Journal of Cleaner Production 121 (2016) 56–63

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Analysing industrial manufacturing in-plant and in-service performance of asphalt mixtures cleaner technologies

M. Sol-Sánchez, F. Moreno-Navarro, G. García-Travé, M.C. Rubio-Gámez*

Laboratorio de Ingeniería de la Construcción de la Universidad de Granada, C/ Severo Ochoa s/n, 18071 Granada, Spain

ARTICLE INFO

Article history:
Received 2 December 2014
Received in revised form
14 January 2016
Accepted 8 February 2016
Available online 16 February 2016

Keywords:
Warm mixtures asphalt
Long-term performance
Cleaner technologies
Road trial section

ABSTRACT

Roads play a significant role in the development of societies. Considerable quantities of asphalt mixes are employed in their construction, with hot asphalt mix (HMA) technology being one of the most commonly used worldwide. In recent times, the development of sustainable technologies has become a priority for most governments, and to this end, warm mix asphalt (WMA) can be considered as a cleaner technology that allows for the production of asphalt mixtures under lower manufacturing temperatures. This in turn allows for a reduction in atmospheric emissions and fuel consumption in comparison with HMA. However, due to the novelty of WMA and the length of time required for the analysis of its performance in real roads, information regarding the feasibility of its use is not easy to obtain. This research therefore analyses the potential for manufacturing a WMA using the same discontinuous industrial plant and the spreading and compaction machinery available for a HMA mixture, whilst also including the construction of a trial section that allows for the study of the performance of the WMA during its service life in a real road. The results suggest that WMA can be produced without modifying the industrial manufacturing process, providing asphalt pavements with comparable (or even better) mechanical performance to that recorded when equivalent hot asphalt mixtures are used. These findings are encouraging for the potential use of this cleaner technology in road construction projects.

1. Introduction

Asphalt mixtures cleaner technologies can be defined as a group of manufacturing processes that are able to reduce emissions and fuel consumption in comparison to hot asphalt mixtures (the materials more traditionally used in road pavement construction). These reductions are evident not only during the industrial manufacturing in plant but also during the spreading and compaction operations.

While hot asphalt mixtures (HMA) are manufactured at 160–170 °C and spread at 150 °C, cleaner technologies used to produce bituminous mixtures include the following categories: Warm Mix Asphalt (WMA) manufactured at a range of 100–140 °C; Half Warm Mix Asphalt (HWMA) with a manufacturing temperature lower than 100 °C, and Cold Asphalt Mixtures (CMA) obtained at temperatures lower than 40 °C (no heating is applied) (EAPA, 2010).

CMA is the technology that leads to the highest reduction in environmental and economic costs in comparison with the other available solutions. WMA, however, is the only technology that reduces emissions and fuel consumption whilst maintaining a level of mixture durability that is equivalent to (or higher than) traditional HMA, thereby minimising the maintenance works needed during the life of the road. Thus, WMA is regarded as one of the cleanest asphalt mixture technologies when considering the entire production cycle of the asphalt mixture (if the whole cycle of the road project is considered, real benefits are to be investigated according to other authors) (Butt et al., 2013).

The literature has shown the environmental improvements that can be achieved by reducing the manufacturing temperature (D'Angelo et al., 2008; Rubio et al., 2013; Blankendaal et al., 2014). In particular, as less heat is applied in the manufacture of the asphalt mix, less energy is consumed during the process, thereby reducing the levels of pollutants emitted into the atmosphere. Further, reducing the manufacturing temperature also allows for longer hauling distances and the possibility of cold weather paving due to the fact that the mix temperature is closer to ambient temperature and there is more time for construction operations

* Corresponding author. Tel.: +34 958249445; fax: +34 958246138.
E-mail addresses: msol@ugr.es (M. Sol-Sánchez), fmoreno@ugr.es (F. Moreno-Navarro), labic@ugr.es (G. García-Travé), mcrubio@ugr.es (M.C. Rubio-Gámez).

http://dx.doi.org/10.1016/j.jclepro.2016.02.046
0959-6526/

Table 1
Characteristics of the aggregates.

Test	Sieves (mm)	12/18 Porphyry % Passing	6/12 Porphyry % Passing	0/6 Porphyry % Passing	0/4 Limestone % Passing
Particle grain size (UNE-EN 933-1)	22,4	100	100	100	100
	16	84	100	100	100
	8	1	62	100	100
	4	1	5	87	96
	2	1	1	60	69
	0,5	1	1	29	31
	0.25	1	1	21	21
	0.063	0.5	0.9	11.8	11.2
Shape of coarse aggregate. Flakiness index (%) (UNE-EN 933-3)		16	25	–	–
Resistance to fragmentation (%) (Los Angeles test, UNE-EN 1097-2)		15	15	–	–
Cleaning of coarse aggregate (%) (Annex C, UNE-EN 146130)		0.5	0.5	–	–
Sand equivalent (UNE-EN 933-8) (%)		–	–	45	54
Relative density and absorption (UNE-EN 1097-6)	Apparent density (Mg/m^3)	2.73	2.73	2.77	2.71
	Apparent density on a saturated surface-dry basis (Mg/m^3)	2.69	2.70	2.70	2.65
	Density after drying (Mg/m^3)	2.7	2.71	2.72	2.67
	Water absorption after immersion (%)	0.6	0.45	0.9	0.8

(Button et al., 2007; Zaumanis, 2010). The fuel, mining, and construction sectors are the main contributors to the environmental impacts of manufacturing WMA mixtures, and WMA technology is able to significantly save energy and reduce GHG emissions by 18%–20% in comparison to HMA (Rodriguez-Alloza et al., 2014). Other studies have also shown that the environmental impact of asphalt can be substantially reduced through application of warm-mix asphalt (WMA) instead of hot-mix asphalt (HMA), with possible reductions of approximately 33% (Blankendaal et al., 2014).

Nonetheless, the reduction in manufacturing temperature is also associated with some disadvantages in terms of the mechanical performance of the asphalt mix. In particular, CMA and HWMA are characterized by a bearing capacity that is lower than HMA (Button et al., 2007), and thus provide a shorter service life under heavy traffic loads. Consequently, in the search for a compromised solution that combines environmental benefits with the quality and mechanical performance of these materials, research into WMA has increased over the last decade (Larsen, 2001; Prowell et al., 2007; EAPA, 2010). Organic and chemical additives have been widely developed in this field, allowing for the reduction in temperature as well as an increase in the workability time, providing bituminous mixtures with a mechanical behavior that is equivalent (or in some cases superior) to that provided by HMA (Chowdhury and Button, 2008; Oliveira et al., 2013). Among the advantages of temperature reduction is the fact that a decrease in binder ageing is associated with an improvement in the mechanical performance of the asphalt mix (Jamshidi et al., 2013).

A further problem associated with using WMA concerns the novelty of this technology. In particular, many WMA research findings are based on results obtained from laboratory experience, while studies of real road construction applications that support the benefits shown by the laboratory research are less common (Kristjansdottir, 2006). As stated by Wen (2011), facilitating the implementation of WMA technologies requires the collection and analysis of definitive information on the material and engineering properties of WMA pavements, since there are concerns regarding the real performance of roads built with WMA. Indeed, among the barriers that could hinder the widespread adoption of WMA technology is the lack of knowledge related to possible increases in costs as a consequence of implementing a new technology, as well as the lack of information related to the mechanical behavior of the WMA throughout the service life of the road.

Some authors (Hassan, 2009) have demonstrated that the application of WMA technology could lead to a slight increase (around 0.5% per ton) in the production costs of the asphalt mix associated with royalty fees and equipment modifications. However, it should be noted that this particular increase is related to a specific case where a foaming process was applied without using additives. Further, the majority of the investigations into WMA technology have focused on laboratory studies, whilst there are also discrepancies between the findings on laboratory-produced and plant-produced mixes (Bower et al., 2012; Wen and Wu, 2015). Given the apparent uncertainty regarding the long-term viability of applying this technology, it is critical for authorities to have information on the mechanical performance of WMA used in real roads if they are to successfully minimize maintenance costs.

The current paper therefore reports the results of a research project (developed between 2010 and 2014) addressing the use of WMA, which comprised a thorough analysis of the various additives used to produce asphalt mixtures at temperatures in the range of 100–140 °C. The aim was to optimize the balance between cleaner manufacturing processes and improved mechanical behavior, whilst also studying the associated economic costs. The project was composed of three research stages. The first stage was developed in the laboratory in order to determine the optimal WMA solution. A second stage assessed the feasibility of manufacturing the WMA in a conventional industrial plant used by HMA, whilst the final phase involved the construction of a trial section in order to examine the mechanical performance of the WMA extended and compacted in a real road.

Based on the results obtained in the first phase (Pérez-Martínez et al., 2014), a WMA with the addition of surfactant-modified bitumen was chosen as the most appropriate solution to obtain a cleaner technology to manufacture asphalt mixtures. This paper shows the results of the second and third stages of the research project in which the optimal procedure was defined for the reproducibility of the mixtures designed in laboratory, along with the testing of a trial section compared with an appropriate control.

2. Materials and methods

2.1. Materials

An AC16S hot mix asphalt and an AC16S warm mix asphalt were used to carry out a comparative study. Both mixtures share the same mineral skeleton and optimum bitumen content (5% over the weight of mixture), the type of binder being the main difference in terms of materials used for the manufacturing of these mixtures.