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Performance of Kaolin Clay on Hot-mix Asphalt Properties

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Performance of Kaolin Clay on Hot-mix Asphalt Properties

M K I Mohd Satar[1], R P Jaya[1,2], M H Rafsanjani[1], N Che` Mat[1], M R Hainin[1], Md. M A Aziz[1], M E Abdullah[3], D S Jayanti[4]

[1]Faculty of Civil Engineering, Department of Geotechnics and Transportation, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia
[2]Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[3]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor Bahru, Malaysia
[4]Faculty of Agricultural, Syiah Kuala of University, 23111 Banda Aceh, Indonesia

E-mail: ramadhansyah@utm.my

Abstract. Kaolin clay is a waste product with numerous applications in construction. This study explored the addition effect of kaolin clay on the properties of hot-mix asphalt. Four replacement levels of kaolin clay were considered by weight of binder, i.e., 2%, 4%, 6%, and 8%. The performance of kaolin clay on the hot-mix asphalt was evaluated through a Marshall stability and flow test, including stiffness, density, voids in total mix, and voids in filled with asphalt. Test results showed that kaolin clay can be satisfactorily used as filler replacement material to increase the asphalt mixture properties. Generally, asphaltic concrete with 2% kaolin clay replacement level exhibits excellent performance with good stability and stiffness.

1. Introduction

Road damage is one of the main problems faced by road users and can be the cause of an accident. An increase in traffic capacity can damage a new road after just a few years. Road damage is due to the deformation of the road. The deformation can either be permanent or temporary. Rutting, a permanent deformation, comprises the majority of deformations that occur on roads nowadays [1]. Various studies have been conducted to ensure asphalt concrete can be used for a long time [2]. As an alternative material, asphalt concrete mixture has been modified using a variety of natural resources to strengthen asphaltic concrete pavement [3]. For instance, the presence of a filler in the asphaltic concrete mixture is important because of the possible interactions with asphalt [4]. During the process of mixing the asphalt and the aggregate together, the mastic asphalt filler forms because of the fineness of the filler [5]. The interaction between the asphalt and the fillers result in certain mastic properties [6], thereby affecting the performance of the mixture [7]. Owing to the increased surface area, the filler can absorb more asphalt, and asphalt interaction can lead to a different performance of the asphaltic concrete mixtures [8]. One common filler is kaolin clay [9], which is an important raw material in various industrial sectors. Kaolin is clay that is composed of kaolin stone. Kaolin clay is one of the main minerals in the world and one of the most widely used minerals [10]. It is mainly

[1] To whom any correspondence should be addressed.

formed after kaolin stone is completely weathered and rain washed [11]. Pure kaolin is soft, easy to disperse suspended in water, has high whiteness, good plasticity and cohesiveness, excellent electrical insulation, good acid soluble cationic, low resistance, physical properties, and improved exchange with other chemicals [12]. In the current study, the potential of kaolin clay as a binder replacement in asphalt mixture was investigated.

2. Materials and Method

2.1. Aggregate

The local natural aggregates from granite used in this investigation are nearly always massive and hard. The coarse and fine aggregates indicated a specific gravity of 2.66 g/cm^3, and water absorption rates were 0.48% and 0.86%, respectively. A gradation test (Figure 1) was conducted following the procedure outlined in BS EN 933-1:2012 [13] and JKR/SPJ/2008-S4 [14].

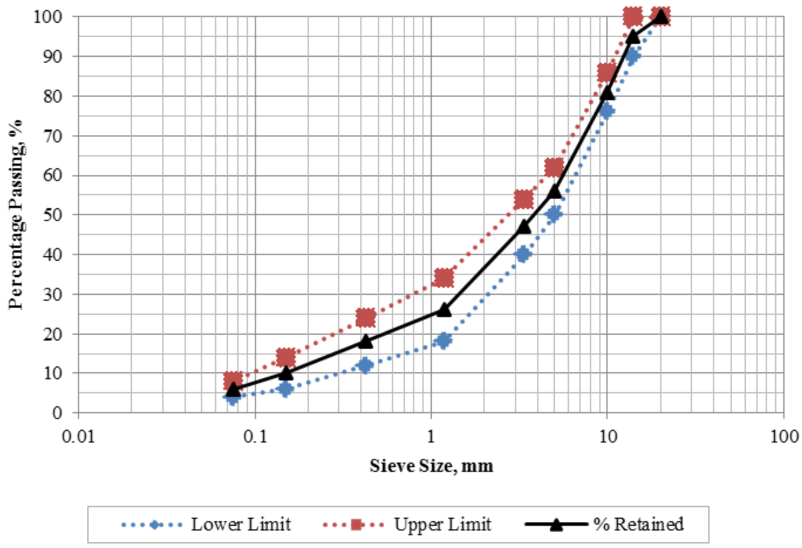

Figure 1. Aggregate gradation used in this study [14]

2.2. Bitumen

Bitumen 60/70 penetration grade was used in this study. The bitumen properties according to a laboratory test were 65 dmm penetration, 51 °C softening point, 1.03 relative density, and 600 cp viscosity at 135 °C.

2.3. Kaolin clay

This study used kaolin clay primarily composed of SiO_2 and Al_2O_3 (over 90%). In general, kaolin clay has a low amount of Fe_2O_3 (0.63%) and about 0.9% of MgO. K_2O (2.5%) and Na_2O (0.02%), which are referred to as alkalis, are also found in kaolin clay. In this investigation, five replacement levels of kaolin clay by weight of bitumen were considered namely 0%, 2%, 4%, 6%, and 8%. The control sample (0%) was designated as KC0, while the 2%, 4%, 6%, and 8% levels were designated respectively as KC1, KC2, KC3, and KC4.

2.4. Sample preparation

Bitumen was heated in the oven until fluid condition was reached, and then prepared kaolin clay was added gradually to the bitumen and blended for three to five minutes. Mixing was continued for a specific duration to produce a homogenous mixture. Three specimens were prepared for each percentage of kaolin clay. After the specimens were compacted using a Marshall hammer, they were tested for stability, flow, density, stiffness, voids in total mix (VTM), and voids in filled with asphalt (VFA).

2.5. Marshall Stability test

In the laboratory, the aggregate, binder, and plastic were individually mixed and compacted at 180±0.5 °C. The mixes were compacted with 75 blows on each side with the standard Marshall hammer to avoid disintegration of materials. After compaction, the specimens were removed from the molds and allowed to cool down. The stability value of each test specimen was then determined in accordance with BS EN 12697-34:2012 [15]. In the stability test, the specimens were prepared with the specified temperature by immersing in a water bath at 60±1 °C for 45 minutes. Next, they were placed in the Marshall Stability testing machine and loaded at a constant deformation rate of 50.8 mm/minute until the maximum load was reached.

3. Results and Discussion

3.1. Stability and Flow

Figure 2 graphically presents the results of the stability and flow test on asphaltic concrete containing kaolin clay. Stability is shown to increase with increasing kaolin clay content up to 2% and then decrease with further additions. The increase in stability may be attributed to the reaction of carbon and hydrogen [6], as well as that of one or more of the elements sulfur, oxygen, and nitrogen [16] with silicon dioxide and aluminium oxide [9]. The results also indicate that stability is sensitive toward variances in kaolin clay content. High percentages of kaolin clay have a decreasing net effect on mix stability. The stability drops from 11,884 N to 10,753 N as the kaolin clay replacement increases from 2% to 8%. The control specimen produced low stability compared with KC1, KC2, KC3, and KC4. However, when the kaolin clay replacement levels are compared, the 2% KC asphalt mixture exhibited the highest stability. High stability values indicate stiff and resistant mixtures. Thus, 2% replacement of KC is considered the optimal limit. The differential movement between initial and maximum loading is also recorded as the flow. The results shown in Fig. 2 indicate that flow for the corresponding kaolin clay content initially increased between 0% to 2% and then started to decrease until 6% KC was reached. Generally, the flow value of KC0 was 3.05 mm, while the 2%, 4%, 6%, and 8% KC replacement levels had corresponding flow values of 3.22, 3.13, 2.65, and 3.20 mm, respectively. Hence, the flows of all the specimens are in the range recommended by the local specification JKR [14] and the Asphalt Institute [17].

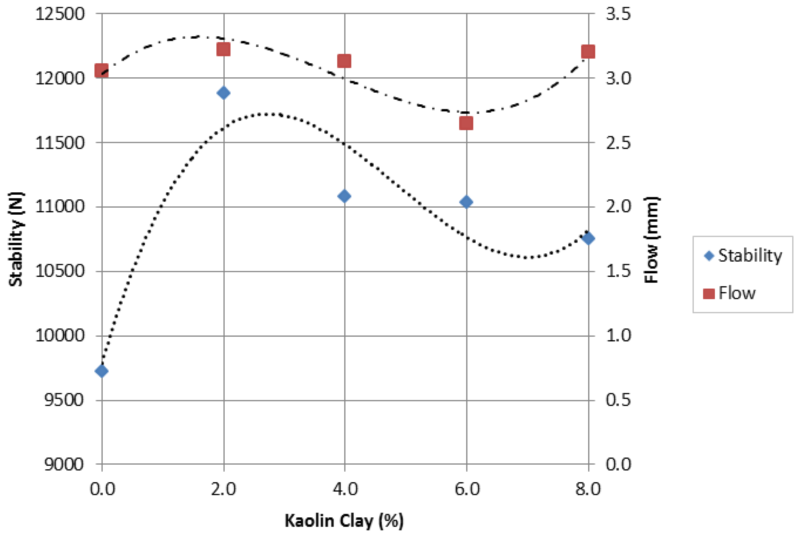

Figure 2. Stability and flow at varying kaolin clay content

3.2. Stability and Density

Figure 3 graphically illustrates the relationship between stability and density of asphaltic concrete at different levels of kaolin clay content. The plotted readings show that the stability and density values increase up to a peak level and then decrease with further additions. However, the rate of increase in stability and density with respect to the kaolin clay content of all the mixes is higher than the control mix because the fine kaolin clay particles help form a denser asphalt mix and increase stability and density. For instance, the maximum density of KC0 was 2.283 Mg/cu.m, which was lower than the maximum density values of KC1, KC2, KC3, and KC4. Hence, a 2% increase in kaolin clay content can cause a 1.2% increase in density. Among all kaolin clay replacements investigated, the KC2 mixes recorded the highest mix density, followed by KC1, KC3, and KC4. For stability, the maximum value recorded was for KC1, followed by KC2, KC3, and KC4.

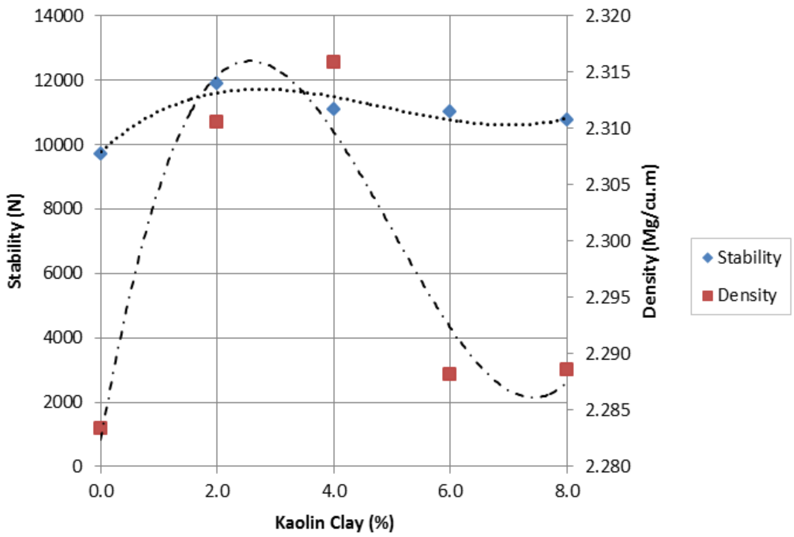

Figure 3. Stability and density at varying kaolin clay content

3.3. Stiffness and Density

Figure 4 graphically illustrates the relationship between the stiffness and density of asphaltic concrete incorporating kaolin clay. The results are the average of three specimens prepared in optimum bitumen content (OBC). They show that the stiffness and density of the asphalt mixture increases with increasing kaolin clay content up to a peak level and then decreases with further additions. The rate of increase in stiffness with respect to the kaolin clay content of the asphalt concrete mix is higher than the control mix. This outcome may be due to kaolin clay being an active filler that improves the stiffness properties of asphalt mixture. For instance, the maximum stiffness for KC1 is 3690 N/mm, while KC0 exhibits a maximum stiffness of 3183 N/mm, which means the addition of 2% kaolin clay to the asphalt mix can increase stiffness by up to 13.7%. Another example is when kaolin clay content increases from 4% to 6%, the maximum stiffness increases from 3540 N/mm to 4169 N/mm and then starts to decrease at 8% replacement.

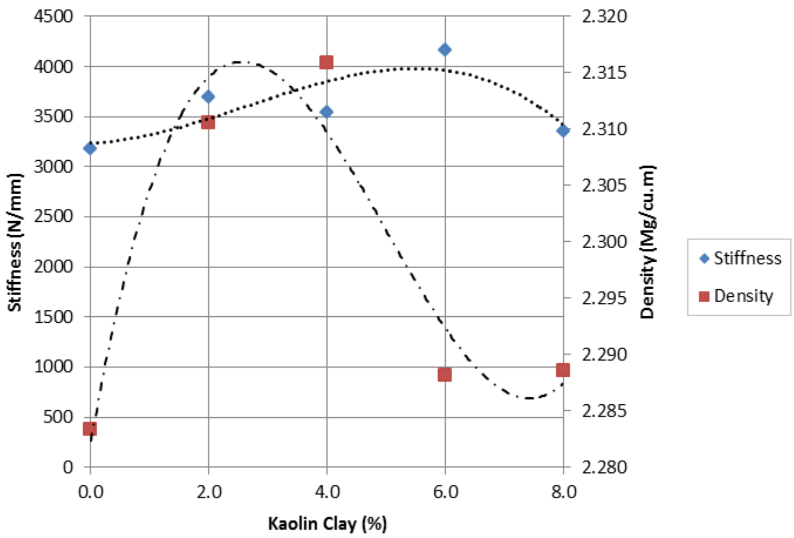

Figure 4. Stiffness and density at varying kaolin clay content

3.4. Voids in total mix

Figure 5 presents the effects of kaolin clay on asphaltic concrete. Generally, VTM decreases gradually with the decrease of kaolin clay up to 4% and then increases with further additions. The results clearly show that KC3 exhibits higher VTM than KC0, KC1, KC2, and KC4. Mixes with low VTM inhibits high susceptibility toward rutting [18,19]. Hence, asphaltic concrete incorporating kaolin clay significantly affects the performance of a mixture because of low void content. For instance, at 0% KC, the VTM is 4.5%, while at 2%, 4%, 6%, and 8% KC, the corresponding VTM are 3.5%, 3.1%, 4.7%, and 4.5%, respectively. However, at all VTM investigated, KC2 mixes record the lowest VTM. VTM is the total volume of small pockets of air between the coated aggregate particles throughout a compacted paving mixture. According to the JKR specification [14], VTM should range from 3% to 5%. Therefore, the VTM values of all specimens are in the range recommended by the JKR specification [14].

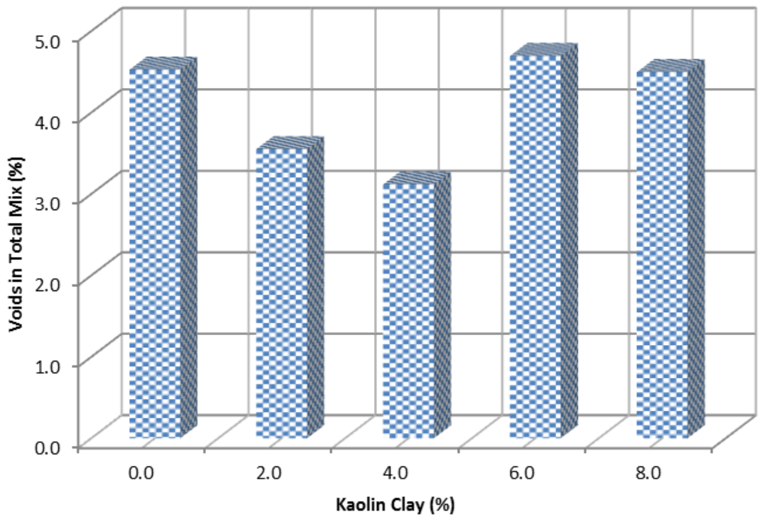

Figure 5. VTM at different kaolin clay content

3.5. Voids in filled with asphalt

From the investigation results shown in Figure 6, the VFA increases as the percentage of kaolin clay increases up to 4% and then decreases with further additions. This phenomenon is due to the constant optimum bitumen content used in mixes for all the percentages of kaolin clay. The results also revealed that the control specimen has the lowest VFA value. VFA is the percentage of the volume of VMA that is filled with asphalt. The control specimen (0% KC mix) exhibits the lowest VFB, followed by 2%, 4%, 6%, and 8%. Samat [20] and Jeffry et al. [21] reported that when the VFA exceeds approximately 80% to 85%, the dense mix becomes unstable and rutting is likely to occur. Hence, the VFB values are within 76% to 84%. According to the JKR specification [14], the VFB of the dense mix should range from 75% to 85%, which can be achieved by incorporating 3.0% to 5.0% bitumen content. However, the local specification does not state the limiting values for replacing or adding the main binder with other materials.

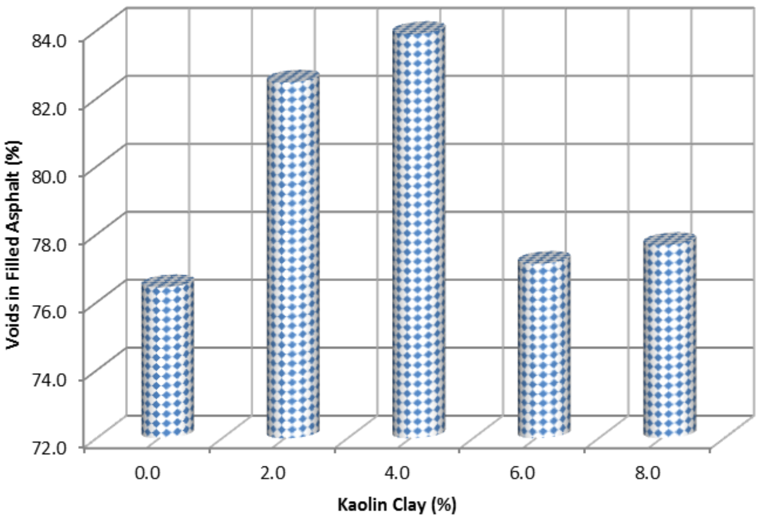

Figure 6. VFA at different kaolin clay content

4. Conclusions

The obtained data suggest that kaolin clay as filler replacement effectively improves the properties of asphaltic concrete. The low replacement level of kaolin clay has an advantageous effect in improving stability and stiffness. Results also indicate that the addition of kaolin clay in asphalt mixtures provides additional improvements in VTM and VFA. Finally, the use of 2% kaolin clay results in the good performance of asphalt mixtures.

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