Renewable and Sustainable Energy Reviews 72 (2017) 473–484

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Asphalt mixtures emission and energy consumption: A review

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ARTICLE INFO

Keywords:
Asphalt mixtures
Hot mix asphalt
Warm mix asphalt
Asphalt rubber mixtures
Reclaimed asphalt pavement
Portland cement concrete
Recycling
Energy consumption
Greenhouse gas emissions

ABSTRACT

The objective of this paper is to assess carbon dioxide emissions and energy consumption for the production of road pavements by means of a literature review. The construction of the main types of pavements requires energy and generates greenhouse gas emissions that impact the environment. Different types of asphalt mixtures such as cold mixtures, warm mixtures, asphalt rubber mixtures and mixtures with reclaimed asphalt pavement were assessed. The fuel used in the burners that heat and dry the aggregates is the main source of emissions. Also, the aggregates moisture content is an important parameter that influences the energy consumption. On the other hand, the energy consumption and emissions to produce Portland cement mixtures are related to the process of cement production. For both asphalt and Portland cement mixtures, the extraction, manufacturing and placement were also evaluated. Moreover, the energy consumption of the pavements structures was evaluated. Pavements composed of Portland cement concrete consume more energy than hot mix asphalt. But, warm mix asphalt technologies can save 20–70% of the energy consumption when compared to hot mix asphalt, mainly due to the temperature reduction in the warm mix processes. In addition, the emissions caused by different fuels used to produce pavement mixtures were compared. Asphalt mixtures and their alternative technologies consumed less energy and emitted fewer gases than Portland cement mixtures. Carbon dioxide emissions for hot mix asphalt and asphalt rubber mixtures can be 70% lower than emissions for Portland cement concrete. Some alternatives to reduce energy consumption and greenhouse gas emissions in asphalt mixtures production are the decrease of aggregates moisture content, reduction of the asphalt mixtures production temperature and use of waste materials in pavement construction. Switching from hot mix to warm mix technologies would reduce the carbon footprint generated by the asphalt industry.

1. Introduction

This paper shows a literature review concerning energy consumption and carbon dioxide (CO_2) emissions for the production of road pavements. The basic road pavements techniques such as, hot mix asphalt, warm mix asphalt, asphalt rubber mixtures, reclaimed asphalt pavement, Portland cement concrete and recycling are investigated. The entire production and construction process is taken into consideration, i.e., extraction of aggregates, laying for the construction of a new pavement, and rehabilitation.

Roads are built up in several layers, consisting of subgrade, subbase, base and surface layer. These layers together constitute the pavement. The pavement can be constructed from a wide variety of materials and mixtures of materials consisting of gravel, stone, asphalt, concrete or improved soils. The types of materials and thicknesses of the pavement layers are determined according to the expected traffic density [1].

There are three main types of pavements, i.e., flexible (asphalt pavement), rigid (Portland cement concrete pavement) and composite (flexible and rigid layers in the same pavement). So, the selection of a type to be used on a road involves many factors such as traffic, material performance, design and location. To the extent that the pavement selection serves users by ensuring that they travel on road pavements that are safe, smooth, quiet, durable, economical, and made of sustainable materials, designers have to succeed in choosing the appropriate type of pavement. Traditionally, processes for selecting a type of pavement are generally used by departments of transportation, responsible for roadway construction, to identify and select the most durable, cost-effective, highest-performing pavement structure for a new roadway [2].

The asphalt pavement takes asphalt (petroleum product) to cement together the aggregates (sand and crushed rock). This mixture is produced at the asphalt plant. In the field, the mixture is spread and compacted on the roadbed. On the other hand, concrete pavement takes Portland cement and water to glue the aggregates. In the field, the concrete is placed into steel moulds until the curing. The World

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http://dx.doi.org/10.1016/j.rser.2017.01.087
Received 15 June 2015; Received in revised form 29 September 2016; Accepted 15 January 2017

Factbook [3] provides some information on people, government, transportation and transnational issues for many countries. From this reference, one can see that most pavements (paved roads) are constituted of asphalt mixtures.

Magnum [4] states that Europe and North America have by far the most extensive networks of paved roads and highways in the world. In Europe, it is estimated that more than 90% of the 5.2 million km of paved roads and highways are surfaced with asphalt materials. In the United States, more than 92% out of 4 million km of roads and highways are surfaced with asphalt. In addition, about 85% of airport runways and 85% of parking areas in the United States are surfaced with asphalt. Canada has about 415,000 km of paved roads, and Mexico has about 178,000 km. For paved roads, the percentage of asphalt roads in Canada is about 90% and in Mexico is 96%.

The Netherlands Environmental Assessment Agency [5], since 2006, states that CO_2 emissions from fossil fuel use and industrial processes (cement production) in China have been greater than the emissions in the United States. Cement clinker production emits the largest amount of CO_2 among industrial processes, contributing to about 4% of global CO_2 emissions from fuel use and industrial activities. In 2013, China produced 58.6% of the cement used worldwide [54].

According to the World Bank [6], the road sector energy consumption includes petroleum products, natural gas, electricity, renewable fuels and waste. Fig. 1 shows the relation among urban population, CO_2 emissions, paved roads, unpaved roads and road sector energy consumption for some countries. In general, CO_2 emissions appear to exhibit a relationship with paved roads and population concentrated in urban areas. The emissions are higher in countries that have more paved roads. Although the United States have the greatest amount of paved roads, China has the highest CO_2 emissions (released by burning fossil fuels in the process of producing and consuming energy).

Nearly 90% of paved roads in the world are made of asphalt mixtures; the remaining 10% are comprised of either Portland cement concrete or composites of hot mix asphalt over Portland cement concrete or vice versa [7]. Once most of the paved roads in the world are made of asphalt, this paper will focus on this material. Asphalt pavement construction involves the manufacture and laying of road construction materials. Construction of new roads frequently implies interference with the environment, such as the alignment of the road and mainly the necessity of huge amounts of natural aggregates needed for construction. The road sector is a concern because roads consume substantial amounts of materials [8].

Considering that the amount of paved roads tends to grow over the years, special attention has to be given to decreasing energy consumption and greenhouse gas emissions.

Energy is required to produce the heat used to manufacture hot mix asphalt. Thus, reducing that amount of heat is one of the main targets to reduce energy consumption, which in turn reduces greenhouse gas emissions and environmental impact. Using low temperature asphalt techniques can reduce energy requirements, emissions and environmental impact [9].

Usually, asphalt mixture plants consume energy in two forms: (i) fossil fuel (petroleum distillation, natural gas, coal) to heat and dry the aggregates; (ii) electricity purchased from the energy utilities to power all other machinery (drum turning, conveyor belts, flight elevator). It takes approximately 300,000 BTU to dry and heat the aggregates to produce 1 t of hot mix asphalt, which constitutes about 7.6–11.4 l of fuel oil or diesel, or about 2.5 to 3.5 therms of natural gas [10].

This paper focuses on energy consumption and CO_2 emissions from road pavements. The most used hot mix asphalt, such as conventional mixtures, asphalt rubber mixture, warm mix asphalt and cold mixture were analysed in order to assess energy consumption and gases emissions during their production. In some cases, Portland cement concrete materials were evaluated. The influence of the plant, the aggregates moisture, and the type of fuel were also assessed.

The main objective of this paper was to assess energy consumption and greenhouse gas emissions from asphalt mixtures production. Some other objectives were also assessed, such as to: (i) evaluate the main types of asphalt mixtures applied in flexible pavements; (ii) identify types of mixtures that may reduce emissions and improve air quality.

2. Systematic review

Studies about emissions and energy consumption due to mixtures production used on road pavement surfaces were surveyed. Researches related to asphalt mixtures and Portland concrete mixtures published from 1995 to 2016 were reviewed. The survey was conducted using selected keywords (asphalt mixtures energy consumption; asphalt mixtures emissions; Portland cement mixtures emissions; concrete pavement energy consumption; hot mix asphalt production; concrete pavements emissions) that resulted in 643 publications which were selected by the following criteria: year of publication (from 1990–2016) in which 379 were discarded; repetitions (142 were discarded); and relevance and relation to the topic (62 were discarded). This resulted in 60 selected articles. The number of publications considered in this paper and their corresponding year of publication are summarized in Fig. 2.

3. Road pavement types

Road pavement is a structure consisting of covered layers of processed materials placed above the natural soil subgrade, whose primary function is to distribute the vehicle loads to the subgrade.

There are two main groups of road pavement types, such as flexible and rigid; and their combination generates a pavement called composite (Fig. 3). Flexible pavements are those surfaced with asphalt materials. These can be either in the form of pavement surface treatments or hot mix asphalt. In flexible pavements, the total pavement structure deflects due to traffic loads. On the other hand,

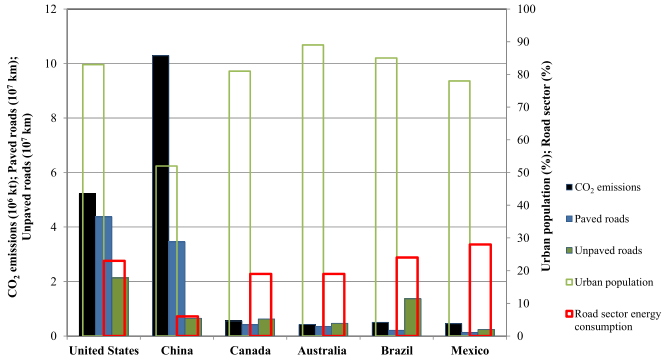

Fig. 1. Urban population, paved roads, unpaved roads, road sector energy consumption and CO_2 emissions for some countries. Based on [3,55].

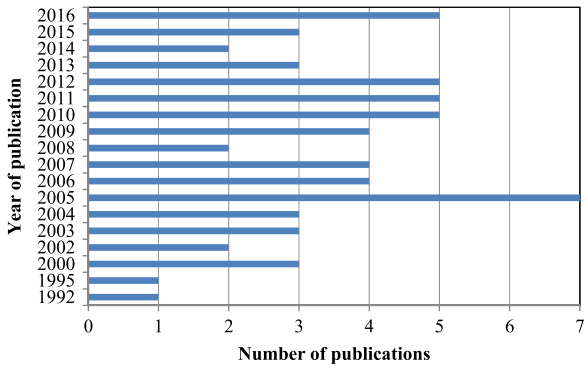

Fig. 2. Number of publications and corresponding year of publication.