Laboratory Study on the Fatigue Resistance of Asphaltic Concrete Containing Titanium Dioxide

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Abstract. This study aims to evaluate the fatigue performance of modified asphalt mixture using Indirect Tensile Fatigue Test. Titanium Dioxide (TiO_2) powder in a form of rutile was used for producing asphalt concrete with lower mixing and compaction temperature compared to conventional hot mix asphalt without reducing its physical and mechanical also resistance to fatigue. The characteristic of the asphalt and modified asphalt was evaluated using penetration test, softening test and rotational viscosity test. Titanium dioxide of 2%, 4%, 6%, 8% and 10% by weight of asphalt has been incorporated into unaged 80/100 asphalt mix in order to improvise its performance and to fulfill the objectives of this experimental study. As a result, TiO_2 as an additive is potential to decrease the penetration and increasing the softening point of the asphalt. In terms of fatigue performance testing, addition TiO_2 additive does help in improving the fatigue properties as it shows greater result than the control asphalt. In conclusion, TiO_2 is great in improving fatigue properties.

1 Introduction

Warm Mix Asphalt (WMA) is one of the technologies that has been gaining attention in recent years, is used to reduce the heating, mixing and compaction temperature of the asphalt mixture, improving the working condition at site, reduced time of compaction in site and minimizes the negative effects on the environment. These technologies can reduce the production temperature of the Hot Mix Asphalt (HMA) by 16°C to over 55°C [1]. It was first applied in Europe in the year 1997, followed by United States in 2002 [2]. Exposure of WMA mixture is relatively new in Malaysia, however, it is becoming a mainstay in construction and pavement industry. To date, long term performances of WMA mixture are still being reviewed and there is no pavement failures or concerns have been observed. WMA is an alternative for hot mix asphalt (HMA) and is produced at a temperature ranging from 120°C to 140°C, which is 10°C to 40°C lower than that of HMA [3]. This environmental friendly technology has claimed to contribute to

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lower emission of fumes, less energy usage, better working environment and longer hauling time without compromising the performance of the pavement. In order to attain lower asphalt production and compaction temperature whilst maintaining its feasible viscosity, additives are needed to be incorporated in the mixture. According to Kilas et.al, three types of commonly found WMA technology in the worldwide are foam asphalt, organic additives and chemical additives [3]. These additives will help in lowering the viscosity of asphalt during the production process of WMA, which is a crucial factor in obtaining high workability of the asphalt. For example, Abdullah et. al was conducted a study on performance of WMA mixture using nanoclay modified asphalt binder called Nano Clay Modified Binder (NCMB) in terms of moisture susceptibility, rutting and fatigue potential [4]. The prepared the WMA samples using mixing temperature 135°C, 125°C and 115°C and less 10°C for compaction temperature. As a result, the fatigue life was decreased as it is decreasing in mixing and compaction temperature. Also, Moatasim et al. conduct on study WMA with modified asphalt using HDPE as an additive, the objective of the study is to evaluate the performances of the asphalt concrete mixtures that using modified asphalt 80/100 with HDPE [5]. From the result, the performance of the concrete mixtures improve when used 5% of HDPE by weight in asphalt blend. Then, Yu Kuang et al., did a researched with two main objective, first is to evaluate on behaviour of Evotherm-J1 and M1 as additive in compaction technology and second objective is to study the effect of Evotherm-J1 and M1as additive in moisture anti strip [6]. The study carried by Diefenderfer et al. (2008), using sasobit as an additive in asphalt with two different mixtures in the study.

In this study, chemical additive known as titanium dioxide (TiO_2) was used to evaluate the properties and performance of the asphalt pavement. The objectives of this study are to; (i) evaluate the physical properties of asphalt modified with Titanium dioxide based on Malaysia Standard Specification and Superpave binder specification and (ii) evaluate and compare the fatigue characteristics of asphalt modified with TiO_2 at warm mix asphalt compacted temperature with conventional hot mix asphalt.

2 Methodology

2.1 Materials

There are several sizes of sieve typically used for Superpave mix design which includes sieve size 37.5mm, 19mm, 12.5mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.600mm, 0.300mm, 0.150mm and 0.075mm.The gradation size was determinate follow the Superpave gradation limit. The TiO_2 used are in form of rutile particles size ranges from 40 nm to70 nm as shown in Fig. 1 and the binder used are asphalt penetration grade 80-100. The selection of rutile form are based on the purity of titanium dioxide substance in its composition and higher surface area as the smaller sizes of particle, the surface area are higher.

2.2 Sample preparation

The modified asphalt was prepared using asphalt of penetration grade 80/100 as base asphalt and several percentage of TiO_2 in powder form. It is started by placing the 500 g of base asphalt in an aluminum can and then placed in the oven at 155°C for approximately half an hour. It was then put on top of a hot plate and continuously observes to ensure that the asphalt stayed constant at 155°C. Next, a specified percentage of TiO_2 by weight of asphalt are gradually added into the asphalt as the high shear asphalt mixer is rotating at 5200 rpm for duration of 30 minutes. The blending parameter used in this task are follows the procedure that came out with the homogeneous mixture in previous study [7].

To evaluate the fatigue characteristic of the mixture, the Optimum asphalt Content (OBC) was determined in the first place. The aggregate gradation with nominal size 9.5 mm was used. The maximum content of the aggregate is 4.75 mm sieve size and the filler content is 2% from total weight of 1200 g. A HMA mixture without TiO_2 content was prepared using mixing and compaction temperature that are 165°C and 155°C respectively. It was denoted as control mixture and WMA mixture that containing TiO_2 were prepared by using mixing and compaction temperature of 135°C and 125°C.

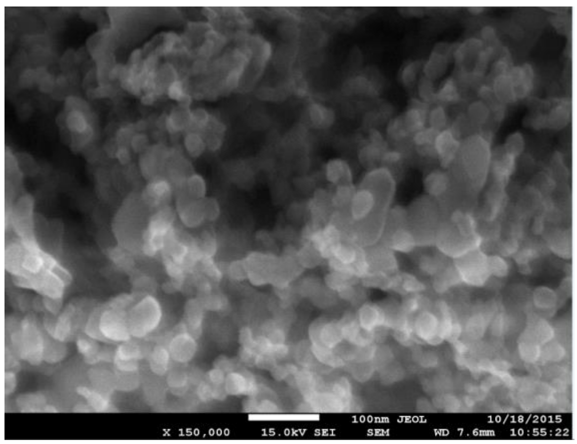

Fig. 1. Morphology of the TiO_2.

2.3 Laboratory testing

A laboratory testing was conducted based on American Society for Testing and Material (ASTM), American Association of State Highway and Transportation (AASHTO), Asphalt Institute Superpave Asphalt Binder Test Methods and Asphalt Institute Superpave Mix Design (SP-2). A penetration test was conducted followed ASTM D5 while softening point test following ASTM D36 [8-9]. Brookfield Viscometer was used in rotational viscosity (RV) test to measure the flowing resistance of asphalt materials [10]. The Superpave™ specification requires that the maximum viscosity of asphalt binder is no greater than 3 Pa.s at 135 °C for the convenience of storage and pumping in construction period [11]. Sieve analysis was conducted to find the aggregates gradation that followed the Superpave aggregates gradation limit [11]. The determination of the OBC was following the trial asphalt content based on 9.5 mm aggregates size with 5%, 5.5%, 6.0% and 6.5% trial asphalt content. After OBC was determined, mixtures sample for Indirect Tensile fatigue test was conducted. Fatigue cracking is one of prominent pavement distress in tropical countries after several years of construction due to weathering and repeated numbers of traffic loads. In laboratory, for asphalt mixture the Indirect Tensile Fatigue test (ITFT) was conducted using Universal Testing Machine (UTM) to evaluate the fatigue performance of modified asphalt mixture with TiO_2 powders. Before testing is conducted, sample and related testing accessories were conditioned at 20°C for a minimum 4 hours in the provided environmental chamber to reach a uniform temperature throughout the specimen. After that, testing is run at the same temperature and the specimen was exposed to a repeated compressive load 45 equal to 600 kPa with a haversine load signal through the vertical diametral plane followed by a loading time of 0.1 s and rest period of 0.4 s. The pattern of loading applied to the specimen is relatively uniform tensile stress perpendicular to the direction of the applied load. After certain period, the testing is terminated and the total number of cycles was recorded.

3 Results and discussions

3.1 Physical and flow behaviour

Softening point test and Penetration test were performed to determine the physical properties of unaged virgin and modified binder. Table 1 shows that the penetration value is gradually getting lower as more additive is added into the binder. This shows that addition of additive does help in improving the hardness of the binder, which is a desired factor in modified binder property. Softening Point test measured the temperature where asphalt material starts to change to liquid state [12]. Higher softening point indicates stiffer asphalt and lower temperature susceptibility at high temperature, which is more preferred in hot climates. As seen in Table 3, the softening point value started to increase for modified binder added with 2% TiO_2 until 8% TiO_2. It can be concluded that the penetration value decreases as higher percentage of additive was added to the binder. This indicates that proper amount of TiO_2 added can help in improving the stiffness of the asphalt.

Table 1. Results of Softening Point and Penetration Test.

Sample (% TiO_2)	Softening point (°C)	Penetration test (mm)
0	46.4	99.8
2	47.7	96.1
4	49.3	94.2
6	50.4	89.4
8	51.1	83.2
10	51.9	79.6

Fig. 2 shows viscosity test results. Conventional asphalt is known to have a higher mixing and compaction temperature compared to modified asphalt. As shown in the table, enhancement the reading by increasing the percentage of additive while the result become decreasing when the temperature raised until 180°C. As a conclusion, this additive can increasing the viscosity of asphalt binder.

The analysis continue with plotting graph in Fig. 3 for determination of recommendation of compaction and mixture temperature value. According to Superpave Asphalt Binder Test Method (SP-1), references line for compaction range and mixing range which are 0.25 to 0.31 for compaction and 0.15 to 0.19 for mixing. It was found that the minimum compaction temperature value for warm mix asphalt has larges value than control, while the minimum mixing temperature value is better than control value, this can be expressed the modified binder is using less energy and fuel than control binder for preparation of binder.

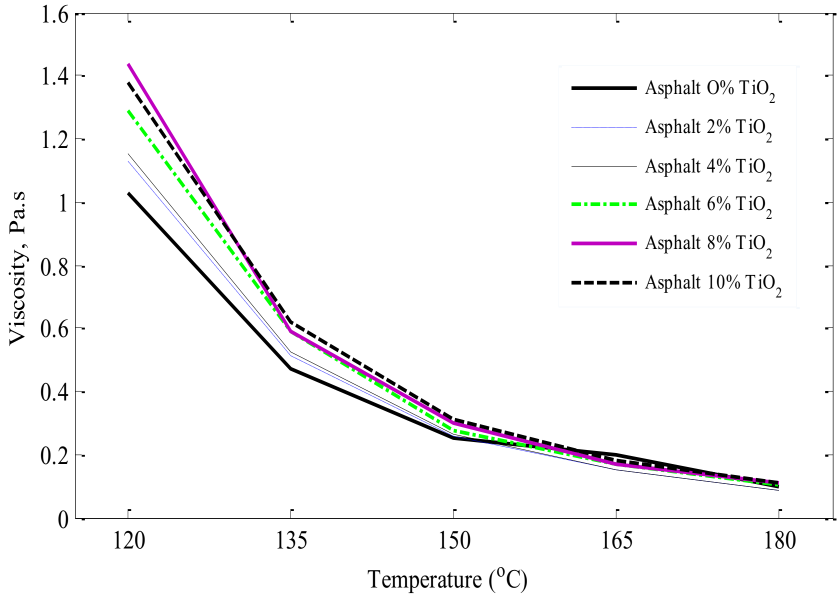

Fig. 2 Rotational viscosity of original asphalt 80/100 and Modified asphalt with TiO_2.

3.2 Resistance to fatigue

Fatigue is a major distresses normally occurred in asphalt pavement. Fatigue occurs at low to intermediate temperature while rutting occurs at higher temperature. The initiation and propagation of cracking generally relates to the magnitude of dissipated energy produced by external loading. In this study, results of ITFT according to the mixing and compaction temperature for the mixture are shown in Table 2 and the trend of fatigue resistance of the mixture is illustrate in Fig. 3. The trend for mixtures compacted at 125°C is showing an increasing pattern as the percentage of TiO_2 increased. This could indicate that proper amount of TiO_2 addition will help to improve the reaction between the binder and the aggregates, which eventually increases the strength of the mixture as a whole and completly increased the performance of the mixture againt fatigue failure.

Table 2. Fatigue life cycle

Sample (% TiO_2)	Mixing Temperature, (°C)	Compaction Temperature, (°C)	Fatigue life cycles
0	165	155	11416
2	135	125	12051
4	135	125	12578
6	135	125	13145
8	135	125	13463
10	135	125	13866

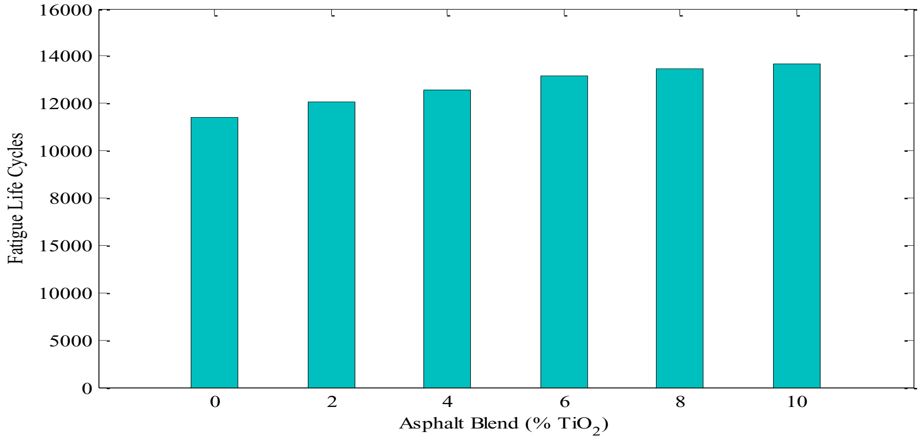

Fig. 3. Number of cycles of modified asphalt with TiO_2.

4 Conclusions

In this study, a TiO_2 in a powder form of rutile particles of 2%, 4%, 6%, 8% and 10% were added to the base binder to investigate for the effectiveness of the additives in improving the properties of the binder. Based on the results presented, the following findings can be deduced with respect to the applications:

- The addition of TiO_2 has significantly improved the penetration and softening point of the asphalt. This demonstrated the improvement of stiffness of the binder and also better temperature susceptibility.
- Addition of TiO_2 has the potential in reducing the mixing temperature of the mixture.
- In terms of fatigue cracking performance of mixture, addition of modified TiO_2 does aid in controlling the effectiveness of mixture towards fatigue resistance.

In conclusion, higher percentage of TiO_2 in form of rutile particles is a good substance to be used as additive in Warm Mix Asphalt as it improved the physical and fatigue performance characteristics of the binder. It is also reducing the temperature of the mixing.

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