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Effect of compaction temperature on the performance of dense-graded asphalt mixture

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Abstract. Compaction temperature is an important parameter that determines the volumetric properties of the compacted asphalt pavement. Using an improper compaction temperature can cause problems on the dense-graded asphalt mixture performance. If the compaction temperature is less than the desirable temperature, it can potentially reduce the density and increase the air voids, thus reduce the pavement strength. This study investigates the effect of compaction temperature on the performance of dense-graded mixture. The samples were prepared by mixing 60/70 pen bitumen and granite aggregates using Marshall mix design method. The samples were compacted using Marshall compactor at various temperatures. The compacted samples were then evaluated for volumetric properties and tested for Marshall stability, resilient modulus and dynamic creep. Based on the results, it was found that the variation of the temperature affects the volumetric properties. On the other hand, the reduction in temperature reduces the stability, resilient modulus and creep performance.

1. Introduction

Hot Mix Asphalt (HMA) pavement in Malaysia is designed to support the traffic load for 10 to 20 years. However, these roads are not able to carry the load within the specified design life due to severe pavement damage and major road maintenance works that cost millions. Primary modes of distress such as moisture damage and permanent deformation are always related to pavement performances [1]. Improper road works practices have been identified as main causes of poor performance of asphalt pavements, particularly for dense-graded mixture. The selection of poor quality material may affect the overall performance of the pavement including stiffness, stability, durability, workability, fatigue resistance, frictional resistance and resistance to moisture damage [2]. Other than the materials, the compaction is also one of the major issues in dense-graded mixture production and an important criterion in producing a good quality of asphalt pavement. This is because a proper compaction temperature will produce better aggregates coating or workability which aid in achieving well performed pavement [3]. In addition, compaction temperature affects the level of aging and influence the mixture structure and density [4]. Hadley et al. [5] conducted an extensive laboratory study to investigate the factors that influence tensile properties of asphalt mixtures and found that compaction temperatures influence the tensile behavior. Compaction works below the standard temperature could

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increase the bitumen's viscosity, thus resist compaction effort. According to Superpave mix design, the asphalt mix is compacted at the temperature corresponding to viscosity of 0.28 Pa.s. This is to provide adequate lubrication for the aggregates for better volumetric properties [6]. The failure to provide the desired compaction temperature will lead to the loss of adhesion bonding between aggregates and asphalt in conjunction with degradation of the aggregates [7]. On the other hand, the volumetric properties of a compacted asphalt mixture provide an indication of the quality of the asphalt pavement. Hassan [8] found that an increase in the compaction temperature from 70℃ to 100℃ has significantly decreased the Voids in Total Mix (VTM) and Voids in Mineral Aggregates (VMA). This has been agreed by Gao et al. [9], who stated that the height of samples and air voids content of dense-graded asphalt mixtures increase significantly when the compaction temperature is lower than 85℃. This is important because the pavement fatigue life will be decreased and increase the permeability if high air voids are detected [10]. In addition, the compaction temperature also affects the stability and stiffness of the asphalt in providing resistance against deformation from the imposed loads [11]. According to Hassan [8], as the compaction temperature decreases from 140 to 110°C, the stability values slightly decrease. However, further reduction in the temperature from 110 to 70°C has considerably reduced the stability with major deformation. On the performance of asphalt mixture, compaction temperature gives a significant effect on resilient modulus [12]. The resilient modulus strength was enhanced at low compaction temperature, as expressed by Bakar [13] but this finding was contradicted by Hurley and Prowell [14] if additive is added in asphalt mixture production. These findings show the importance of understanding the relationship between the compaction temperature and asphalt pavement properties. Therefore, this study is necessary to better understand the behaviour of dense-graded asphalt mixture under different compaction temperatures.

2. Experimental

2.1. Materials

The materials used were granite aggregates and 60/70 pen bitumen as a binder. Crushed granite aggregates were combined in accordance to the gradation limits of Asphaltic Concrete with nominal maximum aggregate size of 14 mm (AC14) as stated in the Malaysian Public Works Department (PWD) [15]. Tables 1 and 2 show the physical properties of the 60/70 pen bitumen and granite aggregate used in this study, respectively. Figure 1 shows the gradation limits for AC14 as specified in the PWD specification for road works.

Table 1. Physical properties of 60/70 pen bitumen.

Properties	Test Standard	Requirement [18]	Result
Penetration at 25ºC (dmm)	ASTM D5	60-70	60.4
Softening point (˚C)	ASTM D36	49-52˚C	43˚C
Viscosity at 135˚C (Pa.s)	ASTM D4402	3.0 (Max)	0.5
Specific gravity	ASTM D70	-	1.030

Table 2. Properties of granite aggregate.

Test	Standard	Requirement [11]	Result
Los Angeles Abrasion	ASTM C131	< 25%	23%
Polish Stone Value	BS 812-114	>40	53
Flakiness	BS 812-105	< 25%	19%
Soundness	ASTM C88	<18%	6.8%
Water Absorption	ASTM C127	<2%	0.9%

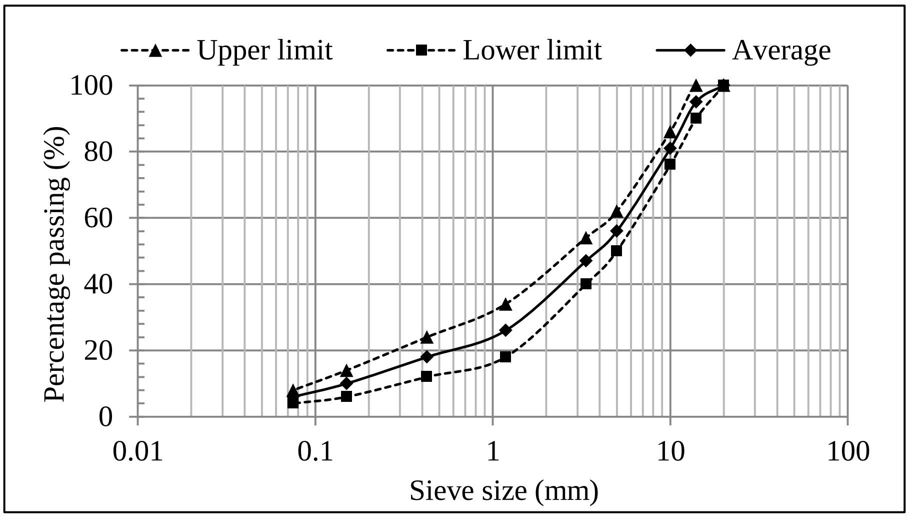

Figure 1. AC14 aggregates gradation.

2.2. Marshall mix design and laboratory performance test

The dense-graded asphalt mixture samples were prepared by mixing the granite aggregates and bitumen 60/70 pen at temperature of 163°C with 4.9% bitumen content. The samples were compacted using Marshall compactor at various temperatures i.e. 80°C, 90°C, 100°C, 110°C, 120°C, 130°C, 140°C, 150°C for 75 blows. The compacted samples were then measured for volumetric properties, Marshall stability, flow and stiffness as standardized by the American Society for Testing Materials (ASTM). In addition, the compacted samples were also tested for performance in terms of resilient modulus and creep. Resilient modulus test was conducted to determine the elastic properties of asphalt mixture at the temperatures of 25°C and 40°C in compliance to ASTM D4123. The dynamic creep test assessed the permanent deformation characteristics of dense asphalt mixture at 40°C as stated in BS EN12697-25.

3. Results and discussion

3.1. Volumetric properties

Figure 2 shows the plot of density, VTM, VFB and VMA of the asphalt mixture against the compaction temperature. The increase in compaction temperature has increased the density of the mix. This can be related to the low viscosity of the bitumen at high temperature, where the asphalt mixture becomes more workable and the mixture can be easily compacted to achieve the target density. As the compaction temperature increased from 80°C to 120°C, the percentage of VTM sharply decreased. The percentage of VTM is 9.6% when compacted at 80°C and reduced to 6.1% at 120°C, while these values slightly decrease as the compaction temperature increased more than 120°C. The increase in workability during compaction resulted in less air voids. Thus, the mixture compacted at higher temperature become denser compared to those compacted at lower temperature. On the other hand, the percentage of VFB is 52.4% at 80°C and increase to 94.4% at 140°C, while the value slightly decreases as the compaction temperature increased to 150°C. Even though at 150 °C the VFB is slightly decreased, the trend is still increasing as the compaction temperature increases. One possible reason as is that it can be quite difficult to control the exact temperature during the laboratory compaction. Higher compaction temperature has caused the bitumen to disperse effectively and coat the aggregate particles that result in increasing of VFB. It can also be seen that the increase in compaction temperature decreases the VMA percentage. This property is related to the voids in total mix (VTM) as higher compaction temperature will provide better compaction to reduce the voids within the mix, thus reducing the VMA that covers the spaces between aggregate particles.

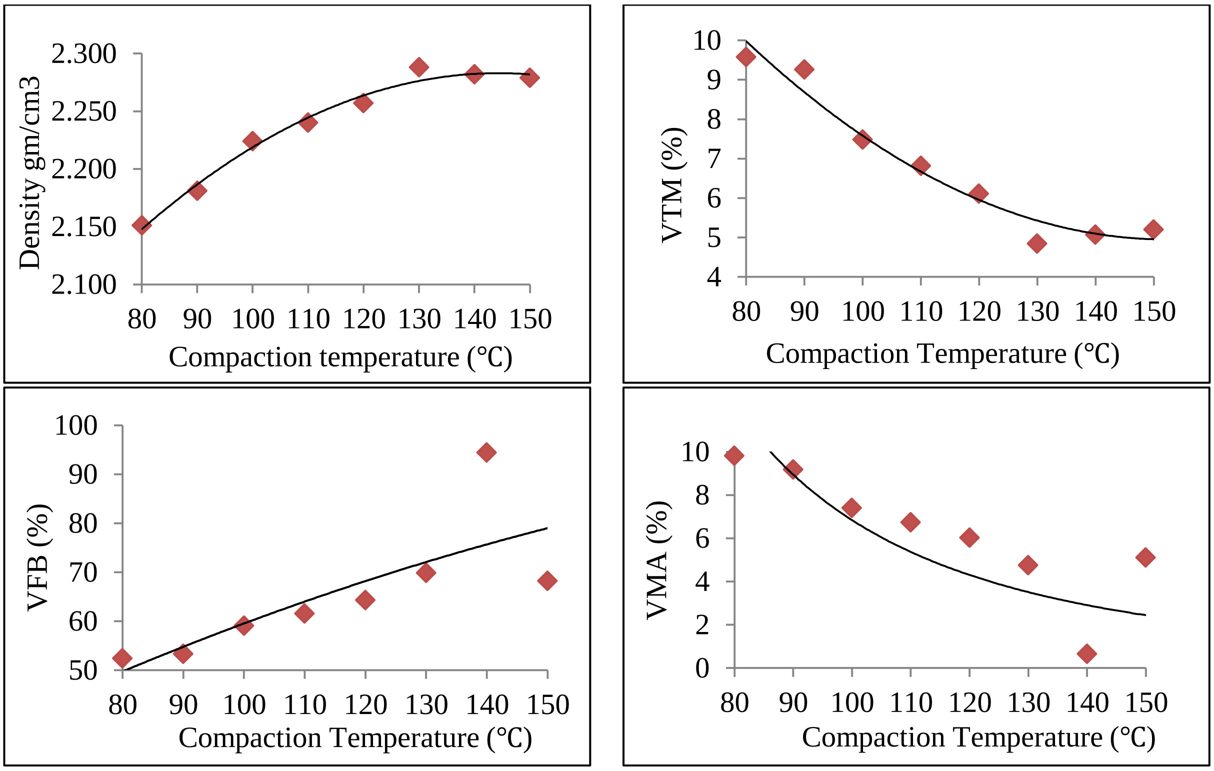

Figure 2. Volumetric properties of dense-graded asphalt mixture with various compaction temperatures.

3.2. Marshall stability, flow and stiffness

Figure 3 shows the Marshall stability, flow and stiffness of dense-graded asphalt mixture with different compaction temperatures. Marshall stability is an indicator of the resistance against the deformation of the asphalt mixture. The stability increases with the increase in compaction temperature from 110°C to 150°C, which satisfies the PWD specification of greater than 8000N. This is because, at higher temperature, the lubrication of the aggregate particle is better due to the high bitumen viscosity which can cause a better interlocking of the aggregate particles during compaction. The flow value fluctuates with the compaction temperature. However, according to PWD, the recommended flow of AC14 is between 2 and 4 mm. Therefore, the results are in compliance with the specification. On the other hand, according to Hassan [8], as the compaction temperature decreases, the flow value increases. Based on the aforementioned results on air voids, high air voids content is observed at lower compaction temperature due to resistance against compaction. This may cause greater densification under loading compared to samples with low voids content, resulting in deformation of the samples. In addition, the stiffness of the mixture also increases as the compaction temperature increased. The Marshall stiffness value at the compaction temperature of 80°C and 90°C are 1821.5 N/mm and 1931.8 N/mm, respectively, which fail to comply to the PWD requirement. However, the stiffness value for the compaction temperature from 100°C to 150°C is found to fulfill the specification as it exceeds 2000N/mm.

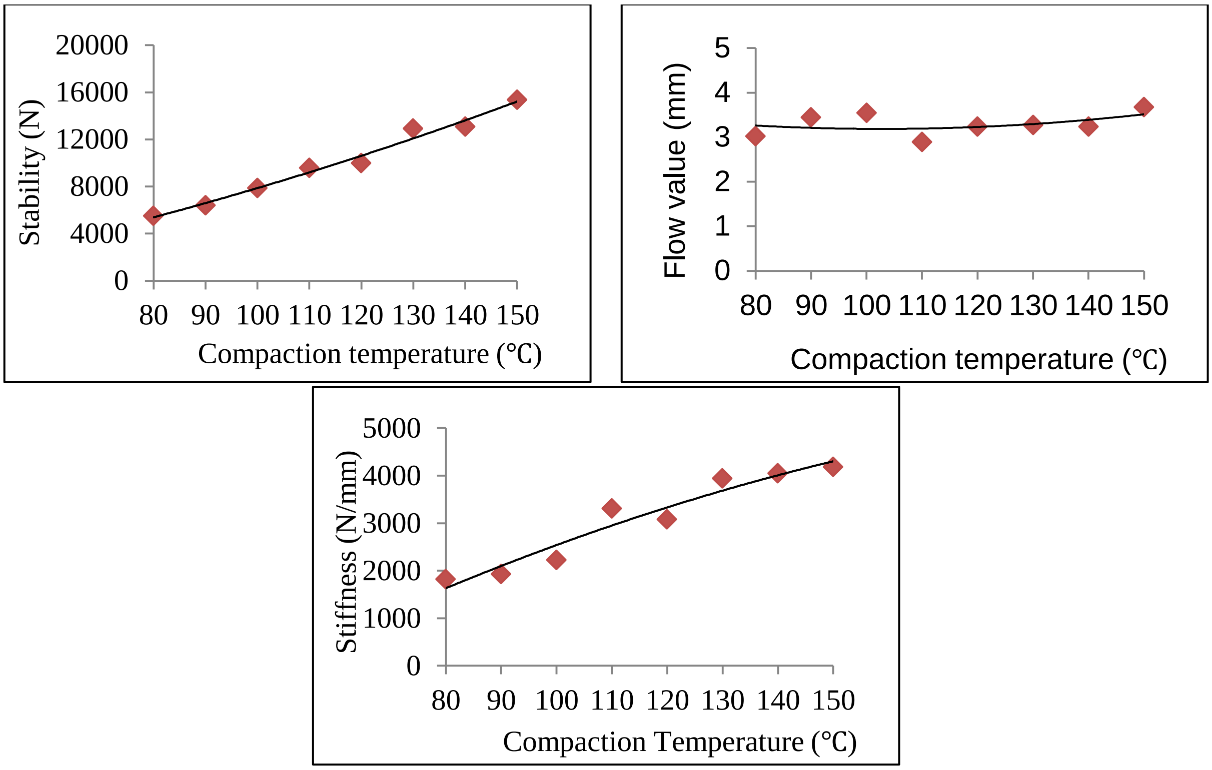

Figure 3. Marshall stability, flow and stiffness versus compaction temperatures.

3.3. Resilient modulus

Figure 4 shows the result of resilient modulus at different compaction temperature. Generally, the resilient modulus of the samples tested at 25°C is found higher compared to samples tested at 40°C. When tested at 25°C conditioning, the resilient modulus increases with the increase in the compaction temperature. The values observed are more than 2000 MPa. However, there is a slight decrease in the modulus for the sample compacted at 150°C compared to 140°C with the values of 3388.2 MPa and 3469.7 MPa, respectively. On the other hand, the resilient modulus of the samples conditioned at 40°C slightly fluctuates but comparable as the compaction temperature increases. This is because the samples conditioned at 40°C are more sensitive due to the decrease in the viscosity of the bitumen, which thus reduces its modulus. Therefore, not much difference can be observed in the resilient modulus tested at 40°C with all the recorded values greater than 600 MPa.

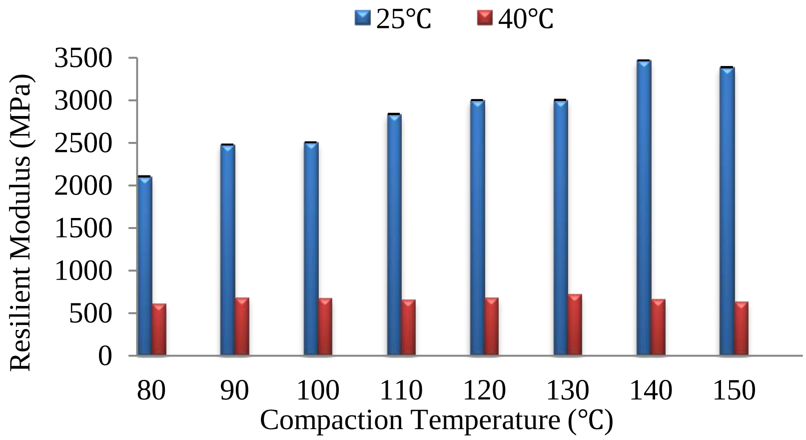

Figure 4. Graph of Resilient Modulus versus compaction temperature.

3.4. Dynamic creep

Figure 5 shows the creep strain slope (CSS) versus compaction temperature. From the graph, it can be seen that as the compaction temperature increases, the CSS decreases. Samples with less CSS have better rutting resistance compared to those with high CSS which can be obtained for samples compacted at high temperature. This is due to the strain of the mixture; the lower the compaction temperature, the higher the strain value results in high CSS. In addition, the creep performance for compaction temperature of 80℃ and 90℃ was poor compared to 100℃ to 150℃. This is because the sample failed earlier than expected before achieving the target 3600 cycles.

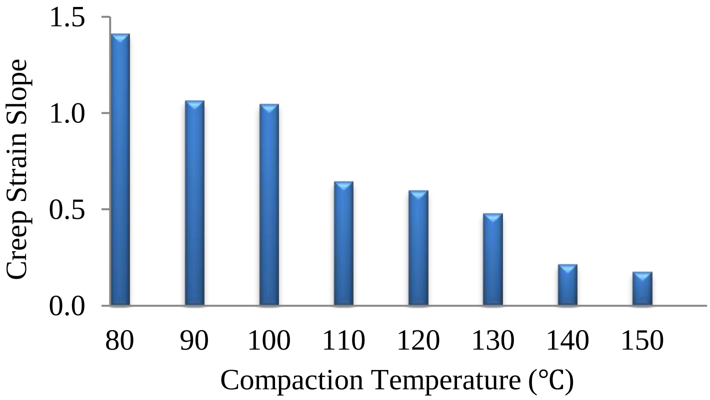

Figure 5. Graph of Creep Strain Slope versus Compaction Temperature.

On the other hand, figure 6 shows the plot of creep stiffness modulus (CSM) at various compaction temperatures. Based on the results, the CSM increases as the compaction temperature increases. The CSM is slightly increased from7.5 MPa to 12.7 MPa as the compaction temperature increased from 80℃ to 100℃. Then the CSM is sharply increased up to 252.7 MPa as the compaction temperature increased to 150℃. This clearly shows that the increase in compaction temperature has caused the mix to become denser and stiffer, thus providing better resistance against deformation.

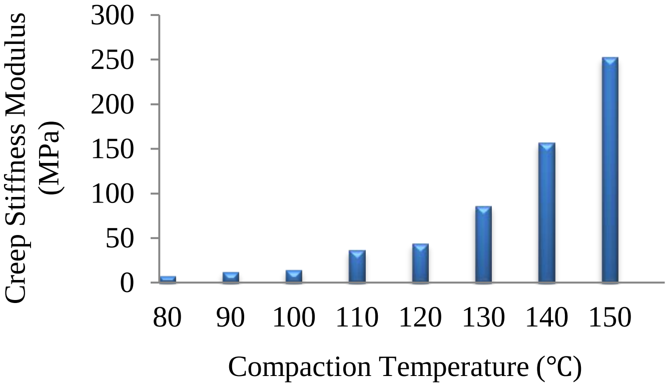

Figure 6. Graph of Creep Stiffness Modulus versus Compaction Temperature.

4. Conclusions

This study investigates the effect of compaction temperature on the performance of dense-graded asphalt mixture. From the results, it can be concluded that different compaction temperatures affect the volumetric properties of dense-graded asphalt mixture. This can be seen from the percentage of VTM and VMA that increased, while percentage of VFB decreased with the increase in compaction temperature. In addition, the increase in compaction temperature has also increased the density of the mix, Marshall Stability, resilient modulus and creep modulus which describe the better performance of dense-graded asphalt mixture. Overall, the dense-graded asphalt mixture should be compacted at the minimum temperature of 110℃ in order to comply with the properties as specified in the specification by PWD.

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