Effects of Kaolin Clay on the Mechanical Properties of Asphaltic Concrete AC14

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Abstract. This study investigated the effect of kaolin clay on the mechanical properties of asphaltic concrete AC14 through Marshall Stability, resilient modulus, and dynamic creep tests. Four replacement levels of kaolin clay (2%, 4%, 6%, and 8% by weight of the binder) were considered. Kaolin clay functioned as an effective filler replacement material to increase the mechanical properties of asphalt mixtures. Asphaltic concrete with 2% to 4% kaolin clay replacement level exhibited excellent performance with good stability, resilient modulus, and creep stiffness.

1. Introduction

Asphaltic concrete mixtures are composed of aggregates and asphalt and widely used in the surface layers of flexible road pavements [1]. Aggregates provide resistance against repeated traffic loads and asphalt adhesive action between particle aggregates; they also contribute to the viscoelastic properties of asphalt mixtures [2]. Aggregates are typically classified by their size according to the blending proportion of the aggregate mix [3]. Generally, aggregate sizes greater than 4.75 mm are categorized as gross, whereas sizes smaller than 4.75 mm are considered fine. A filler is composed of aggregate particles that are smaller than 75 μm in size [4]. The presence of a filler in an asphaltic concrete mixture is important because of possible interactions with asphalt [5]. During the mixing process, when the asphalt and aggregates are mixed, a mastic asphalt filler is formed because of the fineness of the filler. An interaction occurs between the asphalt and fillers and results in certain mastic properties, which affect the performance of mixtures [6]. Given its large surface area, a filler can absorb a large amount of asphalt, and asphalt interaction can lead to different performances of asphaltic concrete mixtures [7]. An example of a filler is kaolin clay, which is an important raw material in various industrial sectors [8]. Kaolin or China clay is white. The main constituent of kaolin is the mineral kaolinite, which is a hydrous aluminum silicate [9]. This constituent is different from industrial clays in terms of particle size and coloring [10]. Manufacturing a ton of pure kaolin generates nine tons of waste. Kaolin waste is produced after mineral extraction, processing, and purification of China clay from its ore [11]. A million tons of kaolin waste will be discarded in landfills if no treatment is applied. When such waste is dried, it turns into dust and causes air pollution. Kaolin waste can be recycled and reused [12, 13]. Partial replacement of the binder or filler by kaolin in asphaltic concrete mixtures improves mechanical properties, enhances durability [14], reduces construction costs, and ensures safe disposal of waste materials. Many studies have utilized kaolin clay as a cement replacement in concrete constructions [15, 16, 17], but relatively little information has been published about the use of kaolin clay as a filler in road constructions. Thus, investigating the effect of kaolin clay on the mechanical properties of asphaltic concrete AC14 is important.

2. Materials and Method

2.1. Aggregate and gradation

Granite aggregates were used in this study. The average density of granite is 2.75 g/cm^3 (range of 1.74 g/cm^3 to 2.80 g/cm^3), and its water absorption rates are 0.48% and 0.86% for coarse and fine aggregates, respectively. The gradation of the aggregates in this work met the requirements of median gradation of the Malaysian Public Works Department, AC14 [18], as shown in Figure 1.

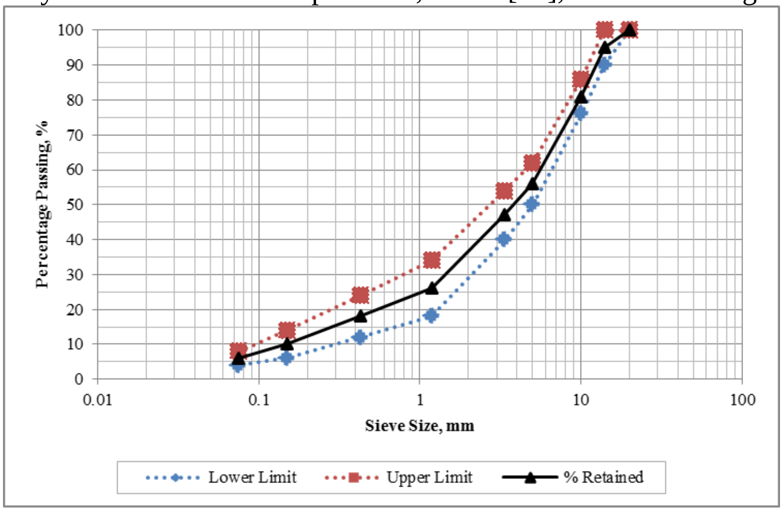

Figure 1. Aggregate gradation used in this study [18].

2.2. Bitumen

Base bitumen with a penetration grade of 60/70 was used. The penetration value, softening point, relative density, and viscosity at 135 °C of the 60/70 binder were 65 dmm, 51 °C, 1.03, and 600 cp, respectively.

2.3. Kaolin clay

Kaolin clay primarily composed of SiO_2 and Al_2O_3 (over 90%) was also used. Kaolin clay generally has a low amount of Fe_2O_3 (0.63%). Approximately 0.9% magnesium oxide, 2.5% K_2O, and 0.02% Na_2O, which are referred to as alkalis, are also present in kaolin clay. Five kaolin clay replacement levels, namely, 0%, 2%, 4%, 6%, and 8% by weight of bitumen, were considered. The control sample was designated as KC0. KC1 to KC4 consisted of 2%, 4%, 6%, and 8% kaolin clay, respectively.

2.4. Marshall stability test

Specimens were prepared at a specific temperature by immersion in a water bath at a temperature of 60 °C ± 1 °C for 45 min. The specimens were then placed in a Marshall Stability testing machine and loaded at a constant rate of deformation of 50.8 mm/min until the maximum load was reached [19]. The stability result (in kN) was recorded by the Marshall testing machine.

2.5. Resilient modulus test

A resilient modulus test can be conducted to assess the response of a pavement mix to traffic loading. This test was performed in this work by measuring indirect tensile strength under repeated loading or pulses using a universal material testing apparatus. Each specimen was tested at 25 °C and 40 °C after 4 h of conditioning, and the test procedures conformed to those stipulated in ASTM D7369 [20]. The samples were initially subjected to five condition pulses, beyond which a 1,200 N peak load was applied along the vertical diameter of the sample. The pulse period and width applied for this test were 3,000 ms and 100 ms, respectively, with 50 ms of rise time.

2.6. Dynamic creep test

The dynamic creep test was developed to estimate the rutting potential of asphalt mixtures. This test was conducted using an asphalt universal testing machine in accordance with the procedures outlined in BS EN 12697:26 [21]. The actual dynamic creep test was conducted at 40 °C, with 1 h of loading time and 0.1 MPa of applied stress.

3. Results and Discussion

3.1. Stability and stiffness

Figure 2 shows the stability and stiffness of the asphaltic concrete containing kaolin clay at different replacement levels. Three specimens were tested for each kaolin clay content, and the average stability and stiffness were determined. The test results indicated that the stability and stiffness of asphaltic concrete incorporated with kaolin clay were higher than those of the controlled mixtures. The stability and stiffness values of the asphaltic concrete increased significantly with increasing kaolin clay content up to a certain level and then decreased with further addition of kaolin clay. The increase in stability and stiffness due to the reaction of carbon and hydrogen in bitumen [8] involved one or more elements, such as sulfur, oxygen, and nitrogen [22] with silicon dioxide and aluminum oxide in kaolin clay [9]. The highest stability and stiffness values were obtained using 2% kaolin clay, and these stability and stiffness values were 18.2% and 13.7% higher than those of the controlled specimens, respectively. However, a significant decrease in stability and stiffness levels occurred when the replacement level was increased from 4% to 8%. An optimum replacement percentage of approximately 2% was observed, and stability and stiffness increased beyond this percentage.

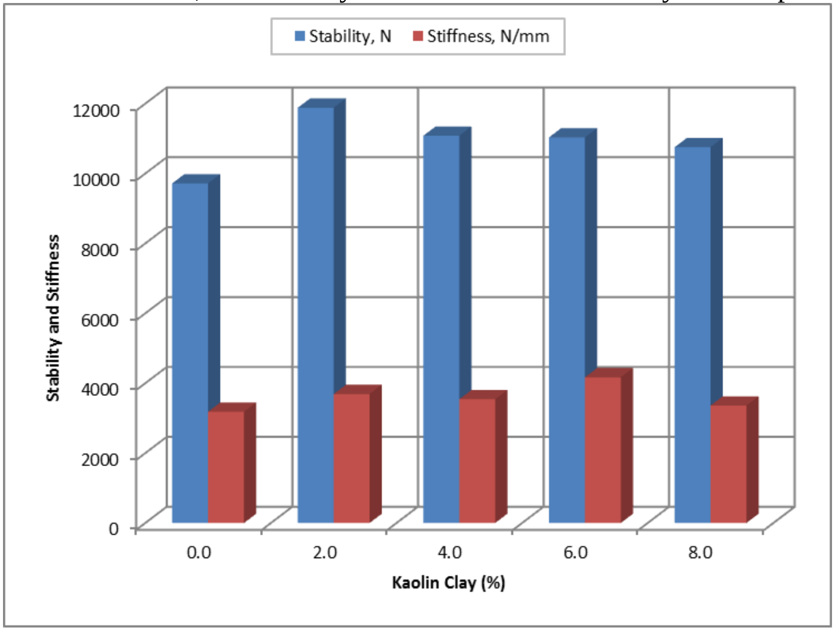

Figure 2. Stability and stiffness at varying kaolin clay contents.

3.2. Stability and weight loss

Figure 3 presents a graphical illustration of the relationship between stability and weight loss. The plotted readings show that stability and weight loss increased when the kaolin clay content increased. For instance, stability and weight loss increased when 0% to 2% kaolin clay content was used. However, the values decreased from 11,083 N to 10,753 N (stability) and 1.2% to 1.0% (weight loss) when 4% to 8% kaolin clay was used for testing. The increase in weight loss was caused by the filling up of pores by the expansive reaction products, thereby densifying the hardened asphaltic concrete [23]. However, when the added kaolin clay content was increased from 4% to 6%, a significant decrease in stability and weight loss was observed. On the contrary, stability and weight loss increased significantly with 8% kaolin clay.

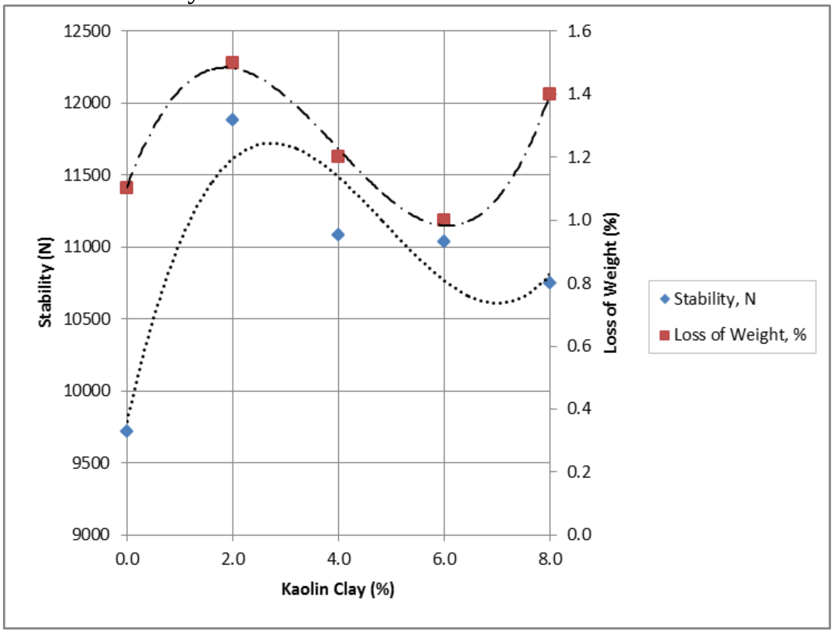

Figure 3. Stability and weight loss at varying kaolin clay contents.

3.3. Resilient modulus

Figure 4 shows the results of the resilient modulus test for mixtures prepared at varying kaolin clay contents. Each value is the average reading of two samples. A distinct peak was observed, beyond which further replacement by kaolin clay caused a decrease in modulus. A resilient modulus of 6,775 to 7,090 MPa was achieved when the kaolin clay content was increased from 0% to 4%. However, when the kaolin clay content was increased from 6% to 8%, a significant drop in resilient modulus occurred. We conclude that the optimum kaolin clay content is approximately 4%, beyond which the resilient modulus value increases. The figure also shows that an increase in the 2% interval of kaolin clay caused a general increase in resilient modulus. Furthermore, asphalt concrete was obtained when the percentage of kaolin clay replacement of the conventional binder did not exceed 2% to 4%. Specimens that exhibited a high resilient modulus presented minimal flexibility under loading. The results also showed that increasing the temperature reduced the resilient modulus of the asphalt mixtures. The resilient modulus of the specimens decreased by approximately 80.25% to 80.18% when the test temperature increased from 25 °C to 40 °C. The high resilient modulus of the asphaltic concrete incorporated with kaolin clay at 25 °C indicated that these mixtures had a higher probability of cracking at 25 °C than at 40 °C. Oluwasola et al. [24] and Mahmud et al. [25] found that asphalt concrete incorporated with steel slag and cubical aggregate exhibits a high probability of cracking at test temperatures of 10 °C, 25 °C, and 40 °C.

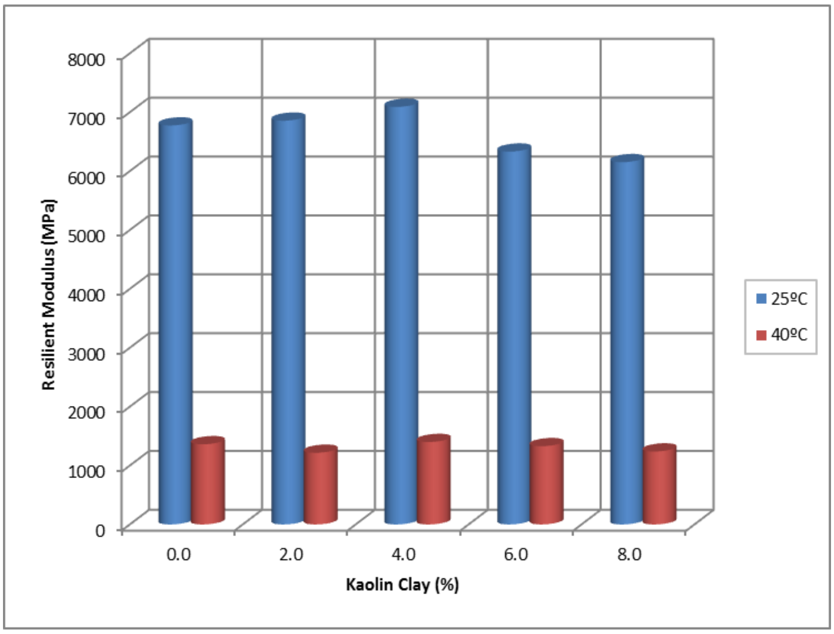

Figure 4. Modulus stiffness at varying kaolin clay contents.

3.4. Dynamic creep

Figure 5 shows the typical creep stiffness values of the asphalt concrete mixtures containing kaolin clay obtained from this study. The average dynamic creep test results indicated that a positive relation existed between creep stiffness and kaolin clay content. The asphaltic concrete mixtures prepared with kaolin clay had a higher creep value than those prepared with a conventional binder. For example, the maximum value of creep stiffness was 18.4 MPa at 0% kaolin clay. However, the dynamic creep increased to approximately 23.6 MPa when kaolin clay replacement increased up to 2%. A difference of more than 28.26% in terms of creep stiffness was observed. Meanwhile, kaolin clay at 4% replacement showed the highest dynamic creep, which was 32.3 MPa and almost twice that of the controlled specimen. Creep stiffness generally increased with increasing kaolin clay content up to a peak level and then decreased with further addition. The incorporation of kaolin clay as a filler increased the capability of the asphalt mixtures to reduce rutting and permanent deformation.

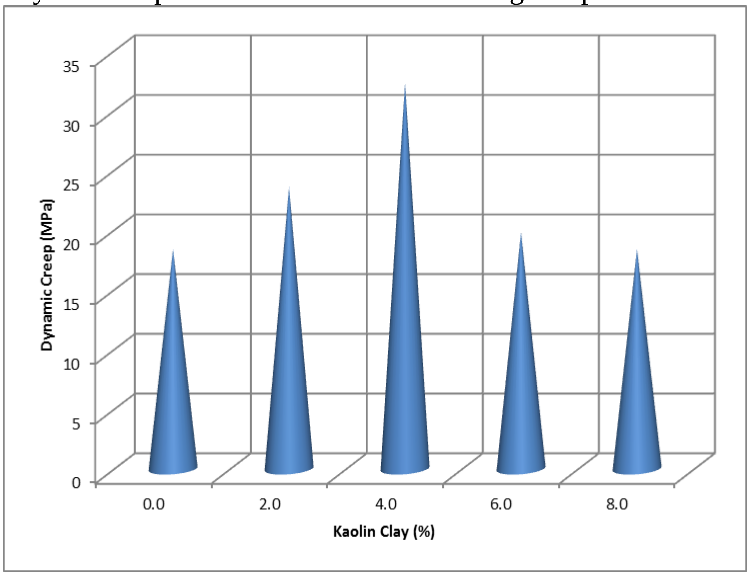

Figure 5. Creep stiffness at different kaolin clay contents.

4. Conclusion

The optimum kaolin clay replacement level was determined. Using 2% to 4% kaolin clay resulted in good stability, resilient modulus, and creep stiffness in comparison with other kaolin clay specimens. The KC1 asphaltic concrete specimen exhibited the highest stability and stiffness among all specimens. The KC2 of asphaltic concrete was the optimal limit for resilient modulus and dynamic creep.

Acknowledgments

The present study was supported by the Ministry of Higher Education Malaysia (MOHE), Fundamental Research Grant Scheme (number 1458) from Universiti Tun Hussein Onn Malaysia, and Universiti Teknologi Malaysia (grant numbers Q.J130000.2522.18H05 and Q.J130000.2522.11H76). The financial assistance for this study is highly appreciated.

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