The Challenges of Warm Mix Asphalt as a Mature Technology

Ali Jamshidi and Greg White

Abstract Laboratory tests and field investigations show promising results of structural performance of warm mix asphalt (WMA). Also, the lower environmental burdens and fuel requirement in WMA production increase sustainability in the asphalt industry. However, there are challenges that significantly affect WMA performance and marketing in the future. In this paper, all these challenges are discussed, and the trend of WMA technology is evaluated. The statistics indicate that the energy market plays a pivotal role in enthusiasm for WMA. Lastly, WMA requires further investigations to meet requirements of post-modern pavement, as a new concept of pavement design in the 21st century.

Keywords Energy crisis · Crude oil price · Greenhouse gas emission · Asphalt industry

1 Introduction

The WMA technology is a great step taken toward sustainable pavement construction. Lower environmental emissions and less energy requirement are main features of WMA. Therefore, WMA has the potential to build a consensus between environment and pavement engineers in eco-pavement design. This fragile consensus depends on WMA technologists paying attention to current and future technical challenges. It should be noted that the perception of WMA in the pavement and environment engineering is different. That is, the environmentalists recognize WMA as a sustainable technology due to reduced greenhouse gas emissions, while the asphalt manufacturers are very keen to produce cheaper asphalt via lower production temperatures. One of the current challenges in pavement technology is early failures due to global warming. For example, Mills et al. (2009) reported that the thermal cracking in the asphalt pavement decreases over the next 50 years in Canada, while rutting deteriorated earlier than expected time. The result is consistent with research carried out by Qiao et al. (2013) which showed that a 5% climate change significantly

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affects longitudinal cracking and rutting. In the United States, results of modelling integrated with into American Association of State Highway and Transportation Officials (AASHTO) and mechanistic empirical pavement design guide (MEPDG) software show that fatigue and rutting cracking increases by 2–9% and up to 40% depending on the climate zone Gudipudi et al. (2017).

This paper narrates how WMA has developed throughout the last 20 years. In addition, current and potential challenges for WMA in the pavement market are discussed. Finally, the potential of WMA for construction of multi-role infrastructure assets, based on post-modern pavement (PMP) concept, are evaluated.

2 History of WMA

Reduction of production and compaction temperatures for asphalt mixtures is not a new matter of research. For example, role of foamed bitumen in reduction of construction temperature was found in 1956 (Kristjansdottir 2006). Then in 1968, Mobil Oil Australia modified and patented the foam bitumen technology, which resulted in a practical procedure for marketing WMA technology (Muthen 1998). In the 1970s, the asphalt industry was challenged by the first oil shock that dramatically affected the cost of pavement construction. Consequently, alternative sources of pavement materials and low-energy asphalt mixes attracted significant attention. For example, the use of various waste materials, such as reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS) and cold asphalt mix technology were developed. In addition, environmental concerns were raised due to the anthropogenic greenhouse emissions associated with asphalt production. Consequently, the interest in sustainable pavement technology increased in order to meet stricter environmental regulations. To address this challenge, the asphalt industry developed new technologies and additives that reduced construction temperatures via various WMA technologies (Table 1).

Since 2000, the introduction and commercialization of WMA began across the world. The rapid rise in energy price associated with the second oil shortage from 2006 highlighted importance of WMA due to the reduced energy required for asphalt production. The second oil shock was significant because the peak point of global oil production was expected in the near future, or may have already occurred (Armstrong and Blundell 2007). The characteristics of the first oil shock in the 1970s was different to that in the 2000s. In the 1970s, the energy crisis was due to the Arab embargo on oil, while the more recent energy crisis is because of lack of oil supply. But both energy crises prompted the development of various WMA technologies to produce more energy-efficient asphalt mixes. Some companies invested enormously in the production of WMA additives. For example, Sasol Wax in the South Africa invested $360 million to pipe natural gas from Mozambique to Sasolburg for production of Sasobit® (Jamshidi et al. 2013). In other words, the increase energy price resulted in the rapid development of WMA solutions. For example, Fig. 1 shows that trend of research on WMA and crude oil price from 2002 to 2018. There is a direct correlation between number of papers published on WMA and crude oil price. For example, the

Table 1 List of the WMA technologies (Rubio et al. 2012)

WMA product	Mechanism	Dosage	Temperature reduction (°C)
Aspha-min	Water-containing technology using zeolites	0.3% by total weight of the mix	20–30
Asphaltan B	Refined montan wax with fatty acid amide for rolled asphalt	2%–4% by mass of asphalt binder	20–30
Advera	Water-containing technology using zeolites	0.25% by total weight of the mix	10–30
Aqua black	Water-based foaming process	2.5% water by weight of the asphalt binder	20–30
Double Barrel Green	Water-based foaming process	2% water by mass of asphalt binder	30–40
Hypertherm		0.2% by mass of asphalt binder	20–35
LT asphalt	Foam bitumen with hydrophilic additive	0.5% by mass of bitumen	40
WAM foam	Soft binder coating followed by foamed hard binder	2–5% water by mass	20–40
LEA	Hot course aggregate mixed with wet sand	3% water with fine sand; 0.4% bitumen weight	20–30
LEAB	Direct foam with binder additive Mixing of aggregates below water boiling point	0.1% of bitumen weight of coating and adhesion additive	20–40
Montan wax			
Sasobit	Fischer-Tropsch wax	Approx. 0.8–5% by weight of binder	20–30
Asphaltan B	Refined Montan wax with fatty acid amide for rolled asphalt	2.0–4.0% by mass of bitumen	20–30
Licomont BS	Fatty acid amide	3.0% by mass of bitumen	20–30
Evotherm	Water-containing technology	0.5% of mass of bitumen emulsion	20–40
Cecabase	Chemical-based	0.2–0.4% by mixture weight	20–30
Rediset	Cationic surfactants and organic additive	1.5–2% of bitumen weight	20–30

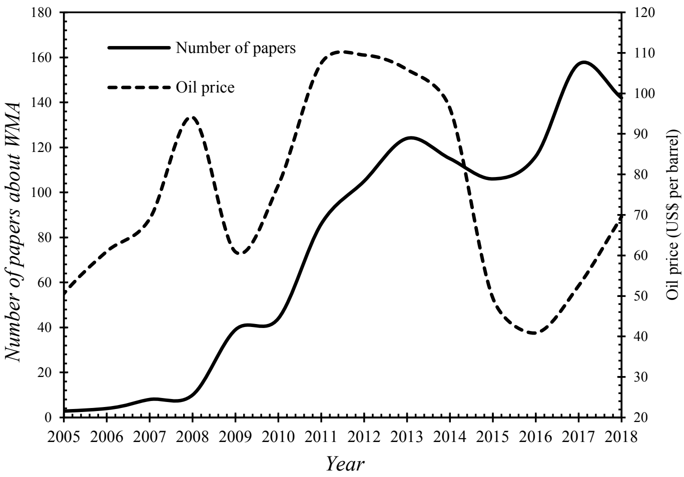


Fig. 1 The relationship between WMA papers and energy market. *Note* 1 the number of papers and technical documents (totally 1,086) were indexed by SCOPUS. *Note* 2 data of energy price is provided based on average annual OPEC statistics

oil price increased significantly from 2009 to 2012, and the number of papers also increased from 39 to 105, a 169% increase. After 2012, the oil price decreased gently, and the number of papers decreased over the same timeframe. In 2016, the oil price was at a low point and the number of papers decreased but increased again as the oil price increased in 2017 and 2018. As a result, the trend of research work depends on the energy market fluctuations.

Figure 2 shows a breakdown of major subjects of WMA in the documents indexed by the SCOPUS data base. Many papers touched on more than a single research topic. From Fig. 2, structural performance in terms of rutting and fatigue are the first and second most prevalent research subjects, respectively, followed by, mix durability

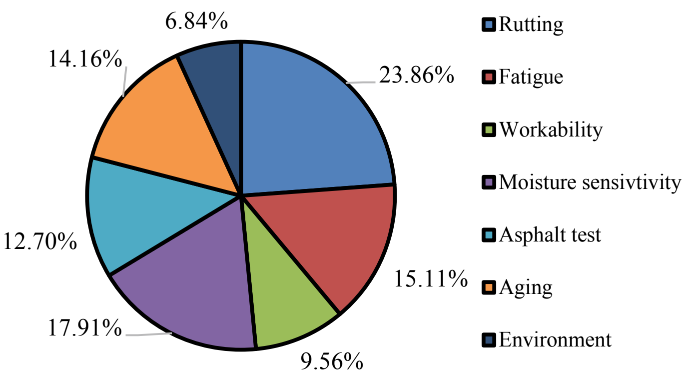
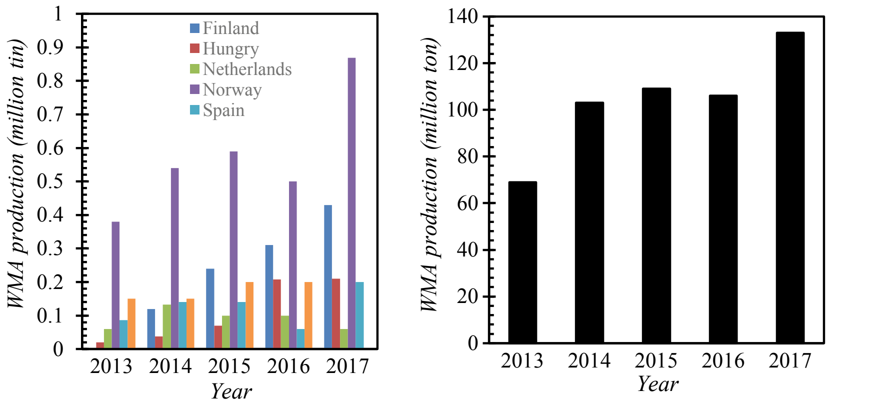


Fig. 2 Subjects discussed in the documents indexed by SCOPUS



(a) WMA (b) WMA production in the United States

Fig. 3 WMA production in different countries, plotted based on data reported by EAPA (2018)

based on moisture sensitivity and aging. The figure also shows that only 6.84% of the research carried out related to environmental issues. As a result, structural stability and durability were main concerns of WMA researchers. Figure 3 shows that the WMA production in some European countries, South Africa, and the United States increased from 2012 to 2017, due to encouraging initial laboratory test results. In addition, promising results of field investigations in the Unites States and Europe spread the use of WMA into the Middle-East and Asian markets.

Obviously, the WMA performance should be equal or superior than the hot-mix asphalt (HMA). So, different manufacturers try to produce more efficient technologies and additives in terms of construction temperature reduction, structural strength, and durability. For example in France, every asphalt manufacturer and agency try to develop own WMA technology (D'Angelo et al. 2008).

3 Challenges and Opportunities of Asphalt Industry

3.1 Long-Term Performance

Cumulative structural and thermal strains/stresses are important factors for the long-term performance of pavements. Although the lower construction temperature of WMA results in less stiffness, the results of field investigation often showed satisfactory structural and functional performance. For example, Diefenderfer (2018) reported that the dynamic modulus, air void content and permeability of foamed WMA cored after 6 years were comparable with HMA samples. Also, the rut resistance of Sasobit® WMA mixtures, as indicated by dynamic modulus, was greater than or equal to that of HMA (Huerly et al. 2009). It seems that the structural performance of WMA is not a challenge. In addition, some additives, e.g., Sasobit®, can be used as compact aid which improves mix workability (Bonaquist 2011). However, the long-term performance of asphalt pavements depends on synergistic effects of structural loading and field ageing. Since the construction temperature of WMA is less than HMA, it is less prone to ageing. Furthermore, the ageing phenomenon in WMA can be different due to various additive types and production technology, binder type, ambient temperature, test temperature, and parameter chosen for analysis. Thus, it is necessary to develop prediction models for various WMA additives which can be used to better understand ageing process. In addition, the use of sustainable materials in the heavy-duty pavements, e.g., airports, is increasing (White et al. 2018). In this regard, shear stress resistance of pavement is important criterion (White 2017). Therefore, the less stiffness, due to the lowered construction temperature, may decrease shear stress resistance of the pavement. As a result, the long-term performance of WMA used in the heavy-duty pavements is matter of concern.

3.2 Recyclability

WMA usually contains some recycled or reused waste material, such as crumb rubber, RAPRAS, or waste glass. The WMA will be reclaimed as new source of RAP in future (RAP-WMA). However, the performance of new mixes containing RAP-WMA is less clear. It is expected that the engineering properties of such new mixes should be comparable with new WMA or HMA. However, further research on the recyclability of the WMA and HMA containing RAP-WMA is required. This is essentially to determining whether recycling RAP-WMA has economic justification or not.

3.3 Selection of Appropriate WMA

Since there are various types of WMA, selection of an appropriate WMA type is subjective, usually determined by local availability of equipment and/or materials. In this regard, it is necessary to compare the structural performance and durability of WMA samples produced using different WMA technologies. However, the comparison is not easy because the mechanism of each WMA technology is different (Table 1). To address this problem, Jamshidi et al. (2015) proposed criteria to compare various types of WMA technologies based on unaged and aged rheological characteristics. It should be noted that the selection of a particular WMA technology also depends on many other factors, including the initial cost, skill of paving crew, service condition, pavement application, availability of machinery and compatibility with the local materials.

3.4 Use of Local Materials, Practice Codes and Construction Technology

WMA technology should be compatible with local materials and current asphalt mixing plant facilities, which is an important factor for marketing WMA technology. Therefore, it is necessary to train the paving crews and engineers regarding its use. It is recommended that practice codes and guidelines for the use of various WMA technologies in local materials and construction practices be developed. It seems that the lack of courses in the field of WMA at universities and industry affects the basic knowledge of engineers to fully understand the complex problems of modelling and characterizing pavement materials and the principles associated with WMA technologies. Therefore, in parallel with the research on WMA, it is necessary to teach the principles of WMA technology. It is also recommended that the WMA manufactures provide periodical workshops to update the engineers dealing with pavement technology. As a result, a close collaboration between the WMA producers and universities can result in rapid development of WMA in future.

In addition, the use of current technology of the asphalt plant without any specific modification can be a motivation for WMA production. For example, Sasobit® can be blended with the hot asphalt binder at a terminal or in asphalt tank, introduced in a molten form, added with the aggregate materials, or pneumatically blown into a drum plant (Hurley et al. 2009). It requires simple modification that can be used in many asphalt mixing plants.

3.5 Costs of WMA

Although WMA technology reduces fuel requirement in the asphalt mixing plant, it may incur extra costs due to modification of the mixing plant and additive material supply. Therefore, WMA may only be an attractive option when the energy price is high. Table 2 shows the cost incurred using various WMA technology. It is clear that the cost can be different, depending on mix tonnage, shipping haul, WMA technology and industrial fuel type. From the table, the costs of HMA and WMA are comparable. However, more cost-effective WMA is more attractive for the asphalt manufacturers.

Table 2 A cost comparison of HMA and WMA production in Iceland (Diefenderfer 2018)

Cost ($US)	HMA	WAM foam	Aspha-Min	Sasobit
Additive cost	–	0.30	4	3.50
Energy	6.5	4.90	4.90	4.90
Reduction in energy cost compared HMA	–	1.60	1.60	1.60
Total	89	87.70	91.40	90.90

Since the WMA reduces the construction temperatures, more RAP or the other waste material can be used which results in more cost-effective mixes. As an example, the costs of WMA containing 30% RAP decreases by 32% (Onor and Sengoz 2015). Consequently, WMA may be better suited as an enabling technology for RAP usage, rather than a technology in its own right. In this regard, it is necessary to develop facilities for waste material management, such as RAP milling and tire shredding. However, development of such facilities may require massive investment, especially in the developing countries.

3.6 New Criteria for WMA Production

WMA technologists focus on the reduction of the construction temperatures, while the role of aggregate material in energy saving is neglected. Furthermore, many asphalt producers use WMA technologies as a compaction aid, producing asphalt at the same temperature as HMA. In both cases, the thermal characteristics of aggregate materials have a significant effect on the energy requirement and greenhouse gas (GHG) emissions. For example, the aggregate type, mechanical strength, gradation and specific gravity may be identical, but thermal properties, in terms of specific heat capacity, can be different. So, the selection of the appropriate aggregate source can result in huge energy saving. For example, Jamshidi et al. (2015) showed that energy requirement for HMA produced by the low-specific heat capacity can be lower than WMA using the high-specific aggregate. Therefore, the thermal properties of aggregate is proposed as new indicator for analysis environmental burdens in the Superpave mix design procedure (Jamshidi et al. 2013). It is therefore necessary for WMA technologists to pay more attention of the thermal properties of aggregate and filler. However, it must be noted that local availability and haulage costs often limit the choice of aggregate sources.

4 Future of WMA

The higher structural performance and lower environmental burdens are important factors for sustainable asphalt pavement design, but on their own, these factors are inadequate. Therefore, a new concept, called post-modern pavement (PMP) was developed to address the structural, sustainability, and socio-psychological requirements (Fig. 4). In other words, not only the high structural performance and sustainability are components, but also the social acceptability of WMA is important factor in future pavement technology. In other words, pavement based on PMP concept is a structural-environmental-social asset, under the policy of integration of the municipal infrastructure assets. However, the social benefits associated with reduced GHG emissions of WMA is not clear. To fill this gap, more research should be undertaken to highlight potential of WMA as PMP for the pavement end-users. For example,

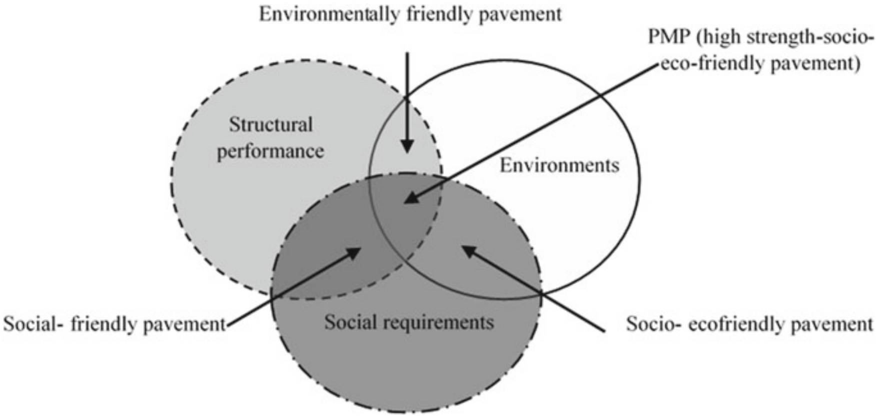


Fig. 4 PMP definition as an interface between structural, environmental, and social requirements (Jamshidi et al. 2019)

White et al. (2018) studied socio-environmental effects of airport pavement runway containing recycle materials and this approach could be extended to different, structurally equivalent, HMA and WMA mixtures.

5 Conclusion

The energy market oscillations play a more important role in WMA development than associated environmental benefits do. Also, the asphalt industry must understand and address the challenges and expectations of pavement and environment engineers to be successful in the future. This means that WMA technologists and suppliers will need to foster and promote the products meet future requirements. In conclusion, WMA is already sufficiently mature to support high strength-low energy asphalt pavement. However, more work is needed to disseminate WMA based on the PMP concept.

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