Evaluation of Moisture Durability of Modified Asphalt Mixture with Nano-Titanium Dioxide Using Surface Free Energy Method

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ABSTRACT

Moisture damage is one of the forms of asphalt pavement distress that occurs due to the presence of water and its effect on the mechanical properties of the asphalt mixture. Using nanomaterial as additives is one of the solutions that delays this event and increases the durability of the mixture. In this study, the effect of nanomaterial (Nano-TiO_2) on the moisture susceptibility of asphalt mixtures was investigated using surface free energy method, indirect tensile strength test (ITS) and resilient modulus (Mr). Asphalt samples were fabricated by neat bitumen with a penetration grade of 85/100 and Siliceous aggregate. The bitumen was modified with 3and 6% (weight of bitumen) of Nano-TiO_2. The results of the bitumen section indicate that by modifying the bitumen with Nano-TiO_2, the acidic component of surface free energy decreases and its basic component increases. On the other hand, as the non-polar component increases, the bitumen free energy would be increased. The addition of Nano-TiO_2 to the asphalt mixture also increased the TSR. TSR reduction through the different freezing-thaw cycles for the modified mixtures was less compared to the control mixtures. The separation energy between bitumen-rock materials is also reduced by modifying the bitumen with this nanomaterial. Therefore, it improves the stripping resistance of the asphalt mixture. In addition, the results of resilient modulus indicate that bitumen modification with Nano-TiO_2 increased the Mr values. Similar to changes in the TSR, the RMR value has been increased for the modified HMA and it increased the hot mix asphalt durability.

KEYWORDS

Moisture damage, Nano-TiO_2, Cohesion and Adhesion, Indirect Tensile Strength, and Resilient modulus.

1. Introduction

In the last decades, a lot of information has been done to identify the moisture susceptibility [1]. Based on thermodynamic theory, the effective internal factors, i.e. adhesion and cohesion, were considered as the most concepts among the other properties [2]. Surface free energy (SFE) and its relationship with bond energy was accepted as an indicator for measuring the adhesion and cohesion of materials [3]. Therefore, by quantifying the moisture potential using the SFE method, the moisture damage of asphalt mixture can be easily investigated.

There are many solutions to prevent the moisture damage of asphalt mixture. Using additives as a modifier of the mixture properties is one of the most common solutions [4]. These additives include nanomaterials, which have been recently considered by researchers. Nano-TiO_2 is also one of the nanomaterials that has been applied in asphalt mixtures in the last decade [5]. However, the effect of Nano-TiO_2 on moisture damage of mixture under different freezing-thaw cycles using SFE method has not been studied. In this regard, this issue was investigated using different techniques such as SFE method, indirect tensile test and resilient modulus test. Therefore, the SFE components of stone materials, neat bitumen, and modified bitumen with Nano-TiO_2 were obtained and compared with the corresponding mixture results. As a result, the effect of Nano-TiO_2 on moisture susceptibility and different freezing-thaw cycles was determined.

2. Materials

2.1. Aggregate

A silica aggregate with NMAS of 19 mm was used to fabricate the asphalt mixture.

2.2. Bitumen

A neat binder with PG64-22 was used in this study

2.3. Nano-TiO_2

Nano-TiO_2 with a maximum particle size of 5 nm was used in this research. Nano-TiO_2 with total weight percentages of 0, 1%, 3% and 5% were blended with bitumen and named T0, T1, T3 and T5, respectively. The uniformity of dispersion of nanomaterials in the modified bitumen was investigated using a field emission scanning electron microscopy (FESEM) as shown in Fig. 1.

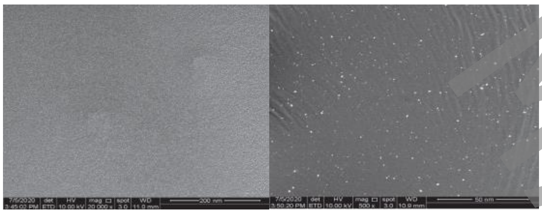

Fig. 1: FESEM image of bitumen modified with 5% Nano-TiO_2 in different magnifications

3. Experimental Program

3.1. Mixing and compact temperature

According to ASTM-D4402, the viscosity of different bitumens were measured at 135 and 160°C using Brookfield device and the mixing and compaction temperatures were obtained.

3.2. Optimum bitumen content (OBC)

OBC was determined according ASTDM D1559. It was found 5.6% for neat bitumen. It should be noted that the addition of Nano-TiO_2 did not have a significant effect on OBC.

3.3. SFE measurement

In this research, acid-base theory was used to measure SFE components including 1-Non-polar component (Γ^{AB}), 2- acidic component (Γ^{+}), and 3- base component (Γ^{-}). Therefore the total SFE (Γ), will be determined as Eq. 1:

$$\Gamma = \Gamma^{LW} + \Gamma^{AB} = \Gamma^{LW} + 2\sqrt{\Gamma^{+}\Gamma^{-}} \quad (1)$$

To aim this, sessile drop (SD) method was applied with three probe liquids. After finding the contact angle of these liquids with known SFE components, three equations as Eq. 2 can be simultaneously considered to find three unknowns of SFE components of bitumen:

$$\Gamma_L^{Total}(1+\cos\theta) = 2[(\sqrt{\Gamma_b^{LW}\Gamma_L^{LW}}) + (\sqrt{\Gamma_b^{+}\Gamma_L^{-}} + \sqrt{\Gamma_b^{-}\Gamma_L^{+}})] \quad (2)$$

In which, ɵ is contact angle of each liquid. Two indexes of b and L are corresponded to bitumen and probe liquid.

3.4. Moisture susceptibility

3.4.1. Indirect tensile strength (ITS) test

ITS test was performed on cylindrical sample with an air void of 7%, according to AASHTO-T283 with 1, 3, and 5 freezing-thaw cycles. Tensile strength ratio (TSR) was calculated as Eq. 3 that ITS_{wet} and ITS_{Dry} are ITS of unconditioned and conditioned mixture sample:

$$TSR = \frac{ITS_{Wet}}{ITS_{Dry}} \times 100 \quad (3)$$

3.4.2. Resilient modulus (M_r) test

M_r of mixture samples was determined as Eq. 4 using UTM25 at 25°C:

$$Mr = \frac{P(\nu+0.27)}{t \times \delta_h} \quad (4)$$

Resilient modulus ratio (RMR) was determined from division of Mr of wet sample to dry sample.

4. Result and summary

4.1. SFE results

Regarding the contact angle of three probe liquids and investigation of their validity using statistical analysis (one way ANOVA), the results of total SFE of different bitumen types were found as Table 1.

Table 1. SFE values of different bitumens (mj/m^2)

Type of bitumen	Γ	Γ^{LW}	Γ^{AB}	Γ^{+}	Γ^{-}
T0	16.3	14.0	2.4	2.6	0.5
T3	17.7	14.9	2.8	2.4	0.8
T6	18.1	15.1	2.9	2.4	0.9

According to Table 1, the total free energy value of neat bitumen is increased from 16.34 to 17.68 and 18.07

(mj/m^2) through adding 3 and 6% Nano-TiO_2, respectively. Therefore, the cohesion failure potential of modified bitumens is less than that of neat bitumen. Acidic properties reduction of bitumen and increasing its alkaline properties leads to improve the adhesion of bitumen-aggregate in the presence of water. Due to the fact that Nano-TiO_2 has an alkalinity behavior (8<PH<10), the change in acidity and alkalinity parameters of the modified bitumens occurs, which affects the bitumen properties. The results presented in Table 1 show that the non-polar component of modified bitumens increases compared to the neat bitumens. Given that the bond of bitumen-aggregate is non-polar; it can be concluded that increasing the non-polar components of SFE improves the strength of this bond.

4.2. Mixture results

4.2.1. ITS and TSR results

ITS value of mixtures and corresponding TSR results were determined, the results of which are presented in Fig. 2 for different freezing-thaw cycles. As shown in Fig.4, using Nano-TiO_2 increases the ITS and TSR value of mixtures (in both dry and wet conditions). Three main reasons can be described for this increase: 1- Nano-TiO_2 has increased the adhesion of bitumen-aggregate. 2- The addition of Nano-TiO_2 increase the bitumen viscosity and makes it harder. Therefore, the bitumen can strongly stick to the aggregate. 3- Increasing the SFE of bitumen has reduced the possibility of failure in mastic.

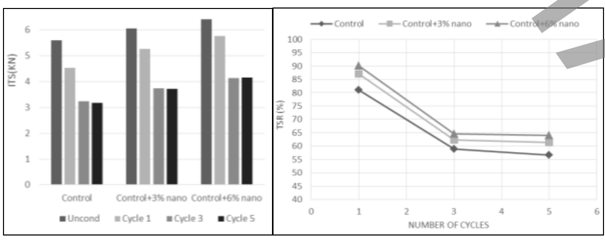

Fig. 2: ITS and TSR results of different mixture

4.2.2. M_r and RMR results

Resilient modulus and their ratio were determined for different mixtures as shown in Fig. 3.

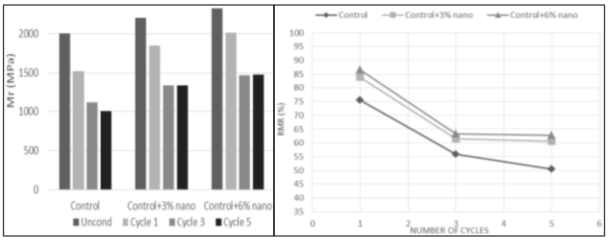

Fig. 3: M_r and RMR results of different mixture

Fig. 3 shows that the using Nano-TiO_2 has increased the M_r of mixtures (in both dry and wet conditions). Also, through increasing freezing-thaw cycles, the decrease in RMR of modified samples is less than that of control samples. It indicates that under multiple freezing-thaw cycles, the modified mixtures have a higher moisture resistance than the unmodified samples. Also, the adding 3% of Nano-TiO_2 has more RMR improvement than 6%. Therefore, it can be said that 3% of Nano material can be selected as the optimum percentage.

References

[1] G. Hamedi, Evaluating the effect of asphalt binder modification using nanomaterials on the moisture damage of hot mix asphalt, Road Materials and Pavement Design (2016).

[2] H. Bashin, DEVELOPMENT OF METHODS TO QUANTIFY BITUMEN-AGGREGATE ADHESION AND LOSS OF ADHESION DUE TO WATER, (2007).

[3] F. Moghadas Nejad, G. Hamedi, A. Azarhoosh, Use of surface free energy method to evaluate effect of hydrate lime on moisture damage in hot-mix asphalt, Journal of Materials in Civil Engineering, 25 (8) (2016) 1119-1126.

[4] [23] N. Esmaeili,, G. Hamedi,, M. Khodadadi, Determination of the stripping process of asphalt mixtures and the effective mix design and SFE parameters on its different phases, Construction and Building Materials, (213) (2019) 167-181.

[5] [20] G. Hamedi, A. Azarhoosh, M. Khodadadi, Effects of Asphalt Binder Modifying with Polypropylene on Moisture Susceptibility of Asphalt Mixtures with Thermodynamically Concepts, Periodica Polytechnica Civil Engineering, 62 (4) (2018) 901-910.