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Multi-Scale Evaluation on the Interaction between Asphalt and Crumb Rubber

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Abstract: Crumb rubber modifier (CRM), made from scrap tires, has been introduced into the production of different types of Hot Mix Asphalt (HMA) in either wet or dry process. There has been few research about the interaction between asphalt and the crumb rubbers added in the dry process. In the study, dynamic shear rheometer (DSR) and atomic force microscopy (AFM) were used to explore the interaction between the asphalt binder and CRM in dry and wet process. The results indicated: (1) rubberized binder in dry process have similar modulus, phase angle and complex viscosity with wet process, regardless of unaging or short-term aging, (2) rubberized asphalt in dry process has lower roughness of topographical image than wet process before short-term aging. However, the short-term aging may decrease the difference of the microstructures of the binders in two processes, i.e., wet and dry processes.

INTRODUCTION

Crumb rubber modifier (CRM) has been incorporated into Hot Mix Asphalt (HMA) because it improves mechanical properties of HMA and deals with the waste tires (1-5). CRM was introduced to the asphalt mixtures by two different techniques: a wet process and a dry process. In the wet process, CRM is mixed with asphalt at high temperature (170-205°C) to form Asphalt Rubber (AR), which is then mixed with aggregate in a drum to produce HMA. In the dry process, CRM is mixed directly with aggregate in the drum to produce an HMA (4 and 5).

Most of the previous work has considered that the wet process had sufficient interaction between asphalt and CRM due to long time blending at high temperature, while asphalt-CRM reaction in the dry process is negligible due to the shorter reaction period and larger particle sizes of CRM used (Rahman et al. 2004). However, recent research found that during the mixing period as well as
transportation and construction, the asphalt-CRM reaction in the dry process is significantly higher than previously thought (2,4,5).

In Georgia of USA, smaller size CRM (i.e. 30 and 40 mesh), lower CRM content (about 10% mass of asphalt binder) and a cross-link agent (transpolyoctenamer (TOR) polymer) were used in the dry process to improve the performance of HMA (6 and 7). Smaller size, lower content and TOR may accelerate the asphalt-CRM reaction in this dry process. However, little research about it was found. To obtain a better understanding about Georgia’s dry process, especially the asphalt-CRM reaction, it is necessary to compare the difference of asphalt-CRM reaction between dry process and wet process and explore the interaction level between asphalt and CRM in Georgia’s dry process.

OBJECTIVE

The objective of this study is to 1) evaluate the mechanical performance of rubberized asphalt binders and 2) investigate the interaction level between asphalt and CRM in Georgia’s dry process and wet process.

MATERIAL

To compare asphalt-CRM reaction degree in both dry process and wet process, three types of binders were selected: virgin asphalt PG 67-22 and rubberized binder in dry and wet process. Rubberized binder in dry process was simulated by mixing virgin asphalt with 30 mesh 10% CRM by the weight of virgin asphalt at 170°C and 900 RMP for 2 minutes. Rubberized binder in wet process was produced by mixing longer time-45 minutes at the similar conditions to the dry process. In dry process, 4.5% TOR polymer by the weight of the CRM was used.

The short-term aging in the rolling thin-film oven (RTFO) at 163 °C for 85 minutes simulates the aging process of asphalt binder in transportation and construction. To explore the asphalt-CRM reaction in transportation and construction, asphalt binders were short-term aged.

TEST METHOD

To explore the mechanical performance of rubberized asphalt binders in dry and wet process, the frequency sweep tests were performed using dynamic shear rheometer (DSR) (Figure 1) according to AASHTO T 240. The frequency sweep test was run with the 25-mm diameter plate and 1-mm testing gap geometry at 50°C.
Atomic force microscopy (AFM) can explore nano-structure of asphalt by imagining technique (i.e. topographical and phase images) and nano-mechanical properties by nano-indentation experiment as well as adhesive force and cohesive force by force spectroscopy experiment (8-11). To investigate the interaction level between asphalt and CRM in dry process and wet process, Nanosurf AFM (Figure 2) was used to measure the microstructure of rubberized asphalt binders. In this test, the AFM tapping mode imaging technique is used for scanning the surfaces of CRM asphalt to avoid the surface and/or tip damage and reduce the tip contamination. ACLA probes, silicon probes, are used in tapping mode. ACLA probe has the probe tip of the 6-nm radius and probe cantilever of 58-N/m spring constant.

Prior to AFM test, an 80-mesh sieve was used to remove the CRM in the rubberized asphalt binders to avoid the effect of CRM particles on AFM measurements. The filtered hot asphalt was poured onto a clean glass substrate, and then placed in the oven (130 °C) for 5 minutes to form the smooth surface, which was critical to successful AFM testing.
RESULTS AND DISCUSSIONS

Frequency sweep test

Figure 3 shows the frequency sweep results of virgin asphalt and rubberized binders in dry and wet processes: (a) elastic modulus (G'), viscous modulus (G'') and complex viscosity (|η*|), (b) complex modulus (|G*|) and phase angle (δ). It can be seen that rubberized binder in dry processes have similar complex modulus (|G*|), elastic modulus (G'), viscous modulus (G''), phase angle (σ) and complex viscosity (|η*|), regardless of unaging or aging. In addition, compared to virgin asphalt, rubberized binders in both dry process and wet process have significantly higher modulus (G’, G’’ and |G*|) and complex viscosity (|η*|) while lower phase angle (σ). The frequency sweep results indicated that dry process and wet process improved the high temperature properties of asphalt binder at the similar level.

Figure 3. Frequency sweep results: (a) elastic modulus (G'), viscous modulus (G'') and complex viscosity (|η*|), (b) complex modulus (|G*|) and phase angle (δ)
AFM test

Figure 4 represents the topographical and phase images of PG67-22 as base binder. Figure 5 shows the phase images of unaged rubberized asphalt in dry process and wet process. Figure 6 is the phase images of short-term aged rubberized asphalt in dry process and wet process. Bee-like structures and darker phases around bee-like structures, which represent the parts with higher modulus (11), can be seen in all asphalt binders (figures 4 to 6). It can be found that the concentration of ‘bee-like’ structures and the area of darker phases of rubberized asphalt in dry process and wet process differs obviously each other before aging and slightly after short-term aging. The obvious difference between the dry process and the wet process may be attributed to the mixing and interaction time difference: the wet process had much longer mixing and interaction time than the dry process. The CRM-binder interaction at higher temperature during the short-term aging could reduce their difference.

Furthermore, roughness of topographical images of rubberized asphalt binder was calculated by Equation 1 and the calculation results showed that roughness of rubberized binder in dry and wet process is 21nm and 14nm before aging as well as 3.2 nm and 3.3 nm after short-term aging, respectively. This finding indicated that the short-term aging during storage and paving may make the microstructures of rubberized asphalt in dry process and wet process to be close, in other words, the short-term aging will decrease the difference of the microstructures of the rubberized binders in two processes, i.e., wet and dry process.

\[ R = \frac{1}{L} \sum_{0}^{L} Z(x) \]  

Where \( Z(x) \) is the function that describes the surface profile analyzed in terms of height (Z) and position (x) of the sample over the evaluation length “L”.

Additionally, it can be also seen that the concentration of ‘bee-like’ structures and the area of darker phases in rubberized asphalt binders were higher than the base asphalt of PG67-22, regardless of dry process or wet process.
CONCLUSIONS

The rheological property and nano-scale structure of asphalt binders were conducted to investigate the interaction level between asphalt and CRM in Georgia’s dry process and wet process. Main conclusions can be drawn as follows:

1. Rubberized binder in dry process have similar modulus (|G*|, G’ and G’’), phase angle (\(\sigma\)) and complex viscosity (|\(\eta^*\)|), regardless of unaging or short-term aging.

2. From the AFM testing results, rubberized asphalt in dry process has similar roughness to wet process after short-term aging, suggesting that both process may have the similar interaction level after the aging.
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REFERENCES

Shen, J., Amirkhanian, S. N., Xiao, F., Tang, B. (2009). “Influence of surface area and particle size on high temperatures of CRM binders”. *Construction and Building Materials*, 23, 304-310.
Singleton, T.M. (2000). “Characterization of Impact Absorbing Asphalt”, University of Nottingham.
Xiao, F., Amirkhanian, S. N., and 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.
Rahman, M. (2004). “Characterization of dry process crumb rubber modified asphalt mixtures”. University of Nottingham.
Rahman, M., Airey, G. D., Collop, A.C. (2010). “Moisture Susceptibility of High and Low Compaction Dry Process Crumb Rubber-Modified Asphalt Mixtures”. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2180*, Transportation Research Board of the National Academies, Washington, D.C., 121-129.
Sheila H. (2007). “Crumb Rubber Test Section on CSNHS-M003-00(560) 01 Houston Peach, Special Research Report 2007-1”, Georgia Department of Transportation.
Shen, J. and Xie, Z. (2012). “Comprehensive Evaluation of the Long-Term Performance of Rubberized Pavement: Phase I: Laboratory Study of Rubberized Asphalt Mix Performance”. Georgia Department of Transportation. FHWA-GA-12-1119. 2012.
Yua, X., Burnhamb, N.A., Mallicka, R.B., Tao. M. (2013). “A systematic AFM-based method to measure adhesion differences between micron-sized domains in asphalt binders”. *Fuel*, Volume 113, 443–447
Allen, R., Little, D., Bhasin, A., and Lytton, R. (2013). “Identification of the Composite Relaxation Modulus of Asphalt Binder Using AFM Nanoindentation”. *Journal of Materials in Civil Engineering*, 25(4), 530–539.
Tarefder, R. A., and Arifuzzaman, M. (2010). “Nanoscale Evaluation of Moisture Damage in Polymer Modified Asphalts”. *Journal of Materials in Civil Engineering*, Vol. 22, No. 7, pp 714-725.
Nazzal, M. D. and Qtaish, L.A. (2013). “The Use of Atomic Force Microscopy to Evaluate Warm Mix Asphalt”. FHWA/OH-2012/19.