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Research paper

Marshall stability of porous asphalt mixture incorporating kenaf fiber

Nur Ezreen Jasni[1], Khairi Azman Masri[2], Ramadhansyah Putra Jaya[3], Mohd Mustafa Al Bakri Abdullah[4], Rafiza Abd Razak[5], Marcin Nabiałek[6], Katarzyna Błoch[7], Agata Śliwa[8]

Abstract: Porous asphalt mixture (PA), known as open-graded surfaces over a stone bed underneath, allows water to go through. These factors can affect the porous asphalt mixture adhesive strength. The high amount of course aggregate promotes the structure of air voids have certain impacts on the acoustic properties of porous asphalt. The materials properties are consisting of both aggregate and bitumen tests. This study also details out the aggregates sieve analysis test to develop new aggregate gradation for PA. According to five ASEAN countries' specifications, the sieve analysis test was done. The countries included are Malaysia, Vietnam, Thailand, Singapore, and Indonesia. The test for the binder includes the softening point, penetration, and ductility. This study also investigates the addition of kenaf fiber in the mixture as an additive. Mechanical performance test for PA using Marshall Stability test to identify the strength and the properties of the conventional PA with the addition of kenaf fiber compared to the new gradation of PA incorporating kenaf fiber. From the results, the addition of 0.3% kenaf modified PA improved the performance of PA in terms of Marshall Stability and volumetric properties.

Keywords: porous asphalt, marshall stability, kenaf fiber, softening point, penetration

[1]MSc., Department of Civil Engineering, College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Pahang, Malaysia, e-mail: reenjasni@gmail.com, ORCID: 0000-0002-6616-8215
[2]PhD., Department of Civil Engineering, College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Pahang, Malaysia, e-mail: khairilazman@ump.edu.my, ORCID: 0000-0003-0046-8669
[3]PhD., Department of Civil Engineering, College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Pahang, Malaysia, e-mail: ramadhansyah@ump.edu.my, ORCID: 0000-0002-5255-9856
[4]Prof., Faculty of Chemical Engineering Technology, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia, e-mail: mustafa_albakri@unimap.edu.my, ORCID: 0000-0002-9779-8586
[5]PhD., Center of Excellence Geopolymer and Green Technology. Universiti Malaysia Perlis, 01000 Kangar, Perlis, Malaysia, e-mail: rafizarazak@unimap.edu.my, ORCID: 0000-0003-1398-7652
[6]Prof., Department of Physics, Częstochowa University of Technology, 42-201 Częstochowa, Poland, e-mail: nmarcell@wp.pl, ORCID: 0000-0001-6585-3918
[7]Prof., Department of Physics, Częstochowa University of Technology, 42-201 Częstochowa, Poland, e-mail: katarzyna.bloch@pcz.pl, ORCID: 0000-0002-5405-1845
[8]Prof., Division of Materials Processing Technology and Computer Techniques in Materials Science, Silesian 21University of Technology, Poland, e-mail: agata.sliwa@polsl.pl, ORCID: 0000-0001-9459-3895

1. Introduction

Porous asphalt mixture (PA) is usually used for parking lot as the mixture allows water to flow into a stone recharge bed through the pavement surface and to penetrate into the ground under the pavement [1–3]. PA is known as the mixture that consist of high air voids content. This is because porous asphalt mixture contains more courses aggregate compared to fine aggregates that can help fill the voids and at the same time, may reduce the air voids content. PA also known as open graded mixture that diminish underground water charges caused by the structure of the mixture that high air voids content. The inconsistent of air voids content in between five Asean countries including Indonesia, Singapore, Vietnam, Thailand and Malaysia lead to the new development of aggregate gradation. Aggregate gradation specifies the void content within the aggregate structure and is a major factor in influencing the air void content characteristics [4].

Due to the disadvantages and inadequacies of PA aggregate gradation in Malaysia, a new aggregate gradation has been developed, combining the aggregate gradation of five Asean countries. The countries involved are Thailand, Singapore, Indonesia and Vietnam. Sieve analysis test are used in order to develop the new aggregate gradation (NPA). These five countries are selected due to the climate changes are almost the same. The weather is one of the main causes of road damage according to Malaysian Highway Authority(MHA) reported by [5]. The elemental composition of an aggregate is the definition of aggregate grading or also can be called as sieve analysis. Aggregate gradation consists of particles of different sizes will give the volume less voids, therefore, when all aggregates of particles are equal in size, more air voids are contained in the compact mass [6, 7]. This study is the creation for the new aggregate gradation which due to the course and fine aggregates, where to reinforce the linkage between the aggregates and the binder from all the current aggregate gradation.

Asphalt mixture is the material most commonly used on pavements. To guarantee the performance and strength of pavement in designed traffic loading conditions, the mechanical properties of asphalt mixture is tested. The strength of the conventional porous asphalt mixture (CPA) and the new gradation porous asphalt (NPA) is tested by using marshall stability test to meet certain requirements. The mechanical properties of an asphalt mixture can be directly tested by laboratory testing. These calculated properties however do not reflect the total mechanical behavior of the mixtures and thus correspond to certain conditions. Currently, in addition to the wide-ranging use of new materials, reported by [8], it is important for a new material design to consider the fundamental mechanisms behind the mixture behaviour, as the mixture incorporating kenaf fiber in this research.

The aim of this study is to perform a new aggregate gradation by using sieve analysis test. The new aggregate gradation that has been developed using five specification from selected asean countries were investigated. The introduction of kenaf fiber in the conventional porous asphalt mixture and the new gradation porous asphalt were added in the mixture to enhance the strength of the mixture. The performance of all the porous asphalt mixture were tested by using marshall properties test. The outcome of this study may contribute to better design of PA. It is also promotes the green and more sustainable material especially for highway construction. In addition, this study will also be extended to field testing to verify the design based on real situation.

2. Materials and methods

2.1. Materials

2.1.1. Bitumen

For this study, three common binder tests have been done in order to evaluate the strength of the bitumen to be used. The tests include softening point test, penetration test and ductility test. All tests have been done in accordance to ASTM D36-95, ASTM D5-97 and ASTM D113-17, respectively.

a) Softening Point Test

Softening point is one of the tests to determine bitumen consistency toward temperature. Bitumen is viscoelastic materials without sharply defined melting points; they gradually become softer and less viscous as the temperature rises [18]. It was conducted in order to determine at which temperature the bitumen starts to melt. The temperature readings start to be taken when a metal ball that is placed on the bitumen falls to the bottom of the beaker. It is indicated that the bitumen has reached certain degree of softness when the metal ball dropped into the bottom [9]. The average reading of the softening point that had recorded was 53.5 that fall in the range 48 to 56 according to specifications for bitumen 60/70.

b) Penetration Test

Penetration test is a method that widely used to measure the consistency of a bituminous material at a given temperature. It determines the hardness or softness of bitumen by measuring the depth in millimeter to which a standard loaded needle will penetrate vertically in five seconds while the temperature of the bitumen sample is maintained at 25°C [19]. The average elongation is in the range 60dmm to 70dmm for bitumen 60/70. The characterisation of bitumen was based on the penetration test (EN1426) with a penetration value of 63dmm measured.

c) Ductility test

Ductility test were performed to determine the ability of bitumen to withstand plastic deformation without rupture. Ductility of a material is a property by virtual of weight that can be pulled without breaking apart the ‘thread. The result for ductility test was in the range needed, that is more than 100 cm for bitumen 60. The characterisation of bitumen was based on the ductility test with an elongation value of 110 cm measured.

Bitumen 60/70 gradation was used as adhesive in the mixture. This modified bitumen was obtained by a chemical reaction between a hydrocarbon binder, according to EN 14023 standard. It was recommended for the bitumen to be fully melted at temperature of 140°C to 150°C before mixing. Physical properties tests of bitumen were performed, as shown in Table 1 below. Durability of porous asphalt mixture depends on the Adequate binder content.

Table 1. Physical Properties Test of Bitumen 60/70

Physical Test	Standards	Laboratory Results	Results Properties
Softening Point	ASTM D36	53.5°C	PASSED
Penetration	ASTM D5	63dmm	PASSED
Ductility	ASTM D113	110cm	PASSED

2.1.2. Kenaf fiber

Fig. 1 shows the kenaf fiber. It is one of the natural fibers that give a lower production cost as it is eco-friendly materials that found in Malaysia. It is widely used as it is multi-usage of it cellulose content [10]. Kenaf fiber that has been used in this study were provided from Lembaga Kenaf dan Tembakau Negara (LKTN). The fiber has been cut to a diameter of about 5 mm to 10mm before mix thoroughly in the mixture.

Fig. 1. Kenaf fiber

Kenaf fiber represents the highest rate of absorption of carbon dioxide, have low density and high modulus and allow low-energy production, which is good for absorbing oil and other organic liquids [11]. Kenaf fiber along with its recent applications and characterization of its advantage composites in terms of mechanical properties, engineering properties, water absorption behaviour and the capabilities of kenaf fiber in enhancing the asphalt pavement. The recent applications of kenaf fiber is still unanswered [11]. Hence, kenaf fiber are used in this paper to investigate the uses of kenaf fiber in enhancing the mechanical performance of porous asphalt mixture especially for stability of the mixture.

2.1.3. Aggregate

Aggregate used in this was a type of granite from the local quarry in Pahang, Malaysia. The sizes are ranging from the maximum size of 20 mm up to filler/quarry dust. The certain amount of filler was also replaced by up to 2% of Ordinary Portland Cement (OPC) to reduce the stripping issue for each compacted PA specimen. Since filler was just a small amount, it may not affect the overall performance of the PA specimen. This can be verified from Fig. 2 where Kenaf fiber is well dispersed in compacted PA specimen.

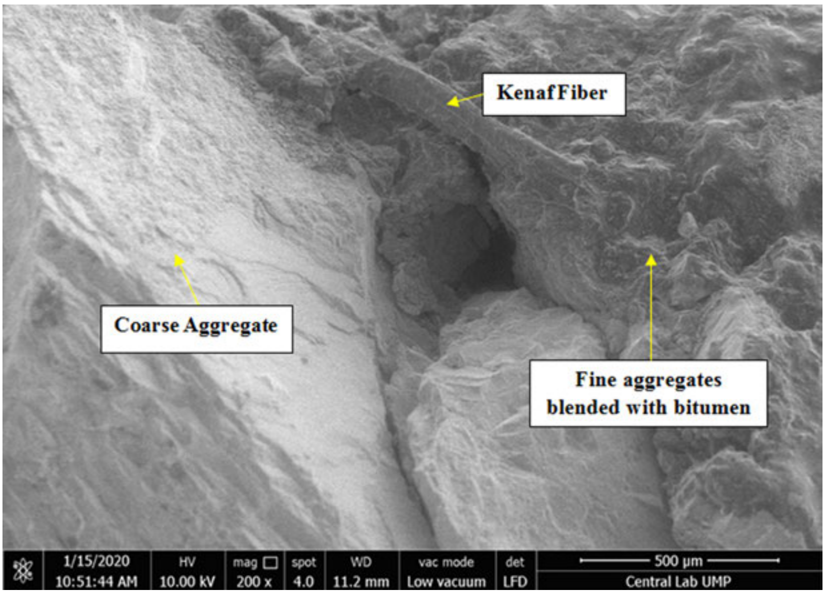


Fig. 2. SEM Images of PA modified with Kenaf Fiber

2.2. Methods

2.2.1. Sieve analysis test

Sieve analysis is very vulnerable to drying effects, breaks before sieving and severe processes themselves. For reproductible results, therefore, detailed specifications are required. Five different types of grading standards from various countries were implemented in this paper i.e. Malaysia (Public Works Department, 2008) [12], Singapore specification is adopted from Land Traffic Authority Singapore [13], Indonesia [14], Vietnam and Thailand are both from previous paper [15].

In such curve or as ’S’ curve the aggregate gradation is expressed. The particle size distribution of the aggregate mass will allow the smaller component to fill the gaps between the larger particles. The crushed granite aggregate of Stockpile A and stockpile B were from Syarikat Quary Bekelah Sdn Bhd. Stockpile A and Stockpile B were termed for crushed granite aggregate and fine aggregate respectively. Laboratory sample preparation started with the use of these two sources for sieve analysis test to develop the new aggregate gradation. The ordinary of aggregate gradation for all countries involved presented in Fig. 3. From the table of ordinary aggregate gradation, the use of fine aggregates for Singapore is more details compared to other countries. Indonesia and Vietnam have the same nominal maximum aggregate size (NMAS), which is 12.5 mm while Singapore and Thailand share the same NMAS of 13.2 mm. Malaysia the only country that use 12.5 mm as NMAS which this show that the aggregate gradation among ASEAN countries is different.

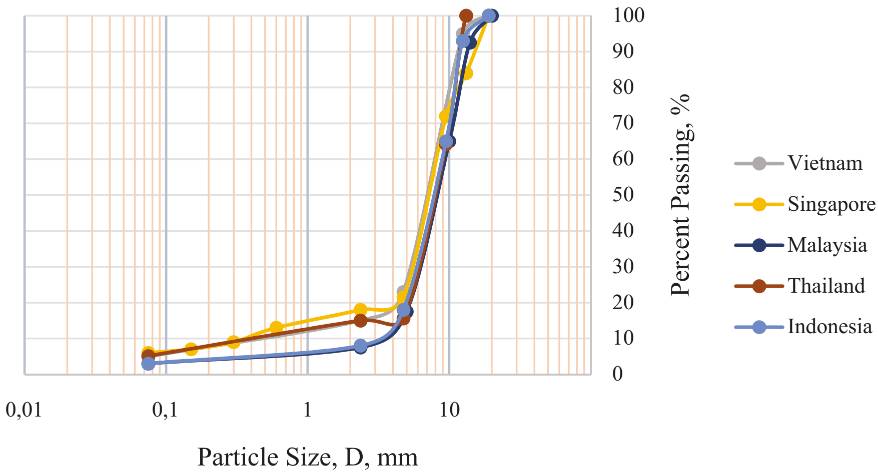


Fig. 3. Ordinary Aggregate gradations for porous asphalt for all five asean countries

Sieve analysis is the method of fractionation of aggregates according to the specified country. The aggregates were sieved using sieve shaker. It is conducted to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. According to the standard sieve analysis test (ASTM C136) [20], the aggregates were analysed using aggregate blending by ratio for three times each country. PA mixture concepts which use aggregate interlocking and aggregate packaging to develop a total mixture that meets volumetric criteria and provides sufficient compaction properties. The ideas depend on a coarse aggregate to have a suitable structure for the skeleton of the mixture with the right amount of a fine aggregate. The aim is to use combination packaging ideas to look at the combined gradation and to link the packaging properties to the volumetrical mixture properties and compaction features. The new concepts proposed for the design and analysis of asphalt mixtures include an examination of the aggregate packaging and the aggregate locking process, mixing of aggregates by volume, a new understanding, of course, and of the subsequent grading. The chosen ratios taken from stockpile A and B respectively for this study were 50% to 50%, 60% to 40% and 70% to 30%. This research is conducted so as to create new aggregate gradation in terms of enhancing presence aggregation by comparing the other five selected ASEAN countries with the same weather and temperature requirements such as Singapore, Vietnam, Thailand and Indonesia with Malaysia.

2.2.2. Marshall stability test

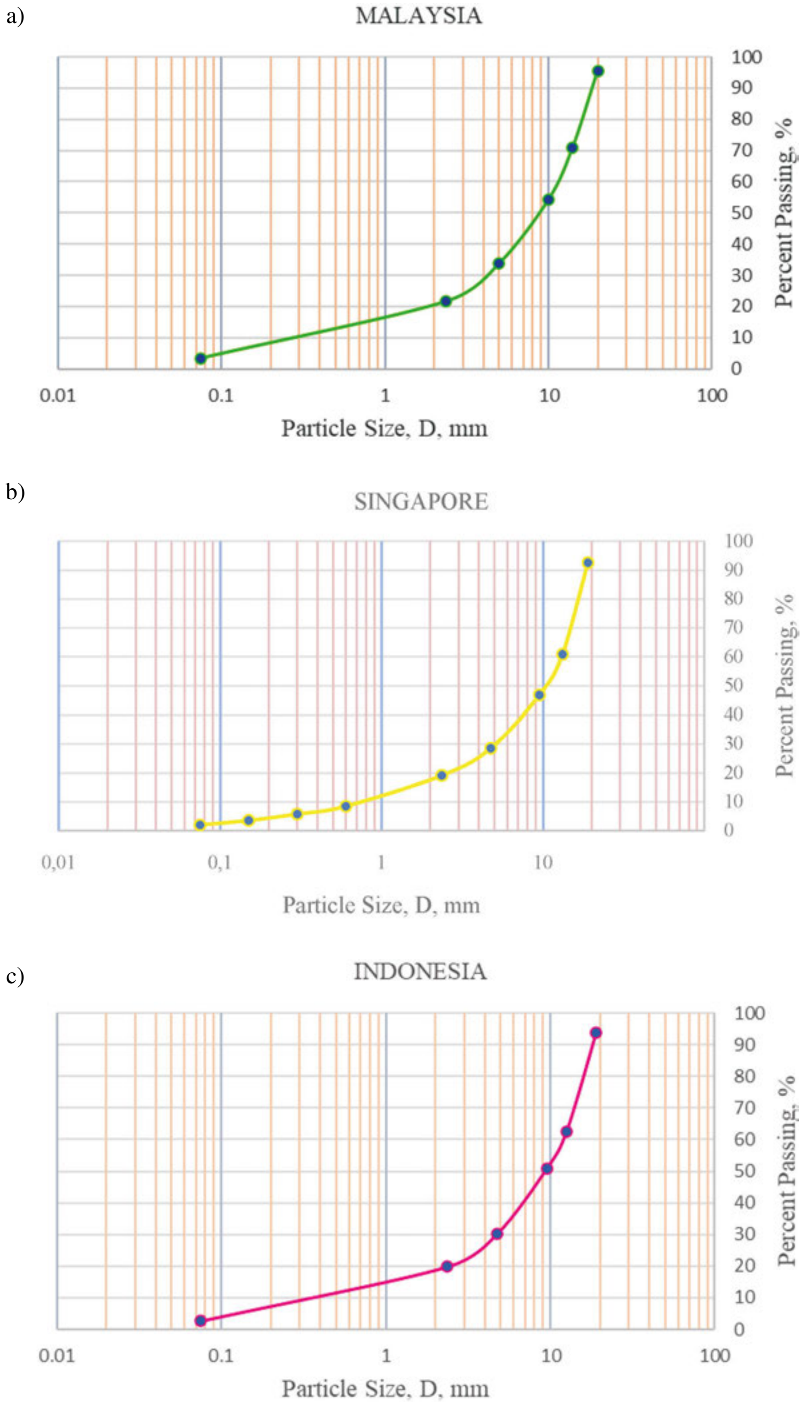
The stability is among the indicators of the strength of the asphalt mixture obtained by the marshall stability test. The test also assesses the relationship between PA stability and different air voids value and particulate division [9]. The mixtures were prepared and these mixtures were named conventional porous asphalt (CPA) and new gradation porous asphalt (NPA). Mixtures that were added with kenaf fiber were name conventional porous asphalt with 0.3% of kenaf fiber (0.3K CPA) and the new gradation porous asphalt with 0.3% of kenaf fiber (0.3K NPA). These four types of porous asphalt mixtures were used to be compared.

The specimen is ready to be tested usually after 24 hours after compaction process. In order to determine the volume of the specimen, the differences between the weight in air and in clean water is needed. Specimen is ready to be immersed in water bath for 20 to 40 minutes at 60°C. The specimen from the water bath was placed in the lower segment of the breaking head. The upper segment of the breaking head was placed on the specimen and the complete assembly was placed in position on the testing machine. The flow meter was installed over the guide rods and, when the load was applied, it was securely attached to the upper segment of the breaking head. The load on the specimen had been applied at a rate of 50 mm per minute to achieve full load and to lower the load. The maximum load was reported and the flowmeter was removed over the guide bar as soon as the load started to fall. The flow and stability value were read and recorded. The time taken for the test to determine the full load from removing the sample from the water bath was no longer than 30 seconds.

3. Results and discussion

3.1. Sieve analysis

Figs. 4(a–e) shows the ‘S’ curve of the average aggregate gradation for selected ASEAN countries. It is plotted in graph after the test have been done three times for each country. Then, each of the result has been calculated and come out with the average graph for each country before combining it in one graph. These five graphs were illustrated to see the pattern for each country. On the other part, the graph was used to differentiate the better specification that determine the upper and lower limit for the new gradation This part is crucial as it is the phase to decide whether each of the


a)
MALAYSIA
100
90
80
70
60
50
40
30
20
10
0
Percent Passing, %
0.01
0.1
1
10
100
Particle Size, D, mm
b)
SINGAPORE
100
90
80
70
60
50
40
30
20
10
0
Percent Passing, %
0,01
0,1
1
10
Particle Size, D, mm
c)
INDONESIA
100
90
80
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50
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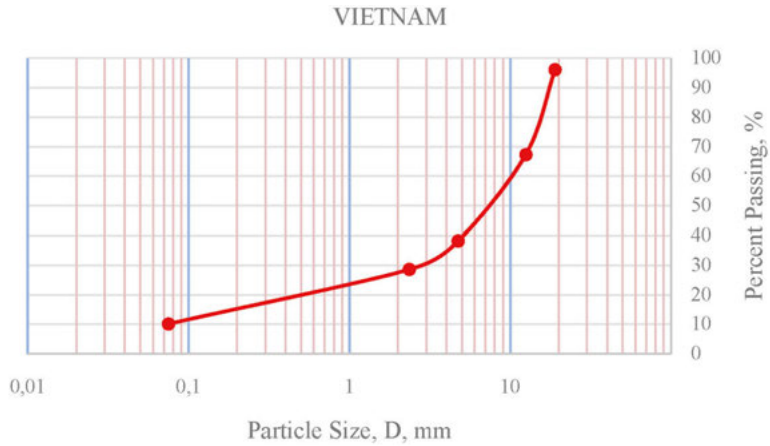
Particle Size, D, mm

Fig. 4 a)–c)

d)



e)

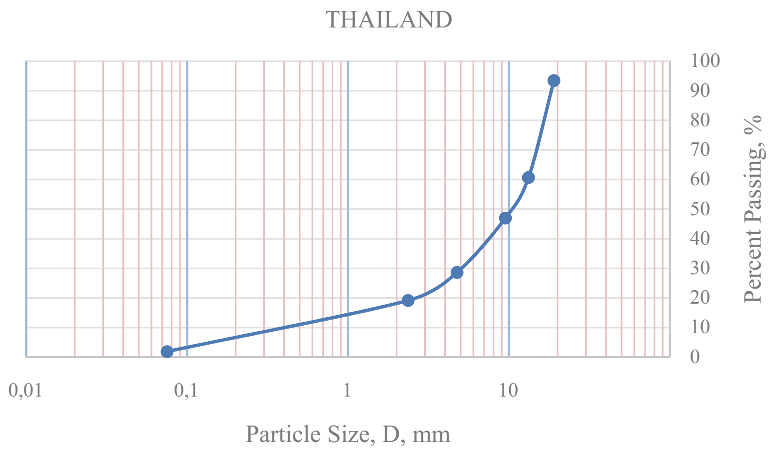


Fig. 4. Average aggregate gradation for five selected ASEAN Countries

countries' specifications were suitable or not in the making of the new aggregate gradation.

Fig. 5 shows the 's' curve of the new development of aggregate gradation that consist of upper and lower line. The graph shows the patterns and the conclusion can be made through the visual observation. From visual observation, Vietnam specifications shows to be picked as best upper line. This is because Vietnam specification seems to have a simple aggregate gradation and yet full of criteria to be choose. For lower line, the graph shows that the fine aggregate should follow Singapore specification and the rest are from Thailand specifications. Singapore specification can be said among the most details specification for fine aggregates. The larger particles are in between may lead to more air voids due to the small particles are not enough to fill the voids [6]. The median line is then calculated by using interpolation method. The median lines indicated the new aggregate gradation.

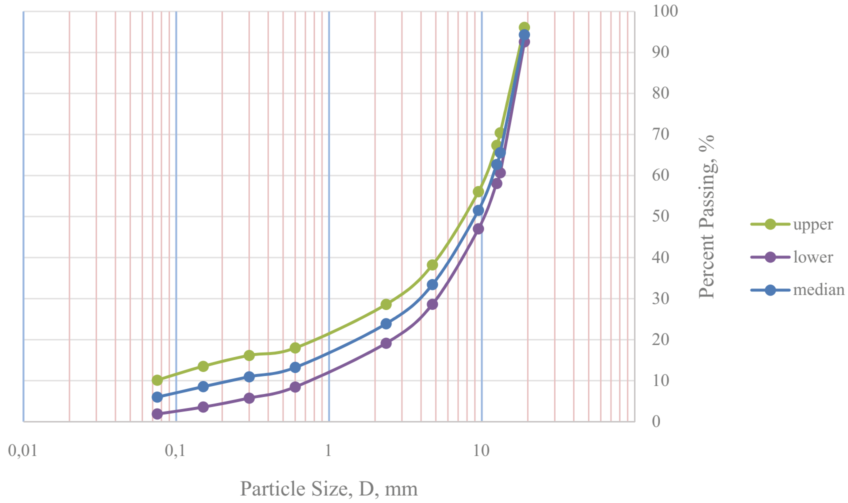


Fig. 5. The New Aggregate gradation 'S' curve

3.2. Marshall stability properties

3.2.1. Stability vs. stiffness

Figure 6 below shows the Stability and Stiffness values for Conventional porous asphalt mixture, New gradation porous asphalt mixture and the additions of 0.3% Kenaf fiber in

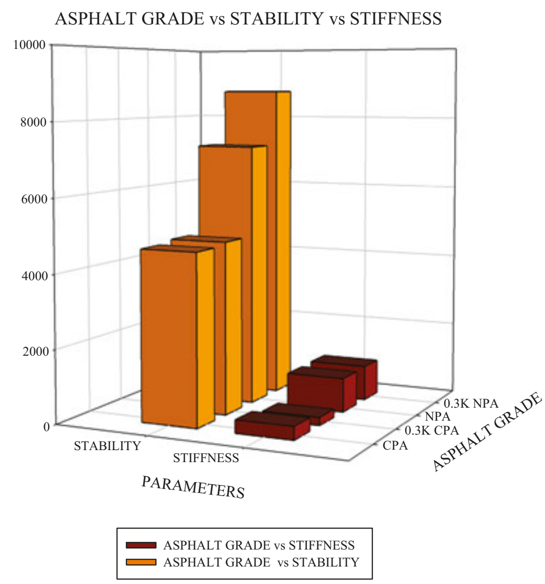


Fig. 6. Asphalt Grade vs. Stability vs. Stiffness

both type of mixture. From the graph, it shows that the CPA mixtures shows an improvement from 4643 N to 4729 N with the addition of kenaf fiber. This trends also illustrates that NPA shows an improvement in terms of stability as compared to 0.3K NPA with the values of 7226 N to 8765 N. The increment of 1.8% and 19.2% respectively may be due to the addition of kenaf fiber. The use of kenaf fiber may able to absorb bitumen and create a good bonding between the fiber and the bitumen making it a stronger mixture. NPA gives the highest values with value of 8765 N for stability and 951.76 N/mm for stiffness while CPA shows contrarily for stiffness when the addition of kenaf fiber has lead to the decrement of 4.4%. As compared to NPA mixtures, the stiffness has increased at about 15.7%. This is might be due to the new aggregate gradation that consist of better gradation for fine aggregate and kenaf fiber shows a good incorporation with aggregate and bitumen.

This trend however indicates that the addition of kenaf fiber in NPA improves in terms of stiffness and stability. The new gradation porous asphalt that has been developed are proved to give better strength to the porous asphalt mixture and the addition of kenaf fiber gives higher stability and stiffness for both type of mixture has been indicated to lead better resistance. This result is consistent with past study [16].

3.2.2. VTM and VFA

The Voids filled with asphalt (VFA) and the void in total mix (VTM) for the porous asphalt mixtures is illustrated in Fig. 7 and Table 1. The highest value of VFA is shown at the new gradation porous asphalt mixture (NPA) with a value of 73.48 and the lowest VFA is the conventional porous asphalt mixture (CPA). Meanwhile, from the VTM graph, it shows that void in total mix is reduced with 7.7% and 30.9% when kenaf fiber was added for CPA and NPA mixture, respectively. The new gradation porous asphalt mixture (NPA)

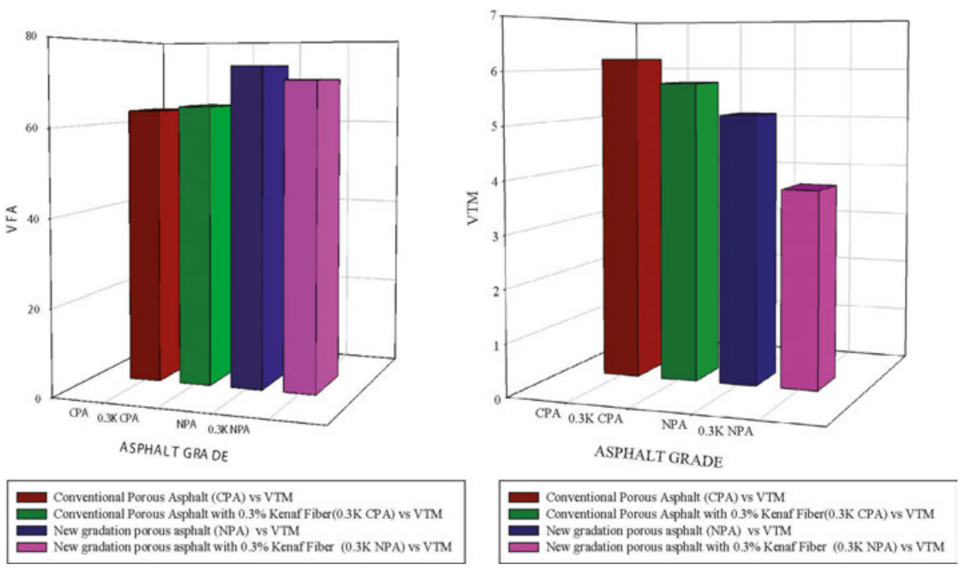


Fig. 7. Volumetric properties VFA and VTM of porous asphalt mixtures

shows a good performance in reducing the voids in asphalt mixture. It shows that the kenaf fiber is tend to have a good bonding in between aggregates and bitumen since the voids in total mix reduced by adding 0.3% of kenaf fiber in the new gradation porous asphalt mixture (NPA). From the graph, the VTM and VFA is slightly reduced with the addition of kenaf fiber but kenaf fiber does not contribute in conventional porous asphalt mixture (CPA) since the value of VFA is increased. Overall, these trends indicate that the existence of kenaf fiber can significantly reduce the air void in asphalt mixture especially to the new gradation porous asphalt mixture (NPA).

Table 2. VFA values for all PA specimens

Asphalt Grade	VFA (%)
CPA	63.33
0.3K CPA	64.41
NPA	73.48
0.3K NPA	70.62

3.2.3. Density

Fig. 8 shows the flow and density trends for all porous asphalt mixture. From the Fig. 8, it shows that the conventional porous asphalt (CPA) and the new gradation porous asphalt (NPA) gives better density with the addition of kenaf fiber. Overall, NPA with addition of kenaf fiber (0.3K NPA) has the highest value of density. Basically, density of an asphalt mixture is much related to the compaction effort and air voids within the mix. The lower the air voids, the higher the density is and the asphalt mixture become more durable. It is a clear trend that density of the new gradation porous asphalt (NPA) is better than the conventional porous asphalt mixture (CPA) but the addition of 0.3% kenaf fiber does not contribute to the durability of asphalt mixture. The addition of 0.3% kenaf fiber tends to give a better durability to the conventional porous asphalt mixture where the differences is just minimal with only 0.4%. This study shows the same trend as past study by [17]. On the other hand, the trends of flow values are same as density for all type of porous asphalt mixture. It could be seen from the graph; the flow value slightly differs for the new gradation porous asphalt (NPA) and the new grade with 0.3% kenaf fiber (0.3K NPA). However, it is increases rapidly from 12.90 to 21.22 when the conventional porous asphalt mixture is added with 0.3% of kenaf fiber. It shows an increment of 48.8% and 16.6% for CPA and NPA, respectively where the usage of 0.3% kenaf fiber proved to have a great bonding with bitumen in both porous asphalt mixture.

The density value is slightly different for CPA with only 0.4% increment while flow increase rapidly with 48.8%. This trend shows the higher the flow, the higher the density of the mixture. This is due to the addition of kenaf fiber that the properties of kenaf fiber that good in strengthen the bonding with aggregates and bitumen. The higher rate of flow value of CPA mixture may also be attributed to the use of filler in the mixture.

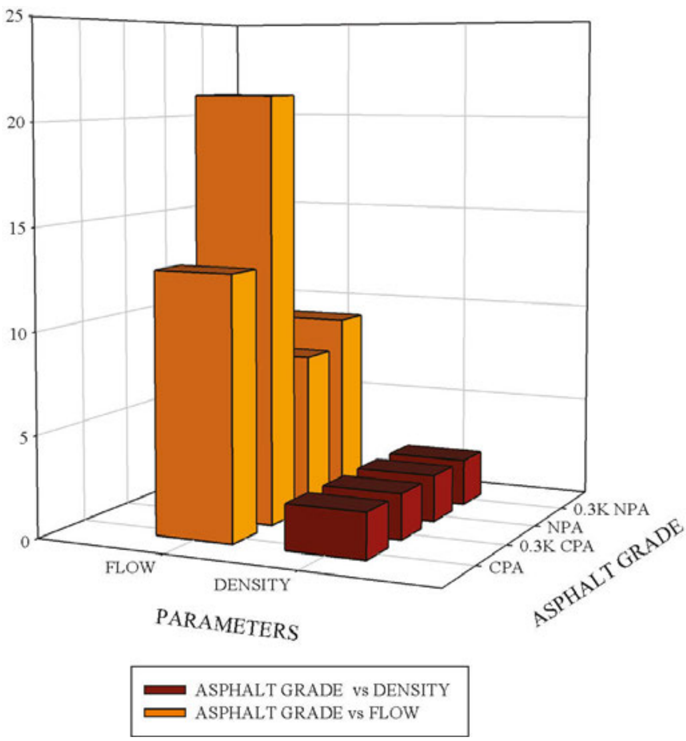


Fig. 8. Asphalt Grade vs. Density vs. Flow

4. Conclusions

Air voids can be consistently generated by the creation of the new aggregate gradation. The emphasis is on the gradation and shape of the aggregate, which mainly affect air voids matter. The grading curves are examined thoroughly in order to know the conduct of the coarse aggregate and of the fine total to achieve a better gradation. It is therefore important that rough and fine aggregates are well classified in order to achieve better asphalt mixture efficiency. The study looks at the Marshall properties of asphalt mixtures the addition of kenaf fiber. The objective of using kenaf fiber that adding into the mixture is to study the performance of porous asphalt mixture that incorporate with kenaf fiber at optimum weight that in line with Malaysian Public Work Department for Road Works It was found that the optimum bitumen content has lead to a better stability than the mixture and other Volumetric Properties. Also, The addition of kenaf fiber in conventional porous asphalt (CPA) and the new gradation of porous asphalt mixture shows a good collaboration. Kenaf fiber tends to improve the stability of the mixture especially the new gradation porous asphalt. However, kenaf fiber does not prone to give better resistance towards the conventional porous asphalt mixture (CPA).

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