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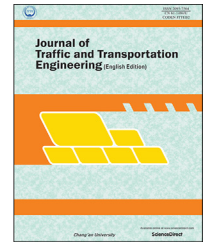

Original Research Paper

Characterization of effects of thermal property of aggregate on the carbon footprint of asphalt industries in China

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HIGHLIGHTS

- Specific heat capacity of aggregate has significant role on energy saving in asphalt mix production.
- Specific energy can be decreased from 30% to 64% owing to use of low specific heat capacity aggregate.
- Results clearly showed the energy saving is sufficient to supply power 44,007 to 664,880 Chinese households per annum.

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ABSTRACT

In this study, the effects of the thermal properties of asphalt binders and aggregate materials were characterized in terms of the specific heat capacity (C) for energy consumption and environmental footprints of hot mix asphalt (HMA) and warm mix asphalt (WMA). Asphalt mixes produced using low-C aggregate are found to be more energy-efficient and environmental friendly, irrespective of the binder type and construction technology. Therefore, different fractions of aggregate blends were replaced with the aggregate provided from a low-C source or sustainable source. Analysis of energy consumption clearly indicated that the specific energy and environmental footprints decrease linearly as the low-C aggregate content increases. The amount of energy saving realized in the asphalt industries by the use of low-C aggregate is significant on a national scale in China. In this regard, China was chosen as a case study. Analysis of fuel requirement clearly indicated that the production of WMA using high thermal sensitivity aggregate can yield significant energy saving sufficient to fuel 44,007 to 664,880 Chinese households per year. Therefore, use of low C aggregate in asphalt mix production can be adopted as a strategy to produce WMA and HMA.

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1. Introduction

In China, transportation infrastructure develops at a high rate owing to the increase in car ownership and road transportation. The percentage of the gross domestic product (GDP) allocated to the development of transportation infrastructure assets is 9% in China, while it is only 1% in Germany (Uddin et al., 2013). Therefore, mega projects undertaken to achieve such development require a large amount of construction and building materials. For instance, the statistics show that China by 6500 asphalt mixing plants produced around 18 megatons of petroleum asphalt by mid-2012 (European Asphalt Pavement Association, 2012). It is expected that China's expressway mileage will reach 140,000 km by 2015, including 35,000 km of national expressway and 30,000 km regional expressway to be built in 5 years (SMI, 2012). The requirements of asphalt binder per kilometer of new highway pavement construction is expected to be 250 tons, and the maintenance and rehabilitation of the pavements will require 140 tons of asphalt per kilometer. Furthermore, the demand for modified asphalt in China reached 26.64 million tons during the Twelfth National Five-year Plan period (2011–2015), according to SMI (2012). It is necessary that the pavements fulfill the structural and eco-friendly characteristics prescribed by the authorities. Therefore, it is necessary to design perpetual and sustainable pavements based on the reclaim, recycle, reuse, and reduce (4R) policies.

In Chinese paving projects, different mix types and construction technologies and materials are used. For example, stone matrix asphalt (SMA) is one of mixes introduced in the Chinese asphalt industry in 1992. The advantages of SMA, such as low noise, relatively high safety for pavement users owing to higher surface friction, and less susceptibility to reflective cracking, were the main incentives for using it in many transportation infrastructure assets. SMA was used, for instance, in Beijing, Changsha, Dalian, Harbin, Lhasa, Kunming, Shenyang, Qingdao, and Xiamen airports (Xin, 2013).

Furthermore, China is ranked as the largest tire producer in the world, producing 5.2×10^6 ton in 2010 (Hita et al., 2016; Liu et al., 2009). These new tires will eventually be discarded and will pose a grave potential threat to the ecosystem and human health. Moreover, the disposal of such a large number of tires imposes increasing pressure on the domestic landfills. One of the application of scrapped tires is in asphalt mix production. Incorporation of crumb rubber in the binder improves the rheological characteristics of asphalt binder and engineering properties of the mixture (Bairgi et al., 2015; Cui and Wang, 2011; Wang et al., 2015; Xie and Shen, 2013, 2015). In addition, some new procedures were developed to increase the productivity of crumb rubber modified mixtures. For example, Xu et al. (2015) proposed a methodology to activate crumb rubber using an ultrasonic focusing apparatus. The results indicated that the modified crumb rubber modified binder has better performance in terms of high- and low-temperature characteristics and ductility. Different types of high-quality asphalt binder, and hence, different asphalt binder modifying materials and technologies, are required to meet increasing demands of road transportation in urban and interstate highways in China. Ma and Zhang (2013) reported that the softening point of the binder modified by natural asphalt rock, which was supplied from the mainland, was lower than that of the control binder; hence, the temperature sensitivity decreased. Therefore, it is expected the modified binders can increase pavement lifespan. Another example is that the construction of asphalt pavement using epoxy asphalt on orthotropic steel bridge decks constructed on the Yangtze River in Nanjing met all the criteria for satisfactory performance. Hence, 500,000 m^2 of epoxy asphalt pavement were used on 20 orthotropic steel bridges until end of 2008 in China (Gaul, 2009).

Reclaimed asphalt pavement (RAP) is another paving material used in China. RAP is produced by the removal and processing of existing asphalt pavements. The engineering properties of RAP depend on the source, content, and particle size (Hamzah et al., 2010; Jamshidi et al., 2012). Furthermore, the aged binder in RAP can improve the performance grade of the resultant aged binder and fresh binder (Jamshidi et al., 2016). RAP is a valuable alternative material with desirable engineering properties. In China, it has been incorporated in many paving projects to realize satisfactory performance. For example, RAP materials based on hot-in-place recycling technology was used in the construction of the pavements of Jing-Jin-Tang Expressway, which connects Beijing to Tianjin (Shui, 2008). Another promising experience of incorporating RAP was the pavement project of Chang-Ju Expressway in Jiangxi Province. The RAP technology utilized in this project was cold central plant recycling. The pavement surface serviceability indicators, including the condition index, riding quality index, and rutting depth index, are within the satisfying range even after five years. Furthermore, policies encouraging the use of RAP in road pavement construction are in place. For example, the Ministry of Finance of China exempts value-added taxes on asphalt mixtures incorporating more than 30% RAP; this exemption decreases the costs of sustainability of paving projects (Shui, 2008). Such policies enhance the productivity of pavement technology and raw material resource management. However, note that incorporation of RAP often increases construction temperature. Thus, the energy consumption and pertinent greenhouse gas (GHG) emissions increase in the mixing plants. To tackle the problem, further energy-efficient technology, e.g., warm mix asphalt (WMA), is recommended for the production of mixtures incorporating RAP and asphalt shingle and crumb rubber. Literature indicates that WMA has been used extensively in China (Table 1).

Table 1 – List of several WMA road projects in China (Jamshidi et al., 2013).

Name	Year	Area (m^2)
Yushen	2010	67,500
Chengqing Highway, Hebei	2010	142,500
Yufa	2010	56,250
Trial road, Jiangsu	2004	30,000
Shandong	2003	500,000
Guangdong	2002	6000
Shijiazhuang, Hebei	2001	5000
Wuxi, Jiangsu	2001	4500
Guangdong	2001	4500
Guangdong	2000	20,000