Development of Warm Mix Asphalt with the Aid of Microstructural Characterization

Abdullah Al Mamun
amamun@qu.edu.qa
Department of Civil and Architectural Engineering, Qatar University, Doha, Qatar

Okan Sirin
okansirin@qu.edu.qa
Department of Civil and Architectural Engineering, Qatar University, Doha, Qatar

Eyad Masad
eyad.masad@qatar.tamu.edu
Mechanical Engineering Program, Texas A&M University at Qatar, Doha, Qatar

ABSTRACT

The polymer-modified asphalt (PMA) reveals different types of advantageous properties depending on the type of polymer. However, one of the unwanted changes in PMA is the required higher temperature for mixing and compaction. To reduce these temperatures, different percentages of warm mix additive (WMA) have been utilized. However, the addition of WMA can lead to different micro-nano structural changes in the PMA and can subsequently affect overall performance of the asphalt pavement. Therefore, understanding the microstructural behavior of the polymer and additive modified asphalt is crucial to achieve the desired performance. This study attempts to substantiate the effect of WMA in three different PMAs and subsequent changes in different properties. These changes can be scrutinized from different perspectives; however, correlating a basic microstructural property to the rheology of asphalt is an effective way to understand the mechanism and predict performance. In this regard, the need for microstructural evaluation in terms of nano-adhesive properties is recommended. It is expected that assessing the adhesive properties by simulating the field condition can address the phase integrity and crystal structure of PMA and subsequent desired performance of the asphalt pavement. Finally, the observed adhesive properties can be further evaluated to find the prospects of other mechanical properties. Therefore, the need for a standard microstructural evaluation method of the adhesive properties has also been addressed in this study.

Keywords: Warm mix asphalt; Multiscale characterization; Polymer modified asphalt; Rheology

1 INTRODUCTION

The polymers used for asphalt modification usually have large chains (straight or cross-linked). The chemical and structural properties of the chains affect the properties of the polymer, as well as polymer modified asphalt (PMA). The most commonly used polymers are elastomers and plastomers. The elastomer improves the elastic properties while the plastomer provides a plastic matrix for the modified asphalt. Based on the type of polymer, asphalt can exhibit different characteristics. One of the significant changes in PMA is the increased mixing and compaction temperatures for the Hot Mix Asphalt (HMA). These higher temperatures can alter the desired performance of the pavement (Roque et al., 2005). On the contrary, lowering the required temperature for mixing and compaction can result in inadequate volumetric properties and, consequently, poor pavement performance. To overcome these problems, the use of warm mix additive (WMA) in PMA is a viable solution.

The WMA reduces the viscosity of PMA that eventually reduces the required higher temperature for mixing and compaction. Warm mix technologies are categorized into three main types: foaming processes, organic additives, and chemical additives. Chemical additives generally do not require significant modification, and the addition of chemical additives helps to improve the coating of aggregate and compaction of the mixture by lowering the viscosity of the asphalt. In the foaming process, the volume of the asphalt is increased by injecting hot water in a predefined way, and therefore, the expanded asphalt requires relatively low temperature to achieve a similar coating ability. The organic additive helps the binder to flow and melt at temperatures below HMA. The melting point of organic additives is kept higher than the temperature used to avoid permanent deformation (Sadeq et al., 2016). It is observed that the mixing and compaction temperatures of the asphalt mixture can be lowered by 20-30°C using various WMAs (Button et al., 2007).

Although the addition of the WMA in the PMA reduces the required temperatures for the mixing and compaction, it is also expected to affect the rheology (Sadeq et al., 2018) and microstructural behavior (Menapace & Masad, 2017) of the binders, and consequently the response of the mixtures. Since the mixtures with WMA are produced at lower temperatures compared to the traditional HMA, the properties of WMA binders/mixtures are expected to deviate from HMA. In addition, WMA can lead to different micro-nano structural changes in the PMA. Correlating a basic microstructural property to the rheology of asphalt could be an effective way of visualizing the mechanism and performance.

This study attempts to scrutinize the effect of WMA in different PMAs. The scope of the study considers three different PMAs and based on the discussion, the need for an integrated and standard microstructural evaluation has been addressed.

2 POLYMER – ADDITIVE MODIFIED ASPHALT

The study contemplates the effect of organic additives on PMA and includes three different polymers: Styrene–butadiene–styrene (SBS), Low-density polyethylene (LDPE), and crumb rubber (CR). Numerous studies have evaluated the effects of polymers and additives on asphalt binders. In the following sections, the effect of different additives on the desired properties of asphalt binder and mixes are discussed.

2.1 Crumb rubber/additive modified asphalt:

One of the potential polymers for asphalt pavement engineering is crumb rubber (CR). CR is produced from the used tires, which consist of four main components: fiber, steel, carbon, and rubber. Here, the rubber shares the significant (60% of the total weight) portion of the tire (Kim et al., 2012). Several studies have been carried out to better understand the use of crumb rubber modified asphalt (CRMA). It is observed that the presence of CR can increase the complex modulus and softening point, elastic recovery, viscosity, tensile strength and decrease the ductility, penetration, and phase angle of the CRMA (Cong et al., 2013). Li et al. evaluated the rutting resistance capacity of CRMA using an asphalt pavement analyzer and concluded that the CRMA has better resistance to rutting than the traditional mixes (Li et al., 2016). In combination with different improved properties, it has also been observed that the presence of CR can also increase the mixing and compacting temperatures of CRMA.

The increased mixing and compacting temperatures of CRMA can be counteracted by WMA. WMA additives can reduce the compaction temperatures of CRMA by up to 20–30°C that subsequently reduces energy consumption without jeopardizing the engineering properties (Akisetty et al., 2011). However, the lowered production temperature reduces the aging of asphalt that subsequently may affect the fatigue and rutting properties of asphalt mixture (Cong et al., 2013). A study concluded that Sasobit®-modified CR modified mixtures improved the rutting performance (Fontes et al., 2010) whereas, Sasobit® was found to have insignificant effect on rutting performance for the CRMA (Navarro & Gámez, 2012). The addition of Sasobit® in CR binder showed increased $G^*/\mathrm{Sin}\delta$ (Navarro & Gámez, 2012), whereas, Advera® had an insignificant effect on $G^*/\sin\delta$ (Xiao et al., 2007). Therefore, the addition of WMA in CRMA exhibited a mixed trend and it can affect the rutting performance ($G^*/\mathrm{Sin}\ \delta$) of CR modified binder differently. In a study, Xiao et al. (2009) evaluated the fatigue performance of different WMA additives for CRMA and concluded that among Aspha-min, Sasobit and Evotherm, only Aspha-min decreases fatigue cracking resistance.

Therefore, in addition to reducing the mixing and compaction temperature, the warm additive can affect the different properties of CRMA. CR creates a gel-covered particle by interacting with the asphaltenes and light fractions of the asphalt. The subsequent absorption results in the swelling of CR modified asphalt (Wu & Zeng, 2012). The changes in temperature can affect this swelling significantly (Xiao et al., 2007), and subsequently, affect other properties. Such changes dictate the need for microstructural evaluation of CRMA.

2.2 Styrene–butadiene–styrene / additive modified asphalt

In asphalt pavement construction, the most commonly used polymer is Styrene–butadiene–styrene (SBS) (Zhang et al., 2018). It is a block copolymer that makes a coherent bonding with asphalt. The use of SBS in asphalt provides different desired properties such as increased elastic response (Li et al., 2019), lowers the creep stiffness (Iskender et al., 2012), and improved resistance to rutting and fatigue (Kalyoncuoglu & Tigdemir, 2011), etc., yet it also increases the compaction and mixing temperature. Therefore, the use of different warm additive is very common for SBS modified asphalt. The use of WMA (e.g. Sasobit) in SBS modified asphalt can reduce the viscosity depressant characteristics by at least 10oC (Hofsink & Barnard, 2009).In a study, SBS modified binders were incorporated with a different type of additive and it was observed that the production temperature of the WMA was reduced by at least 16oC than the traditional HMA (Wang et al., 2013). Another study concluded that Sasobit can reduce the viscosity of SBS modified asphalt and subsequently reduce the required compaction temperature by 25oC (Li et al., 2016).

In addition to reducing the compaction and mixing temperature, the use of warm additive also affects other properties of SBS modified asphalt. A study investigated the effect of two different additives (Sasobit and Aspha-min) on the performance of SBS modified asphalt by evaluating high failure temperature values from the DSR test (Kim et al., 2010). It was concluded that the additives increase the resistance to rutting at high temperatures. In another study, researchers evaluated the effect of Sasobit and Aspha-min on SBS modified asphalt mixture for different characteristics (Kim et al., 2012). While comparing the performance based on rutting, it was concluded that mixtures with Sasobit outperform all the other mixtures whereas Aspha-min incorporated mixtures were the least effective. However, in terms of fatigue life, SBS modified mixture showed higher fatigue resistance than the similar additive modified mixture at different stress levels (Fakhri et al., 2013).

These changes of SBS modified asphalt due to WMA indicate the microstructural changes in the asphalt. An evaluation of SBS modified asphalt using Transmission Electron Microscopy (TEM) indicates that the morphology and formation of phases may vary following the sources of asphalt and polymer (Yildirim, 2007). Another study concluded that SBS modified asphalt has a tendency of partial miscibility and, in a stagnant condition with a higher temperature it exhibits phase separation phenomena (Jasso et al., 2015). Therefore, the addition of WMA has been reported as a possible reason for forming a kind of gel, crystal or network structure in the SBS modified binder that dictates a further need for microstructural evaluation (Shang et al., 2011).

2.3 Low-density polyethylene / additive modified asphalt

Several studies also recommend using Low-density polyethylene (LDPE) as a plastomer in asphalt modification. Fang et al. (2009) modified the asphalt binder using PVC packaging waste (0-10%wt. of asphalt) and evaluated different properties such as softening point, ductility, elongation and tension, penetration, low-temperature flexibility and found improved performance (Fang et al., 2009). Further microscopic evaluation reveals the development of dissolved and continuous polymer-rich microstructure due to increased polymer. Fang et al. (2012), studied the micro-structure of polyethylene (PE) modified asphalt by Scanning Electron Microscope (SEM) and concluded that the introduction of momtmorillomite improves the dispersion and homogeneity of PE modified asphalt that subsequently results in increased penetration, softening point, with improved ductility.

Ho Susanna et al. evaluated the low-density polyethylene wax materials and concluded that the molecular weight and its distribution significantly affect hot storage stability (Ho et al., 2006). Punith and Veeraragavan evaluated the homogeneity of the PE-modified binder using florescent microscopy scanning and concluded that the blending temperature can affect the penetration and softening point values significantly (Punith & Veeraragavan, 2011). Therefore, it is expected that the use of LDPE can affect the mixing and compaction temperatures. However, to the authors' knowledge, none of the previous studies attempted to study the effect of WMA in LDPE modified asphalt. Therefore, the microstructural evaluation is expected to provide an insight to assess the effect of WMA in LDPE modified asphalt.

3 THE NEED FOR MICROSTRUCTURAL EVALUATION

Different PMAs have provided many remarkable advancements in improving the multi-functional properties and have proved to be promising candidates for high-performance asphalt pavements. However, the addition of WMA can lead to different micro-nano structural changes in the modified asphalt binder. WMA can bring changes in microchemical structure and subsequently reduce the viscosity of asphalt. The microstructure regulates the thermo-rheological behavior along with different mechanical properties such as elasticity, plasticity, and stiffness of asphalt (Das et al., 2013). The addition of additive in PMA also imparts the need for evaluating the phase integrity by microstructural assessment. It is crucial to understand changes in the microstructural behavior of PMA due to WMA to provide desired performance rather than having negative consequences. To this end, scrutiny of microstructural properties of WMA modified asphalt is needed.

4 THE PROSPECT OF MULTISCALE CHARACTERIZATION

The behavior of asphalt depends largely on its intermolecular microstructures and chemical structure. Thus, the evaluation of micromechanical behavior could help in predicting the performance of asphalt mixtures. Different nano and microstructural evaluation techniques have played a significant role in evaluating the properties of modified binder meticulously. In such cases, Atomic Force Microscopy (AFM) has been employed in measuring nano-scale intermolecular forces. In general, the force spectrum technique of AFM is a suitable tool for characterizing the nanomechanical properties of pavement materials. Numerous studies have been carried out to assess different properties - van der Waals forces, friction, contact force- of asphalt using AFM (Mamun & Arifuzzaman, 2018). AFM has also been used in several studies to evaluate the changes in adhesion of modified asphalt binders at the nanoscale. These studies observed that adhesion in asphalt changes due to the presence of polymer and the changes in adhesive properties can affect the phase integrity of modified asphalt (Mamun & Arifuzzaman, 2018). Therefore, evaluation of the adhesive properties of WMA modified asphalt can provide an insight of microstructural properties.

Till date, very few studies have considered the adhesive properties of WMA modified asphalt in microstructural evaluation. Nazzal et al. concluded that the warm mixes increase or decrease the adhesion of asphalt binders in a dry state and wet state, respectively (Nazzal et al., 2015). In another study, AFM has been successfully used to evaluate different nanomechanical properties including adhesion, the cohesion of asphalt binders by evaluating the effect of warm additives (Abd et al., 2018). However, those studies are insufficient to provide an integrated microstructural insight of WMA modified asphalt, since the evaluated adhesive properties have not been correlated with the mechanical properties of asphalt. In addition to that, those studies considered different methodologies to assess the adhesive properties at a certain temperature. However, the nanoscale adhesion and microstructures of the modified binder should be evaluated at different temperatures since the asphalt pavement experiences different temperatures during its service life. The variation in temperature is expected to affect the phase integrity and crystal structure of the modified binder. Therefore, for each PMA, it is imperative to have a comprehensive study of microstructural evaluation by developing an appropriate methodology for measuring such changes by simulating the real field condition.

5 CONCLUSION

This study discusses the effect of warm mix additive in different PMAs. It is inferred that a comprehensive evaluation at the microstructural level is a prerequisite to understand and estimate the synergy between asphalt and warm additive. Based on it, the following conclusions are drawn:

1. The warm additive can affect different rheological properties of PMA, which is governed by changes in the characteristics of the asphalt microstructure. To evaluate the effectiveness of any warm additive, these changes in asphalt binder should be assessed carefully.
2. In further investigations, different AFM techniques (i.e. force spectroscopy, tapping mode imaging, and nano-indentation) can be employed on warm mix modified asphalt to characterize the micro or nano-scale structures of asphalt.
3. The microstructural evaluation of warm additive modified asphalt can be analyzed from different perspectives; however, correlating the adhesive properties to the rheology of asphalt could be an effective way of visualizing the mechanism and performance.
4. The adhesive property of modified asphalt is one of the basic properties that is expected to subsequently affect the overall performance of the asphalt mixture. Therefore, a standard method should also be developed to measure the change in adhesion/cohesion of the warm additive modified asphalt binder.

REFERENCE

Abd, D. M., Al-Khalid, H. & Akhtar, R. (2018). Adhesion properties of warm-modified bituminous binders (WMBBs) determined using pull-off tests and atomic force microscopy. *Road Materials and Pavement Design*, *19*(8): 1926-1939. Taylor & Francis. DOI: 10.1080/14680629.2017.1374993.

Akisetty, C., Xiao, F., Gandhi, T. & Amirkhanian, S. (2011). Estimating correlations between rheological and engineering properties of rubberized asphalt concrete mixtures containing warm mix asphalt additive. *Construction and Building Materials*, *25*(2): 950-956. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2010.06.087.

Button, J. W., Senior, P. E., Fellow, R. & Estakhri, C. (2007). *A Synthesis of Warm-Mix Asphalt*. Available from http://tti.tamu.edu/documents/0-5597-1.pdf [accessed 15 February 2019].

Cong, P., Xun, P., Xing, M. & Chen, S. (2013). Investigation of asphalt binder containing various crumb rubbers and asphalts. *Construction and Building Materials*, *40*: 632-641. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2012.11.063.

Das, P. K., Kringos, N., Wallqvist, V. & Birgisson, B. (2013). Micromechanical investigation of phase separation in bitumen by combining atomic force microscopy with differential scanning calorimetry results. *Road Materials and Pavement Design*, *14*(sup1): 25-37. Taylor & Francis. DOI: 10.1080/14680629.2013.774744.

Fakhri, M., Ghanizadeh, A. R. & Omrani, H. (2013). Comparison of Fatigue Resistance of HMA and WMA Mixtures Modified by SBS. Procedia - *Social and Behavioral Sciences,* 104: 168-177. Elsevier. DOI: 10.1016/J.SBSPRO.2013.11.109.

Fang, C., Yu, R., Zhang, Y., Hu, J., Zhang, M. & Mi, X. (2012). Combined modification of asphalt with polyethylene packaging waste and organophilic montmorillonite. *Polymer Testing*, *31*(2): 276-281. Elsevier. DOI: 10.1016/J.POLYMERTESTING.2011.11.008.

Fang, C., Zhou, S., Zhang, M. & Zhao, S. (2009). Modification of Waterproofing Asphalt by PVC Packaging Waste. *Journal of Vinyl & Additive Technology, 15*(4): 229-233. DOI :10.1002/vnl.20204.

Fontes, L. P. T. L., Trichês, G., Pais, J. C. & Pereira, P. A. A. (2010). Evaluating permanent deformation in asphalt rubber mixtures. *Construction and Building Materials*, *24*(7): 1193-1200. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2009.12.021.

Ho, S., Church, R., Klassen, K., Law, B., MacLeod, D. & Zanzotto, L. (2006). Study of recycled polyethylene materials as asphalt modifiers. *Canadian Journal of Civil Engineering*, *33*(8): 968-981. DOI: 10.1139/L06-044.

Hofsink, W. & Barnard, M.C. (2009). SMA wearing courses on runways and taxiways: recent experience in South Africa. Available from https://trid.trb.org/view/914660 [accessed 26 February 2019].

Iskender, E., Aksoy, A. & Ozen, H. (2012). Indirect performance comparison for styrene–butadiene–styrene polymer and fatty amine anti-strip modified asphalt mixtures. *Construction and Building Materials*, 30: 117-124. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2011.11.027.

Jasso, M., Hampl, R., Vacin, O., Bakos, D., Stastna, J. & Zanzotto, L. (2015). Rheology of conventional asphalt modified with SBS, Elvaloy and polyphosphoric acid. *Fuel Processing Technology*, 140: 172-179. Elsevier. DOI: 10.1016/J.FUPROC.2015.09.002.

Kalyoncuoglu, S. F. & Tigdemir, M. (2011). A model for dynamic creep evaluation of SBS modified HMA mixtures. *Construction and Building Materials*, *25*(2): 859-866. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2010.06.101.

Kim, H., Lee, S. -J. & Amirkhanian, S. N. (2010). Effects of warm mix asphalt additives on performance properties of polymer modified asphalt binders. *Canadian Journal of Civil Engineering*, *37*(1): 17-24. DOI: 10.1139/L09-118.

Kim, H., Lee, S. -J. & Amirkhanian, S. N. (2012). Influence of warm mix additives on PMA mixture properties. *Journal of Transportation Engineering*, *138*(8): 991-997. DOI: 10.1061/(ASCE)TE.1943-5436.0000406.

Li, J., Zhang, F., Liu, Y., Muhammad, Y., Su, Z., Meng, F. & Chen, X. (2019). Preparation and properties of soybean bio-asphalt/SBS modified petroleum asphalt. *Construction and Building Materials*, 201: 268-277. DOI: 10.1016/j.conbuildmat.2018.12.206.

Li, X., Zhou, Z. & You, Z. (2016). Compaction temperatures of Sasobit produced warm mix asphalt mixtures modified with SBS. *Construction and Building Materials*, 123: 357-364. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2016.07.015.

Mamun, A. A. & Arifuzzaman, M. (2018). Nano-scale moisture damage evaluation of carbon nanotube-modified asphalt. *Construction and Building Materials*, 193: 268-275. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2018.10.155.

Menapace, I. & Masad, E. (2017). Evolution of the microstructure of warm mix asphalt binders with aging in an accelerated weathering tester. *Journal of Materials in Civil Engineering*, *29*(10): 04017162. DOI: 10.1061/(ASCE)MT.1943-5533.0001998.

Navarro, F. M. & Gámez, M. C. R. (2012). Influence of crumb rubber on the indirect tensile strength and stiffness modulus of hot bituminous mixes. *Journal of Materials in Civil Engineering, 24*(6): 715-724. DOI: 10.1061/(ASCE)MT.1943-5533.0000436.

Nazzal, M. D., Abu-Qtaish, L., Kaya, S. & Powers, D. (2015). Using atomic force microscopy to evaluate the nanostructure and nanomechanics of warm mix asphalt. *Journal of Materials in Civil Engineering*, *27*(10): 04015005. DOI: 10.1061/(ASCE)MT.1943-5533.0001254.

Punith, V. S. & Veeraragavan, A. (2011). Behavior of reclaimed polyethylene modified asphalt cement for paving purposes. *Journal of Materials in Civil Engineering*, *23*(6): 833-845. DOI: 10.1061/(ASCE)MT.1943-5533.0000235.

Roque, R., Birgisson, B., Drakos, C. & Sholar, G. (2005). Guidelines for use of modified binders. Available from https://trid.trb.org/view/768711 [accessed 15 February 2019].

Sadeq, M., Masad, E., Al-Khalid, H., Sirin, O. & Little, D. (2016). Rheological evaluation of short- and long-term performance for warm mix asphalt (WMA) Binders. *Springer, Dordrecht*. pp. 129-139. DOI: 10.1007/978-94-017-7342-3_11.

Sadeq, M., Masad, E., Al-Khalid, H., Sirin, O. & Mehrez, L. (2018). Linear and nonlinear viscoelastic and viscoplastic analysis of asphalt binders with warm mix asphalt additives. *International Journal of Pavement Engineering*, *19*(10): 857-864. Taylor & Francis. DOI: 10.1080/10298436.2016.1213592.

Shang, L., Wang, S., Zhang, Y. & Zhang, Y. (2011). Pyrolyzed wax from recycled cross-linked polyethylene as warm mix asphalt (WMA) additive for SBS modified asphalt. *Construction and Building Materials*, *25*(2): 886-891. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2010.06.097.

Wang, C., Hao, P., Ruan, F., Zhang, X. & Adhikari, S. (2013). Determination of the production temperature of warm mix asphalt by workability test. *Construction and Building Materials*, 48: 1165-1170. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2013.07.097.

Wu, C. & Zeng, M. (2012). Effects of additives for warm mix asphalt on performance grades of asphalt binders. *Journal of Testing and Evaluation, 40*(2): 104279. DOI: 10.1520/JTE104279.

Xiao, F., Amirkhanian, S. & Juang, C. H. (2007). Rutting resistance of rubberized asphalt concrete pavements containing reclaimed asphalt pavement mixtures. *Journal of Materials in Civil Engineering*, *19*(6): 475-483. DOI: 10.1061/(ASCE)0899-1561(2007)19:6(475).

Xiao, F., Wenbin Zhao, P. E. & Amirkhanian, S. N. (2009). Fatigue behavior of rubberized asphalt concrete mixtures containing warm asphalt additives. *Construction and Building Materials*, *23*(10): 31440-3151. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2009.06.036.

Yildirim, Y. (2007). Polymer modified asphalt binders. *Construction and Building Materials*, *21*(1): 66-72. Elsevier. DOI: 10.1016/J.CONBUILDMAT.2005.07.007.

Zhang, D., Chen, Z., Zhang, H. & Wei, C. (2018). Rheological and anti-aging performance of SBS modified asphalt binders with different multi-dimensional nanomaterials. *Construction and Building Materials,* 188: 409-416. DOI: 10.1016/j.conbuildmat.2018.08.136.

Cite this article as: Al Mamun A., Sirin O., Masad E., "Development of Warm Mix Asphalt with the Aid of Microstructural Characterization", *International Conference on Civil Infrastructure and Construction (CIC 2020)*, Doha, Qatar, 2-5 February 2020, DOI: https://doi.org/10.29117/cic.2020.0035