt binder. Those concerns are coupled with significant pressure to build, maintain, and rehabilitate in a sustainable way and agencies must look for alternative construction and maintenance methods as well as alternative materials.

New techniques are being developed to make production processes more efficient with less consumption of energy: these aspects can lead to both environmental and economic advantages. These practices include:

- WMA (Warm Mix Asphalt) is the name given to a variety of technologies that allow producing asphalt mixtures at lower temperatures (lower temperatures means in general lower than 140 °C) at which the material is mixed, compacted, and placed on the roadways. EAPA has stated that WMA is generally produced in a temperature range from 100 to 140 °C, while HWMA (Half-Warm Mix Asphalt) is fabricated between 70 and 100 °C (EAPA, 2010). Standard HMA (Hot Mix Asphalt) is produced at about 160 °C instead. Benefits of WMA are reported in literature (Rubio et al., 2012) and include: lower plant emissions, reduced energy consumption, increased RAP content, and paving benefits among which improved workability and compaction efficiency together with quicker turnover to traffic due to shorter cooling time. Moreover, it is reported that lowering production temperatures allows to reduce energy consumption up to 35% or more (D'Angelo et al., 2008).
- The use of RAP (Reclaimed Asphalt Pavement, generated from milling operations of existing flexible pavements) is another material-related technology that reduces asphalt binder and aggregate demand, thus saving natural resources. Several studies show that if asphalt recycling is performed properly, hot mix asphalt containing RAP has the same qualities as asphalt produced from virgin material (Miliutenko et al., 2013).
- Incorporation of recycled materials and by-products (Chiu et al., 2008; Huang et al., 2009; Jullien et al., 2006; Sayagh et al., 2010) that can contribute both to reducing wastes and preserving natural resources.

* Corresponding author. Tel.: +39 02 2399 3231; fax: +39 02 2399 3280.
E-mail address: martinairene.giani@polimi.it (M.I. Giani).

http://dx.doi.org/10.1016/j.resconrec.2015.08.006
0921-3449/

Glossary

CED	Cumulative Energy Demand
CIR	Cold In-Place Recycling
DALY	Disability-Adjusted Life Years
EAPA	European Asphalt Pavement Association
FU	Functional Unit
GGP	Greenhouse Gas Protocol
HMA	Hot Mix Asphalt
LCA	Life Cycle Assessment
NAPA	National Asphalt Pavement Association
PAHs	Polycyclic aromatic hydrocarbons
PM	Particulate Matter
RAP	Reclaimed Asphalt Pavement
TOC	Total Organic Carbon
U.S. EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
NMVOC	Non-Methane Volatile Organic Compounds
WMA	Warm Mix Asphalt

• Different maintenance strategies that can be applied to ensure pavement quality after its useful life, among these Cold-In-Place Recycling (CIR) is a technique that can lead to less environmental impacts compared with other rehabilitation techniques (Miller and Bahia, 2009; Thenoux et al., 2007). CIR consists of pulverization of the asphalt layer, addition of a stabilizer (foamed bitumen or asphalt emulsion), mixing of stabilizer and pulverized material, laydown with a recycling machine and compaction. The advantage of this technology is that recycling occurs at the roadway being rehabilitated, thus reducing the amount of material that must be hauled to the job site. Natural resources such as asphalt binder and aggregates are conserved as a result. In particular, foamed bitumen, which is considered in the present case-study, is produced by mixing a low amount of cold water with a mass of hot bitumen (160–180 °C). Once the pavement is recycled and compacted, a thin HMA layer is placed over the recycled layer.

Several researchers have studied the effects on the environment due to construction, maintenance and disposal of pavements (Stripple, 2001; Birgisdottir et al., 2007; Huang et al., 2009; Santero et al., 2011a,b; Muench, 2010) and the application of new techniques described above. These studies apply Life Cycle Assessment (LCA) that is a popular methodology in different fields of research, since it investigates environmental aspects of a product, a service, a process or an activity by identifying and quantifying the related input and output flows utilized by the system and its delivered functional output in a life cycle perspective (Baumann and Tillmann, 2004). LCA studies include all the processes associated with a product from its 'cradle-raw material extraction' to its 'grave-disposal'. The concept and working phases of LCA are described in the ISO 14040 series on LCA, that were released by International Organisation for Standardization (ISO) in late 1990s and 2000s. Life cycle assessment is being accepted and applied by the road industry, to measure and compare the key life-time environmental impacts of asphalt products and laying processes.

In 2001 the Swedish Environmental Research Institute published a report in which a comprehensive inventory analysis was done based on a 40-year life cycle (Stripple, 2001). Energy consumed during the construction phase is approximately 35% of the total energy consumption. Consumption for lighting and traffic control is more than half of the total consumption during operation phase. In maintenance phase, energy consumption is less than 13% of the total.

Park et al. (2003) reported that the most energy intensive process occurring in a road life cycle is manufacturing of construction materials. The authors stated that construction and demolition consume more energy than maintenance/repair. This conclusion, however, is probably a result from assuming a relatively low number of maintenance cycles (Park et al., 2003).

Several LCA studies of road pavements have been focused on comparing asphalt and concrete pavements (Santero et al., 2011a,b). Results indicate that asphalt pavements imply a smaller use of energy (if the inherent energy in asphalt is not considered) – energy consumption increases to 27 TJ/km by using concrete pavement instead of asphalt (Stripple, 2001) – and lower emissions than concrete pavements. A recent study (Anastasiou et al., 2015) regarding LCA of concrete pavement construction considers the use of industrial by-products such as fly ash and steel slag as alternative aggregates, and show that a high rate of cement clinker substitution can contribute significantly to reduce environmental impacts.

Miliutenko et al. (2013) showed that hot-in-place asphalt recycling is more beneficial than hot-in-plant recycling, but do not report any combination of cold and warm techniques with CIR. Cross et al. (2011) reported that cold in-place recycling reduce energy and greenhouse gas emissions compared to other rehabilitation techniques (above all mill and fill the pavement with HMA overlay). Moreover, some studies focalize only on energy consumption while do not consider other impact categories: it is reported in literature that recycling with foamed bitumen can lead up to a reduction of 20–50% of the energy consumption (Thenoux et al., 2007).

A notable fact is that impacts of the traffic component are considered to be more environmentally significant than construction, operation and maintenance of the road lifetime (Stripple, 2001; Yu and Lu, 2012; Vidal et al., 2013). Several studies have shown that, including use phase (impacts from vehicles travelling on the road) in a life cycle study, impacts occurring from other phases of life cycle would be negligible, because of much higher impacts from traffic within all the life cycle. In detail, Stripple estimated that energy expended in initial construction is roughly equivalent to the energy used by traffic on the facility for 1 or 2 years depending on the specific case study.

How it can be noticed from the discussion above, it results difficult to compare the different studies regarding LCA of pavements since none of the existing LCAs include all phases of the lifecycle, different functional units are used and different assumptions are made (Santero et al., 2011a,b; Muench, 2010). Moreover, the environmental performance of asphalt pavements is very sensitive to transportation distances, hence the comparisons that can be done are very site specific (Miliutenko et al., 2013).

In the present case study use of RAP, WMA technology and CIR is combined in order to assess what can be the advantages in terms of impacts on the environment. According to the annual report Asphalt in figures (EAPA, 2014) the total production of HMA and WMA in Italy in 2013 reaches 22.3 million tons while the available reclaimed asphalt consist of 10 million tons, 20% of which is used in hot and warm recycling. Comparing asphalt pavements considering different percentages of RAP, different production temperatures and the use of CIR is a relatively new study among the pavement LCA literature. The present study is site-specific; therefore, it can be compared with LCAs studies that consider the use of WMA, RAP and CIR technology separately.

2. Methodology (LCA framework)

The life cycle assessment methodology observes and analyzes a product or service over its entire life cycle in order to determine its