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The Influence of Basalt Aggregate on The Mechanical Performance of Hot Mix Asphalt (HMA) Mixtures

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ABSTRACT

The capacity of the pavement's load path structure, stiffness, and strength to handle an increase in traffic load over time decreased. The rutting influence has emerged as one of the most serious failures in recent years, along with the rise in large traffic volume on roads, particularly in tropical settings. To increase the resilience and long-term performance of asphalt mixes in dynamic situations, a lot of research has been done. This paper investigates the effect of basalt aggregate on the improvement of rutting and moisture performance of hot mix asphalt (HMA) mixtures. In this respect, Marshall mix design was employed in the preparation of the specimens. Dynamic creep and moisture susceptibility test have been carried out to evaluate the mechanical properties of the HMA mixture with 30%, 50% and 100% of basalt aggregate replacement. As a result, the performance (creep modulus, permanent deformation and tensile strength) of modified HMA improved remarkably 40- 90% with replacement of 50% basalt aggregate. According to these investigations, the mechanical characteristics of HMA mixtures are significantly impacted by basalt aggregate and its combinations with granite aggregate in asphalt mixes.

1. Introduction

Hot mix asphalt is a flexible pavement that is broadly used for its comfort from patching potholes to paving roads, asphalt paving can match a diffusion of production challenge desires. One type of premix that is often used in road building worldwide is hot mix asphalt (HMA). Multiple layers of asphalt or bituminous concrete over a granular material foundation on a prepared subgrade make up flexible pavements [1]. When developing flexible pavement, the load and intensity of the load transmitted from the surface are taken into consideration. The thickness of flexible pavement is influenced by a subgrade's resilience [2]. Additionally, innovative tire designs with high pressure, temperature variations, various axle loads that are out of control, and traffic trends have all contributed to the development of flexible pavement distress [3,4].

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Rutting, which is shown by the etching of the wheel path in the road, is the word used to describe the buildup of permanent deformation or consolidation in an asphalt pavement surface over time. [5]. Because the binder on the surface of older asphalt roads tends to adhere to the soles of shoes during the summer, asphalt roads are said to be flexible. Rusting can be brought on by the aggregate and binder that move in asphalt roads. In addition, Ahmed *et al.,* [6] observed that weak asphalt mixes, low pavement thickness, and lack of compaction can all cause rutting. Creep is defined as a material being distorted to the point of quick failure or loss of usefulness as a result of having to maintain a load for a lengthy period [7]. The dynamic creep test makes advantage of the response relationship between pavement load and deformation, according to Yin and Zhang [8]. The evaluation of asphalt pavement's resistance to persistent deformation has also been recommended. Rutting is the term for channeled depressions in an asphalt surface that develop over time as a result of exceeding weight restrictions and poor foundation construction. Tire paths are created along a road by the gradual compaction of asphalt by trucks [9]. Rutting is a significant signal of distress for two reasons, according to Aman *et al.,* [10]. Ruts may cause hydroplaning on impermeable surfaces by holding onto water, which poses a significant risk to cars. Steering gets increasingly difficult and possibly dangerous as the depth of the rut grows. Rutting severely impairs the structural and practical performance of a pavement [11]. The rutting layers are determined by the degree of stress and the relative effectiveness of the asphalt layer. The applied load, individual and combined layer thickness, and layer material characteristics all have an impact on stresses inside the layer of a pavement system [12].

The Mechanistic-Empirical Design Guide (MEPDG) has established three separate phases for the permanent deformation behavior of asphalt pavements under a specific combination of material, load, and environmental circumstances as shown in Figure 1. The main stage has a high initial rutting level with a decreasing rate of plastic deformation, which is mostly connected with volumetric change. Although shear deformations progress more quickly than rutting in the secondary stage, which has a steady rate of development that is also linked to volumetric changes. Under no volume change conditions, the tertiary stage has a high amount of rutting, which is mostly connected with plastic (shear) deformations [13,14]

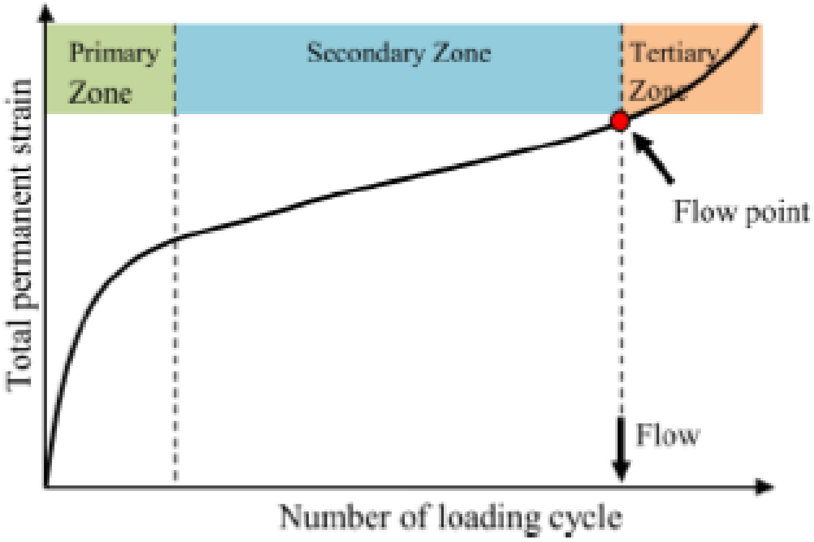

Fig. 1. Pavement material permanent deformation behaviour under repeated load [12]

Moisture has long been recognised as a key element in the early deterioration of asphalt mixes since moisture entry into the asphalt mixture composition is the principal cause of aggregate-binder adhesive failure and cohesive failure in binder or mastic. Figure 2 shows schematic of these 2 mechanisms [15] resulting to water damage. Asphalt binder is a strong cement that is easily sticky, exceedingly waterproof, and long-lasting, making it an excellent choice for road structure. It is also resistant to most acids, alkalis, and salts.

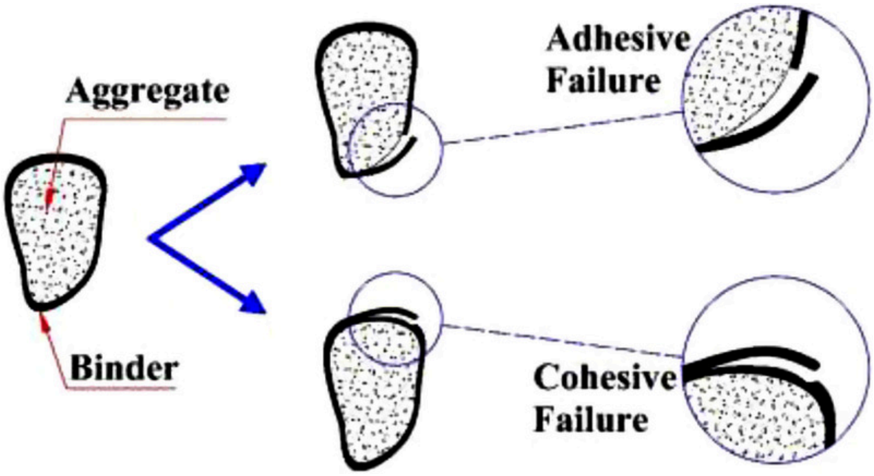

Fig. 2. Adhesive and cohesive failures due to water damage [16]

Around the world, basalt aggregate has been used for many different construction projects for a very long time. Due to their diverse textures and compositions, basalts are capable of a broad variety of physico-mechanical functions. Most basalts are suitable for creating crushed rock aggregates for a variety of building purposes, even if certain basalts have better aggregate quality than others [17]. A hard, thick volcanic igneous rock called basalt may be found practically everywhere on the earth.

Furthermore, basalt aggregate, a naturally occurring aggregate that is affordable and readily available, can be utilized as a coarse aggregate in concrete mixes to create a moderately strong and affordable concrete. Hot Mix Asphalt (HMA) commonly uses traditional crushed local basalt because of its widespread availability, high density, strength, wear resistance, and other desirable characteristics. Basalt aggregate, however, is inferior to asphalt in terms of adhesion due to its weak porosity and absorption, which leads to low stripping resistance in asphalt concrete mixes using this kind of aggregate [18,19].

In Malaysia, basalt aggregate has not been widely employed in pavement constructions due to lack of basalt aggregate specifications. Motivated from these gaps, the comprehensive study on the replacement basalt aggregate is crucial completely to enhance the rutting resistance or mitigate permanent deformation in the asphalt mixture. Thus, the primary objective of this study is to earn a better understanding of basket aggregate application in HMA mixture and provide a benchmark to the pavement industrial application.

2. Material and Method

This section describes the material and method employed in this study. The raw material was characterized using various methodologies outlined in this section.

2.1 Material

Material preparation in this study used granite aggregate obtained from Hanson quarry, Johor and basalt aggregates from JKR Temerloh, Pahang respectively. The asphalt binder penetration grade 60/70 was supplied by Kemaman bitumen with small amount of quarry dust as filler. The purpose of this experiment is to determine how basalt aggregate composition and its interactions with granite aggregate in hot mix asphalt (HMA) mixes affect the final product.

2.2 Sample Preparation

According to the Marshall mix-design technique, 5.5% of the total sample weight of the HMA mixes needed to be asphalt binder. The volumetric characteristics were assessed in order to determine the design asphalt binder content in terms of stability, flow, density, and total air voids content. According to JKR's specification (JKR/SPJ/2008), laboratory samples were created using the aggregate gradation designated for the HMA mixture AC 14 Wearing Course [20]. Then, multiple aggregate percentage combinations were employed in this study for basalt at 0%, 30%, 50%, and 100% of the total weight. The mixture was made using the penetration grade of asphalt binder 60/70. The Marshall compactor was used to compact 60 specimens containing basalt aggregate at a rate of 75 blows per face in line with ASTM D 1559 [21]. The investigation was wrapped up with a dynamic creep test and moisture susceptibility test at Advanced Highway Laboratory (UTHM) to explain the mechanical properties of the HMA mixes.

2.3 Experimental Program

This section describes the mechanical performance of the hot mixture asphalt (HMA) mixtures subjected to creep and moisture sensitivity incorporating basalt aggregates. All the test strictly followed American for Testing and Material (ASTM), British Standard (BS), American Association of State Highway and Transportation Officials (AASHTO) and Jabatan Kerja Raya Malaysia (JKR) standard and specifications.

2.3.1 Dynamic creep test

The dynamic creep test was performed as outlined in EN 12697-25:2005 [22] using UTM- 5P as shown in Figure 3 to determine the creep modulus and permanent deformation of asphalt mixture. The conditioning stress for this test is 10kpa for 120 seconds and was applied toward asphalt mixture specimens. Then, the fabricated specimens were conditioned in the chamber for 2 hours to achieve uniform temperature before testing. The UTM-5P machine was set up by placing the sample between two metal steel that works to distribute load uniformly over the top surface of a sample and the test parameter was programmed as specified in Table 1. When it reached 3600 cycle, the test was stopped for each sample and the result for permanent deformation with creep modulus was recorded. This test technically was simulated from a real field where stress level indicates to vehicles pressure tire that made contact toward road surface which is wearing course. Loading and rest time, represent the repeated load of moving traffic. Dynamic creep modulus (DCM) and creep strain slope (CSS) were determined using Eq. (1) and Eq. (2), respectively.

$$DCM = \frac{applied\ load\ stress}{\varepsilon 3600 - \varepsilon 2000} \tag{1}$$

Where; DCM represents Dynamic creep modulus(Mpa) ε3600 is an accumulated strain at 3600 cycle and ε2000 is an accumulated strain at 2000 cycles.

$$CSS = \frac{\log \varepsilon 3600 - log\varepsilon 2000}{log 3600 - log 2000} \quad (2)$$

Where; CSS is a Creep strain slope; ε3600 is an accumulated strain at 3600 cycle and ε2000 is an accumulated strain at 2000 cycles.

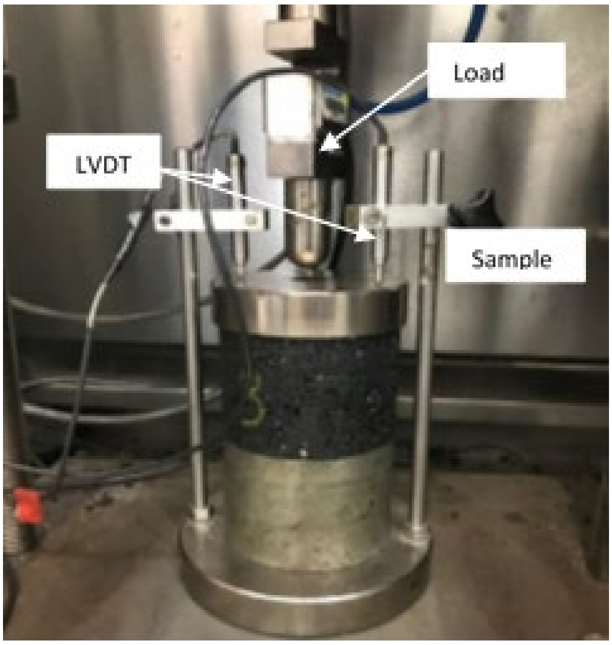

Fig. 3. Dynamic creep test setup

Table 1
Dynamic creep test parameter

Parameter	Information
Temperature (℃)	40
Pulse width (ms)	100
Rest period (ms)	900
Contact stress (kPa)	9
Deviator stree (kPa)	200
Stop test after cycle	3600

2.3.2 Moisture susceptibility test

Moisture sensitivity is one of the significant failures in asphalt concrete pavement. Modified-Lottman test was accomplished based on AASHTO T283 [23] procedure in order to identify the pattern of moisture Susceptibility of Hot Mix Asphalt (HMA). The advantage of this test is that the physical and mechanical properties of mixture, water, and traffic action and pore pressure effect can be taken into account. The total of twenty-four (24) specimens were prepared and divided into two subsets of three specimens. One subset was tested in dry condition and other subset is subjected to a moisture condition. For a moisture condition subset, specimens need to be conditioned by saturating with water (70%–80% saturation level) followed by having a warm-water soaking cycle (60

°C water bath for 24 h). After that, the specimens were removed and place at room temperature (25± 0.5°C) for 2 hours ± 10 minutes. The specimens were tested for indirect tensile strength (ITS) as shown in Figure 4 by loading the specimens at a constant rate (50.8 mm/min vertical deformation at 25°C) and the force required to break the specimen was recorded. The indirect tensile strength (ITS) of the conditioned specimens were compared to the control specimens in order to determine the indirect tensile strength ratio (ITSR). The indirect tensile strength ratio (ITSR) was calculated by using the following Eq. (3):

$$\mathrm{ITSR} = 100 \times \frac{\mathrm{S}_1}{\mathrm{S}_2} \quad (\%) \tag{3}$$

Where, ITSR = The indirect tensile strength ratio (%)
S1 = The average tensile strength of the wet subset (kPa)
S2 = The average tensile strength of the dry subset (kPa)

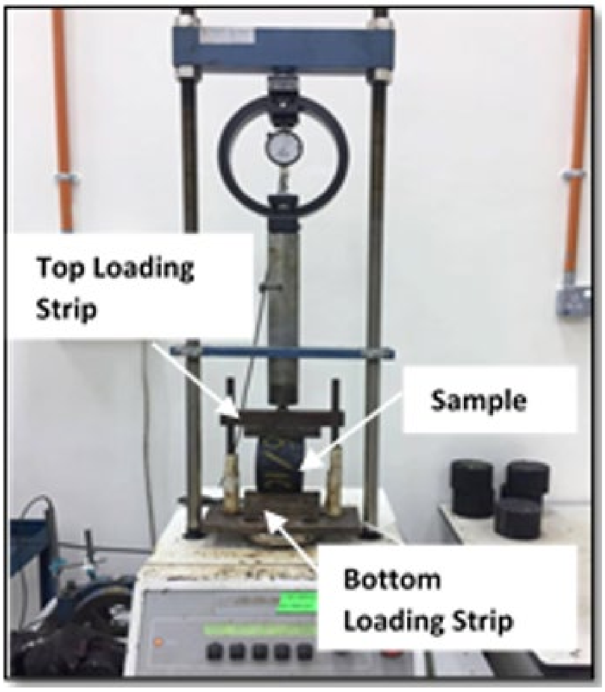

Fig. 4. Configuration of the ITS test

3. Results and Discussion

The mechanical performance test was carried out to evaluate the influence of basalt aggregate constituent to the moisture and dynamic creep asphalt mixture under loading conditions. The control and modified specimen were further analyzed in the subsequent subsection.

3.1 Dynamic Creep Analysis

Figure 5 shows the effect of a 200 kPa force on an asphalt mixture's creep modulus at a 40°C temperature. The creep modulus increases up to 50% basalt aggregate replacement and decreases at 100%, according to the general trend, which is shown by a bell curve. The specimen of asphalt mixture containing 50% of basalt aggregate had a maximum creep modulus of 1024.4 MPa after being exposed to 200 kPa of loading, while the control specimen had a minimum creep modulus of 548.0

MPa. This demonstrates that, as compared to the control, the basalt that contains 50% of the material has the greatest creep modulus at a deviator stress of 200 kPa by around 87%. Basalt aggregate has good durability and excellent resistance to stresses that are applied gradually, impacts, and abrasions, as stated by Li *et al.,* [24]. This shows that adding 50% basalt increases the creep stiffness measurement from the control sample by up to 18% when compared to the control specimens.

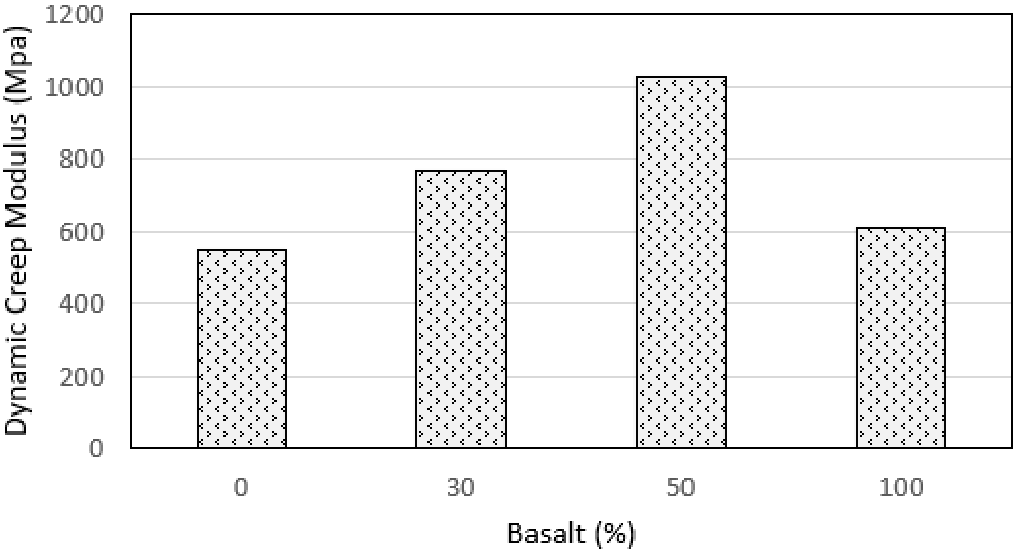

Fig. 5. Effect of basalt aggregate on dynamic creep modulus at a temperature of 40°C

Figure 6 shows the plotting of the creep steady slope using a deviator stress of 200 kPa and a control temperature of 40°C. The overall trend is shown by a graph that fluctuates, with a gradually steady slope that decreases from 0% to 50% and then rises again to 100%. The specimen of asphalt mixture containing 50% basalt aggregate had the smallest creep steady slope, which is 0.13, whereas the specimen containing 0% had the greatest creep steady slope, which is 0.21 MPa, after being subjected to 200 kPa of stress. This demonstrates that, as compared to the control, the 50% basalt mixture has the lowest creep steady slope at 200 kPa deviator stress by around 38%. This shows that compared to 0% basalt, 50% basalt can lower the creep steady slope value from the control sample by up to 38%.

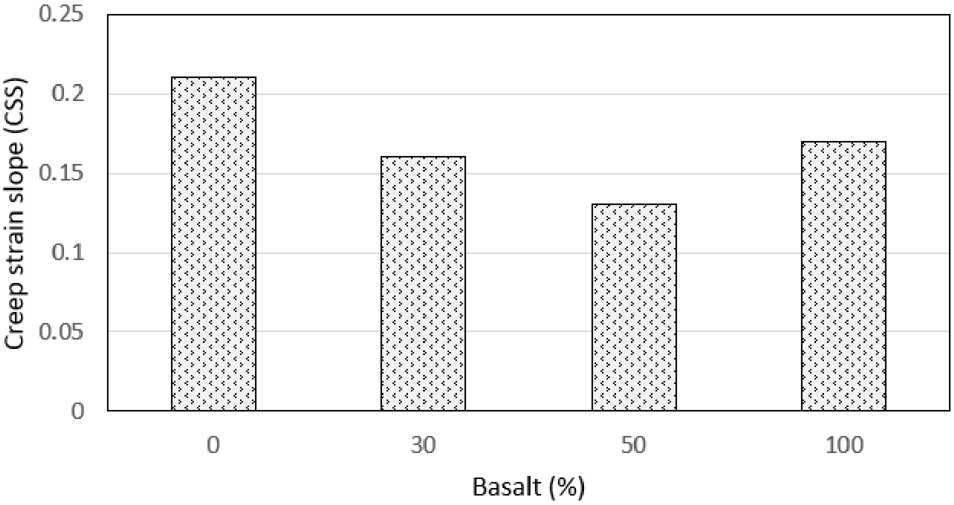

Fig. 6. Effect of basalt aggregate on creep steady slope at a temperature of 40°C

Figure 7 demonstrates that the control specimen has higher permanent deformation than that of basalt modified asphalt mixtures. The permanent deformation diminishes as the proportion of basalt aggregate rises to 50% and then rises back at 100%, according to the overall tendency, which is erratic. The specimen of asphalt mixture containing 50% of basalt aggregate had the smallest permanent deformation, which is 0.226mm, whereas the specimen containing 0% had the most permanent deformation, which is 0.428mm, after being subjected to 200 kPa of stress. This demonstrates that, when compared to the control specimen, the basalt specimen with a basalt content of 50% had the lowest permanent deformation at a deviator stress of 200 kPa by about 89%. This shows that 50% basalt has an excellent performance in permanent deformation compared to 0% basalt, which can distort up to 89% more than the control sample. As agreed by Zhao *et al.,* [25], permanent deformation values for basalt aggregates indicate better permanent deformation compared to the granite aggregate. The material will be more rut-resistant because of the low permanent deformation value. Therefore, it is considered that the optimal limit for basalt aggregate replacement in HMA is 50%.

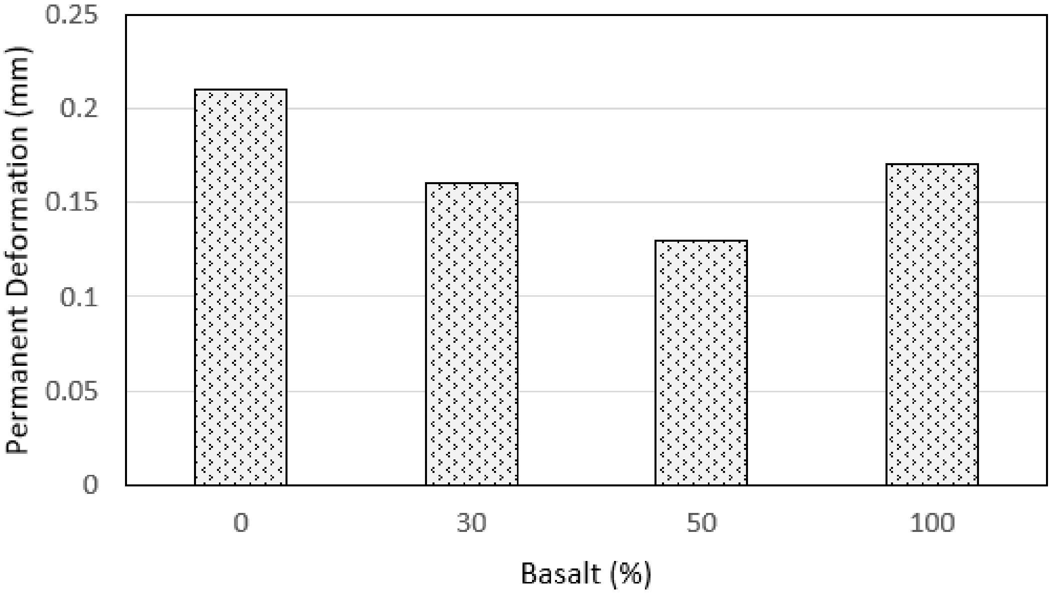

Fig. 7. Effect of basalt aggregate on permanent deformation at a temperature of 40°C

3.2 Moisture Susceptibility Analysis

Figure 8 presents the indirect tensile strength (ITS) results of the specimens for dry and wet subsets prepared at 165°C mixing temperature. This ITS results were averaged based on three specimens. As a comparison, the control of HMA mixture were prepared using 100% basalt and all specimens were tested by using indirect tensile strength equipment. Results from this Figure 8 indicate that all specimens tested at dry conditions exhibits higher tensile strength as compared to wet specimens.

Generally, the strength of the dry subsets shows variance results with increasing of basalt content. The decrease in strength at lower percentage of basalt replacement could be attained up to 50%. On the other hand, the tensile strength increases with increasing basalt replacement up to 100% basalt. This may due to the friction between the basalt aggregates and presence of the asphalt binder in the mixture.

The range of the indirect tensile strength of dry specimens was recorded between 515 Kpa to 1200 Kpa. It shows that a higher tensile strength was achieved by specimens with 100% basalt replacement. The lowest tensile strength came from 50% basalt modified specimens. Incorporating 30% and 100% basalt into the mixture improve the indirect tensile strength nearly 35% and 57% compared to the control mixtures, respectively. It can be found that basalt replacement has significantly affected the indirect tensile strength. This finding indicates that the tensile strength of dry specimen's mix is superior when mix with 100% basalt.

The effects of basalt replacement on tensile strength under wet conditions reveal the finding trend of the uneven result shows as basalt content increased. In general, the data did not show much improvement of tensile strength in the mixture under wet conditions These mixtures exhibit slightly lower tensile strength compared to the control, while a small increase in strength as shown in mixture with 50% of basalt replacement. The data of the tensile strength for wet specimens were recorded in the range between 487 Kpa to 727 Kpa. The higher tensile strength of wet specimens was achieved with 100% basalt replacement and the lowest from specimens with 50% basalt replacement. The tensile strength of 100% basalt replacement has signicantly improved approximately 18% compared to the control specimens. This observation shows that the bulk specific gravity of the basalt specimens contributes to the higher tensile strength.

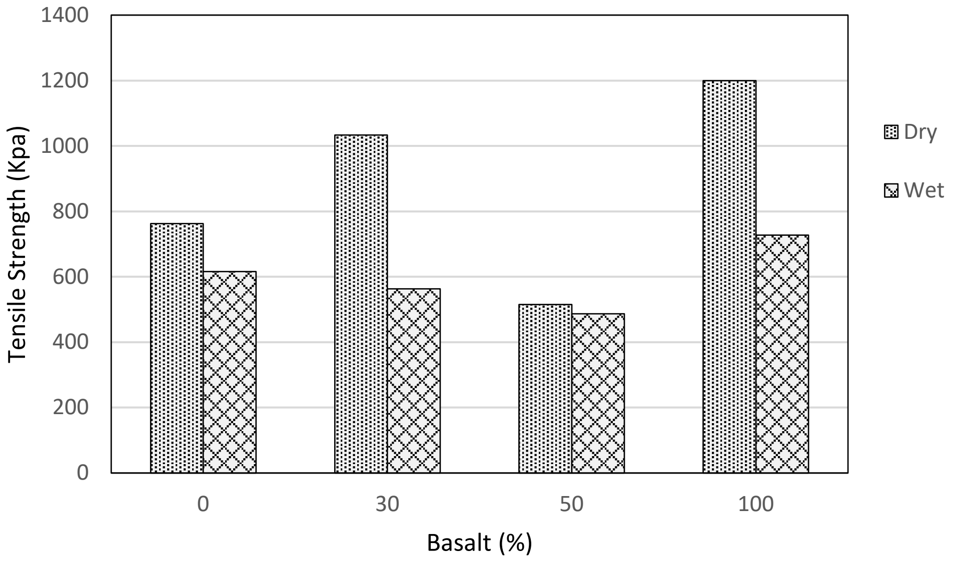

Fig. 8. Effect of basalt aggregate on Indirect tensile strength (a) Dry subsets (b) Wet subsets

Figure 9 shows graphical results of indirect tensile strength ratio (ITSR) value computed for control and modified specimens tested at 25oC. To obtain indirect tensile strength ratio (ITSR), the specimens were divided into two groups namely wet and dry subsets and ratio of the wet to dry subset were computed. The graph exhibits low moisture damage susceptibility for the mixture based on consistent values of ITSR which control and 50% basalt replacement of the specimens met the minimum ITSR threshold of 0.80.

As can be seen from this Figure 9, a general trend indicating that the mixes prepared with low to intermediate percentage of basalt indicate uneven trend of ITSR value. In particular, the 50% basalt replacement mixture has significant effect on moisture susceptibility with higher ITSR value computed (94.72%) compared to control specimens. It can be concluded that the presence of 50% basalt aggregate in hot mix asphalt (HMA) enhanced the performance of the mixture even though the specimens. The ITSR value of 0.8 and above is highly recommended for the mixture that able to resist moisture susceptibility. Therefore, the basalt replacement up to 50% satisfied the ITSR threshold that suggested by AASHTO T 283.

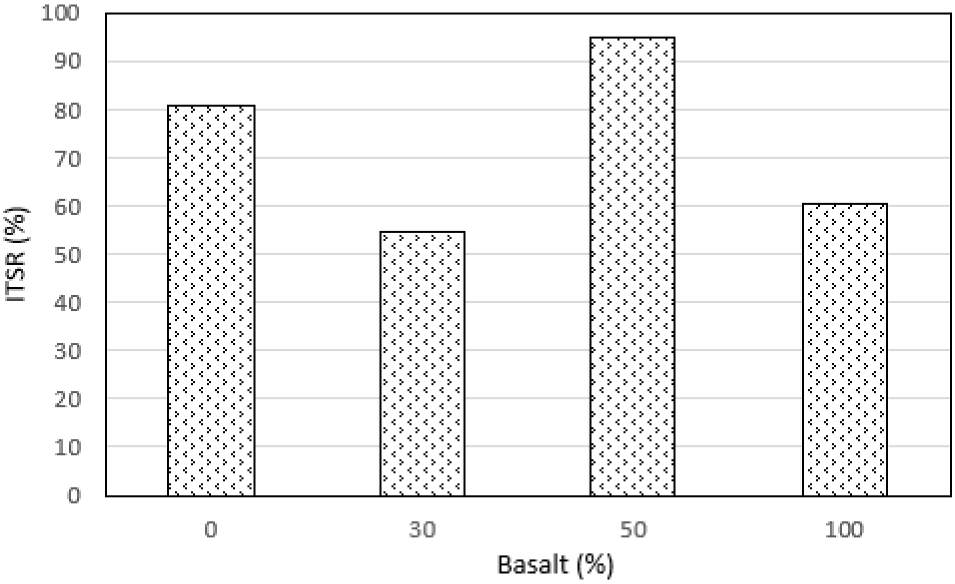

Fig. 9. ITSR value of the specimens

4. Conclusions

The results presented have provided an insight to understand the influence of basalt aggregate modified mixtures under performance test. The aggregate materials play the significant role in order to achieve better result and quality of the specimens. Investigation on these materials complied with standard and specification for Road Works Malaysia and Marshall specifications. The following finding were drawn:

i. 50% basalt replacement in HMA mixture has significant effects on the dynamic creep modulus (DCM) especially at 40oc compared to the control specimens.
ii. In addition, the mixture susceptibility of pavement rutting corresponds to creep steady slope (CSS) revealed the lowest CSS found in the mixture with 50% basalt replacement. This situation clearly explained that the mixture with lowest CSS able to resist more rutting.
iii. Furthermore, the permanent deformation of the mixture is significantly decrease about 46% and show a good permanent resistant under high temperature compared to the control mixture specimens. The resistant to rutting indicate that is statistically significantly compared to control
iv. Overall the moisture susceptibility results show 50% basalt replacement mixture satisfied the TSR threshold of 80% that suggested by AASHTO T 283. Therefore, the mixtures designed with 50% basalt replacement is recommended based on its good performance to rutting and moisture susceptibility.
v. Further investigation should be studied on the other performance of HMA mixture i.e resilient modulus, indirect tensile fatigue and Marshall test at the optimal basalt content.

vi. This study has conducted laboratory based on the specimens. Nonetheless, a field trial is recommended to evaluate and validate the performance of HMA mixture incorporating basalt replacement aggregate.

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