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INFLUENCE OF USING BATU PAHAT SOFT CLAY ON THE MECHANICAL PROPERTIES OF HOT MIX ASPHALT MIXTURE

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ABSTRACT

There many potential ways to enhance the performance of bituminous mixture used in the surfacing course of road pavements. Due to inadequacy from previous research on Batu Pahat soft clay (BPSC) application as an additive in hot mix asphalt (HMA) mixture, BPSC was used as an additive and introduced in powder form in this present study. The purpose of this research is to evaluate and investigate the effects of BPSC particles on the performance of the HMA mixture. The experimental work for this survey included the use of five percentages of BPSC (0%, 2%, 4%, 6%, and 8%) in reference to the weight of bitumen; a design for the HMA was executed using the Superpave method for each additive ratio, and the optimum bitumen content for each percentage was used. In additional, with respect to assessing an impact for BPSC particles in the asphalt mixture, moisture susceptibility, resilient modulus, and dynamic creep tests were conducted. Through blending steps, the binder was kept at 160 °C, and the shear rate mixer was used for approximately 1 h at 3000 rpm. The results demonstrated that dynamic creep prepared with BPSC modified bitumen had a better resistance to deformation than the controlled mixture. In addition, the BPSC particle reduced the susceptibility to moisture damage and increased the strength of asphalt mixes. BPSC particles likewise improved the durability and rutting resistance of the resilient modulus. The increasing BPSC to 4% appears to hold the greatest potential for beneficial modification of the binder. This research proves that BPSC can improve properties such as, resilient modulus and moisture sensitivity and result in superior performance compared with unmodified bitumen under dynamic creep.

Keywords: asphalt mixture, Batu Pahat soft clay, dynamic creep, moisture susceptibility, resilient modulus**,** superpave mix design.

INTRODUCTION

Road construction necessitates high amount of bitumen, which is a non-renewable material (Kamaruddin, 2014). The demand for a durable pavement, with good mechanical properties has contributed to the study of various alternatives for hot mix asphalt (HMA) mixture (Burguete). In this study, the use of modified bentonite bitumen as an additive to HMA mixture to enhance asphalt mixtures compared with the conventional HMA was explored. In addition, bentonite leads to a relative increase in mechanical properties of asphalt mixtures (Ziari *et al.* 2014). Behiry (2013) found that using hydrated lime had better results than using Portland cement. The investigation of Jahromi *et al.* (2009) revealed that nanoclay would enhance the mechanical properties of HMA and obtain superior performance compared with unmodified bitumen under dynamic creep .In comparison, nanoclay showed a better effect in improving physical and rheological properties of asphalt binders and rutting resistance, which may contribute to the homogeneous dispersion of nanoclay particles that led to form a flake structure in an organically modified montmorillonite asphalt binder (Muniandy *et al.* 2013). Goh *et al.* found that using nanoclay as an additive on the asphalt mixture would enhance the moisture sensitivity of asphalt mixture (Goh, 2011). Moreover, the research of Hafeez *et al.* (2011) showed that adding of hydrate lime in HMA would improve the behavior of resilient modulus and dynamic modulus. El-Shafie *et al.* (2012) stated that adding macro and organically modified nanoclay on the physical properties of asphalt binder increased viscosity, softened point, and reduced penetration of asphalt binder. Nanoclay modification could boost characteristics of asphalt binder and mixture in terms of stiffness, strength, durability, and resistance to aging and thermal stability (Van de Ven *et al.* 2009). Moreover, in the a previous study of Van de Ven *et al.* (2008), they found that other clay modified in an obvious way would presented the possibility for other applications like dense asphalt or as additive to prevent binder drainage during transportation.

In another study, the researchers found that nanoclay could improve, stiffness modulus indirect tensile strength and result in excellent performance compared with that of unmodified bitumen under dynamic creep (RO and MI, 2013). The clay minerals, mostly specified by their small particle size, affinity for water, and response to chemical reactions in their environment, are referred for their crystallization and viscosity-increasing capabilities in aqueous components (Jordan, 1963). In this regard, using mineral filler with asphalt has obtained dramatic increase in terms of Marshall Stability and stiffness. Hence it would be more beneficial to use mineral filler in the HMA mixture (Yilmaz *et al.* 2011). Adsorption for asphalt and resins upon montmorillonite happens rapidly and in great extent under near-anhydrous laboratory conditions. A factor that affects adsorption is the exchangeable cation on the clay (Clementz, 1976). Furthermore, using kaolinite clay combined with polymer modified bitumen can enhance storage stability, and using the expanded clay in the bitumen can enhance the layers of wearing course via a new calculation of the volume of the mixture (Ouyang *et al.* 2005).

In a survey by Hafeez and Kamal, they detected that using the filler to proportion asphalt obtained a major range and indicated a comparatively better performance during its service life. The study by Ahmed *et al.* (2006) found that using cement dust as an alternative to conventional limestone of HMA can increase in indirect tensile strength. In the study of Chen *et al.* (2011), recycled brick powder as an additive in the asphalt mixture was improved to obtain better mechanical properties compared with mixtures with limestone filler. They found that recycled fine aggregates powder has an ability to amend the properties of asphalt mixture, such as moisture sensitivity and fatigue resistance, as well as enabling its use for pavement construction, especially in hot regions. The study of Akbulut *et al.* (2012), in addition, showed that using granite sludge as filler with HMA results to less damage to our environment. The performance of HMA design is greatly affected by the quality and the quantity of fines ingredients or mineral fillers in the mixture; the mineral filler in HMA is an important element of mix design and, hence, plays a significant role in stiffening and toughening the asphalt binder (Anderson, 1996).

MATERIALS AND EXPERIMENTAL METHOD

Aggregate

Aggregates used in this present research were obtained from the Batu Pahat Queerly. The gradation of mix design for aggregates and physical properties for aggregates are shown in Table-1 and 2 respectively. Figure-1 shows the gradation curve of aggregate mix design and the aggregate gradation was selected according to ASTM D 3515-96 (D-4).

Table-1. Physical properties of aggregate.

Aggregate Test	Value %	Method
Uncompacted Void Content of Fine Aggregate	47.78%	AASHTO T 3041
Aggregate Impact Value (AIV)	25%	BS 812: Part 112:1990
Elongation Index (EI)	24%	BS 812: Part 1:1975
Los Angeles Abrasion Value (LAAV)	31.15%	ASTM C: 131-81
Flat and Elongated Particles	5.87%	ASTM D 4791

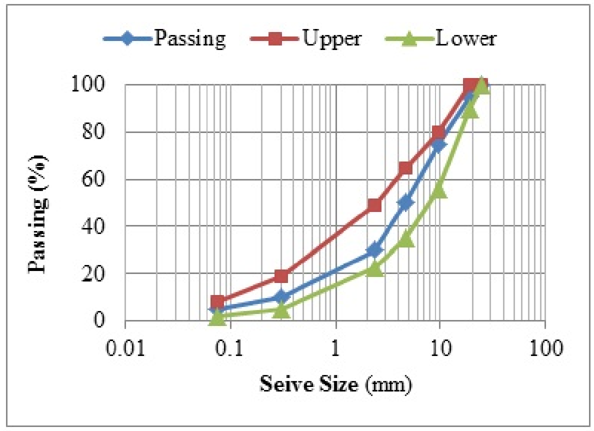

Figure-1. Gradation curve of aggregate mix design.

Table-2. Gradation of aggregate superpave mix design with specific gravity (SG).

Sieve Size	Percent Passing (%)			
	Upper Limit	Lower Limit	Design	SG (g/cm)
19 mm	100	90	95	2.625
9.5 mm	80	56	75	2.632
4.75 mm	65	35	50	2.637
2.36 mm	49	23	30	2.747
0.300 µm	19	5	10	2.681
0.075 µm	8	2	5	2.723
Dust	0	0	0	2.73

Asphalt Binder

In this present research, 80/100 of penetration grade was used in order to prepare all the test samples. We noticed that the SG for the asphalt binder was taken as 1.03.

Additive of BPSC

Batu Pahat soft clay (BPSC) was obtained by excavating 1.5 m below the ground. BPSC was dried using a forced-draft oven at temperature 155 °C to eliminate moisture and compact the clay, and it was then sieved using a No. 200 sieve. BPSC was used as additive different ratios (0%, 2%, 4%, 6%, and 8%) to determine the optimum bitumen content. Bitumen was prepared using a high shear mixer, and the asphalt binder was modified with BPSC particles in various ratios (0%, 2%, 4%, 6% and 8%) in reference to the weight of bitumen. We noted that once the BPSC was sparse and homogeneous during the process of mixture design, bitumen was kept at 160 °C for an hour and mixed by the shear rate 3000 rpm. BPSC was then mixed with aggregates using with a wet process. The properties of BPSC are presented in Table-3.

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Figure-2. BPSC.

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Mix Design Procedure

The processes adopted to enhance the Superpave HMA mixture, i.e., the procedure of using Superpave samples in this study, were according to AASHTO T312 and PP-28-200 procedures. Superpave mix design, when mixed at optimum binder content (OBC), should have an accepted volumetric property at 4% air voids (AVs) based on certain Superpave standard at the design number of gyrations. The project traffic load that was chosen in this study was <30 million equivalent single axel loadings, and the number of gyrations (N_{des}) of 125 were selected. The compatibility assessment of the asphalt mixture was specified at the initial number of gyrations (N_{ini}) after nine gyrations, with 205 gyrations as the maximum number of gyrations (N_{max}).

The volumetric properties of the asphalt mixture were calculated based on G_{mb} ASTM D2726 and G_{mm} , with estimated density at the corresponding number of gyrations, and the theoretical maximum density was calculated through the Rice method according to AASHTO T209 or ASTM D2041 by using a loose mixture method. This method required 19-mm nominal maximum aggregate size at 1200 g. Other requirements that must be satisfied in the Superpave criteria are voids of total mineral, voids of mineral aggregate, and voids filled with asphalt. The dust proportion is also one of the major components in determining the stability and durability of asphalt mixes according to Superpave specifications.

The OBC was established at 4% AVs in the graphs plotted between the volumetric properties against binder content, which ranged from 3% to 5%. The volumetric property data were compared to the Superpave volumetric mix design requirements. Once the OBC was selected, two additional specimens were fabricated and compacted to N_{max} at the OBC. The process to determine G_{mb}, and G_{mm} were repeated again to ensure that N_{max} did not exceed 98%. The OBC was obtained from volumetric properties of the Superpave mix design, i.e., 5.85%, 5.90%, 5.50%, 5.55%, and 5.80%. The specimens were compacted by using 125 gyrations.

Compaction Mixture Procedure

All specimens prepared have undergone mixture conditioning. Mixture conditioning for the volumetric mixture design procedure was applied to laboratory-prepared loose mixture only. The aggregate must be kept in a forced-draft oven for 2–4 h to achieve equilibrium at the selected temperature. The binder was heated at the desired temperature at 150 ºC for 2 h; then, the mixture and pan are placed in a forced-draft oven for 2 h ±5 min at 135 ºC for an unaged condition and compacting temperature. The mixture was stirred after 60 ± 5 min to preserve regular conditioning.

Moisture Sensitivity Test

The damage of moisture sensitivity can be defined as the decrease in the strength, stiffness, and durability due to the presence of moisture, leading to adhesive failure during the binder (Nejad *et al.* 2012). The procedure test of moisture susceptibility AASHTO T283 was adopted by the Strategic Highway Research Program. This test step is comparable to the Lottman test procedure with a bit of modification. The immersion–compression test was conducted in 1950s as the first moisture damage test on compacted samples beneath ASTM standard (Solaimanian *et al.* 2003). The test was performed by compacting specimens to an air void level of 6%–8%. Six specimens were used for determining the moisture sensitivity. The specimens were separated into two subsets, i.e., dry and wet, and each subset has three specimens. Three samples of dry subset were selected as unconditional and the other three specimens were selected to be conditioned by saturating the sample with water and going through a freeze cycle, subsequently having a water bath at 60 ºC for 24 h. The samples were then tested for indirect tensile strength by placing the sample between the steel loading strips using UTM-16. The load was applied to the specimen by constant head rate, i.e., at 50 mm/min, and the maximum compressive force was recorded until the specimen cracked. The moisture sensitivity test can be calculated using the following equations as explained below:

$$S_t = \frac{2P}{\pi t D} \quad (1)$$

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$$\mathrm{TSR} = \frac{S_{t(cond)}}{St_{(dry)}} \quad (2)$$

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where S_t, is tensile strength (kPa), P is the maximum load, N it is specimen thickness (mm), d is the specimen diameter (mm), S_(t(dry)), is the average tensile strength of the dry subset (kPa), and S_(t(cond)) is the average tensile strength of the conditioned subset (kPa).

Resilient Tensile Modulus Test

Resilient modulus of asphalt mixtures is the most popular form of stress–strain measurement used to evaluate elastic properties. Moreover, the resilient modulus has not been used much to present the HMA stiffness because more emphasis has been placed on the dynamic modulus (Nejad *et al.* 2012).

The indirect tensile modulus uses a non-destructive method to observe the effects of temperature and loading rate (Alataş and Yilmaz, 2013). According to previous study by Moreno-Navarro *et al.* (2014), the internalization of additives could lead to a better mechanical behavior of high modulus asphalt mixes, and could thus improve their function. The resilient modulus at 25 ºC is based on the mixture's resistance to fatigue, while the resilient modulus at 40 ºC displays the mixture's resistance to rutting. The test method is described in ASTM D 4123. Stiffness modulus of asphalt mixtures is considerably reduced when the temperature is increased. The strain is measured using liner vertical differential transduce and used along with the applied stress to compute the resilient modulus of the design procedures. All the samples of the resilient modulus test were performed by placing the test samples in a controlled temperature at 25 °C and bringing them to the specified test temperatures at least 24 h before testing. The specimens of stiffness modulus tests were subjected to conditioning loading pulses. The applied force automatically adjusted to achieve the requested horizontal strain or deformation value. Horizontal and vertical deformations were observed and measured though the test. The specimens were then subjected to conditioning and loading pulses. The pulse repetitions used in this study were at 1000 ms.

Dynamic Creep Test

The dynamic creep test was developed to assess the permanent deformation of asphalt mixtures. The test was carried out by applying a static load to an asphalt mix sample, and the result of rutting was observed during the time (Yusoff *et al.* 2014), in spite of the plurality of deformation recapture after the load is extracted. By handling millions of load cycles; the smaller quantities of deformation would be cumulative and eventually gather in surface rutting. The total of this deformation is greatly affected by the quantity and number of cyclic loads, as well as environmental temperature. Universal testing machine, which is the most commonly used device to measure the permanent deformation of asphalt mixture, was utilized. In this study, the specimen's diameter is high at 100 mm. A loading stress of 100 kPa was applied on the specimens, and the loading cycles applied were 3600 cycles (for approximately 1 h). Dynamic creep test was conducted at 40 ^{o}C, and to reach a uniform mixture temperature, all the specimens were placed in controlled temperature chamber for at least 1 h (Moghaddam *et al.* 2014).

RESULTS AND DISCUSSIONS

Moisture Sensitivity Test

Tensile strength ratio (TSR) is used to predict the moisture susceptibility of the mixtures. According to previous studies, a TSR above 0.8 was typically utilized as a minimum acceptable value for HMA. Mixtures with TSRs less than 0.8 are susceptible to moisture, and mixtures with ratios greater than 0.8 are relatively resistant to moisture damage (Niazi and Jalili, 2009).

The moisture susceptibility of an asphalt mixture, generally called moisture damage, is among the most critical distresses of asphalt pavements. Moisture damage can be defined as the decreased values in terms of stiffness, strength, and durability in asphalt mixtures caused by moisture. The water trapped in the coated aggregate may cause moisture damage, which leads the pavement to several distresses like stripping, potholes, localized bleeding, shoving, and structural failure due to penetration of moisture into an asphalt pavement. We observed that 4% BPSC is the least susceptible to moisture damage, with a TSR of 125.62, followed by 2% with 118.9, followed by 6% with 107.08, then 8% with 11.48, and the control sample with 97.8, as shown in (Figure-3). This finding indicates that the strength of the asphalt mixes increases with increase of BPSC contents, all the values of BPSC content has seems to be suitable for surfacing of major roads by providing above 80% TSR.

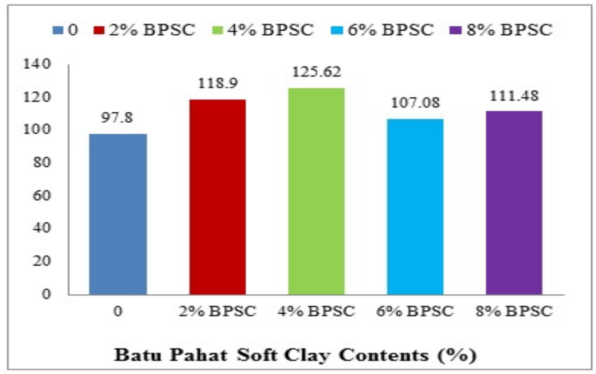

Figure-3. TSR.

Resilient Modules Test

Each column of (Figure-4) shows the percentage of BPSC content. The test was done by using two of different temperatures, i.e., 25ºC and 40ºC. The pulse repetition used in this test was at 1000 ms. The temperature of 25 ºC, that indicates the resilient stiffness modulus increased slightly with an increase in the ratio of BPSC during asphalt mixture with different values of pulse repetition, especially at 4%, which showed less susceptibility to fatigue, with a high resilient stiffness modulus of 5952 MPa when compared with the rest of the percentages of BPSC, i.e., 2%, 6%, and 8%, and gave less stiffness than 4% BPSC compared with the controlled mixture, as illustrated in (Figure-4).This finding shows that additional BPSC would improve resistance to fatigue deformation at middle temperatures compared with the controlled sample.

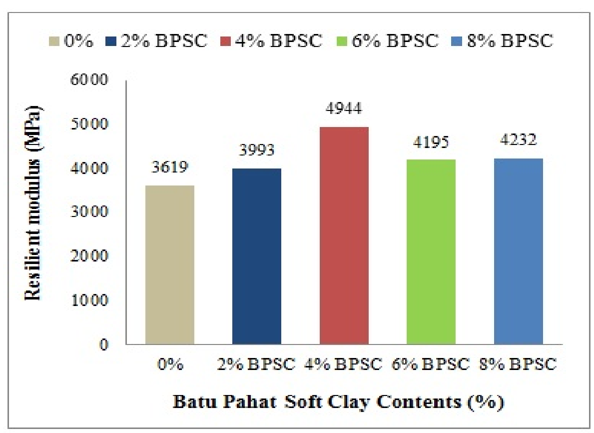

Figure-4. Resilient modulus test at 25 °C.

On the other hand, as temperature increases at 40 °C (Figure-5), stiffness reduces; thus, the addition of 4%

BPSC gave higher resilient modulus value compared with that of the controlled sample.

Considering the difference in the resilient modulus values at higher temperatures, this indicates that 4% of BPSC is less susceptible to rutting compared with the controlled mix, as illustrated in (Figure-5). At a pulse period of 1000 ms of the resilient modulus test, 4% of BPSC shows the highest resilient modulus of 1164 MPa, followed by 2%, 6%, and 8%of BPSC and the controlled sample. This study has found that the addition of 4% BPSC-modified asphalt mixtures increased compared with the controlled mixture.

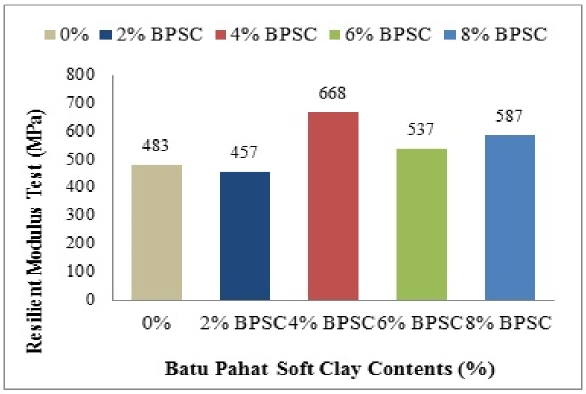

Figure-5. Resilient modulus test at 40 °C.

Dynamic Creep Test

The data from the dynamic creep test curve was obtained and plotted to illustrate the relationship between rutting (mm) and number of cycles with different percentage of BPSC, as shown in (Figure-6). The outcome of this test indicates that when BPSC was added to the asphalt mixture, beneficial results in terms of dynamic creep behavior are obtained, where the deformation of the mixture decreases, as illustrated in Figure-6, 4% of modified BPSC showed the lowest rutting value of 0.25 mm, reaching a cycle of 3600, followed by 2%, 6%, and 8% of BPSC and the mixture control. This indicates that the presence of BPSC improves resistance to rutting compared with the controlled mixes.

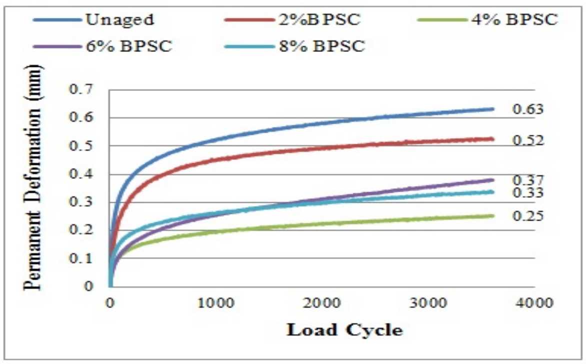

Figure-6. Dynamic creep test.

CONCLUSIONS

Based on the limited laboratory works that were done in this study, we conclude that the addition of 4% BPSC is the optimum content to enhance the performance characteristics of the HMA mixture.

Moisture susceptibility of the mixes also improves the strength of the asphalt mixes increment with the addition of BPSC particles. Moreover, the resilient modulus of mixtures that was prepared with modified BPSC bitumen is higher than the control mixture; stiffness was significantly increased at 25 °C, while it decreased at 40 °C.

In this research, we can summarize that BPSC can boost the permanent deformation (rutting) and the resistance to fatigue in asphalt mixtures. We used BPSC to evaluate the permanent deformation of asphalt mixture. The dynamic creep test was done at 40 °C and different stress levels. The rutting properties of modified BPSC were noticeably enhanced compared with the controlled mixture, and the BPSC with the 4% ratio of indicated good resistance against permanent deformation.

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