MECHANICAL PERFORMANCE OF TWO DIFFERENT GRADATIONS OF POROUS ASPHALT MIXTURES INCORPORATING BAMBOO FIBER

Shoaib Md Shahnewaz, Khairil Azman Bin Masri*, Nadiatul Adilah Ahmad Abdul Ghani, Ramadhansyah Putra Jaya and Chin Siew Choo

Received: July 10, 2023; Revised: October 30, 2023; Accepted: January 16, 2024

Abstract

Porous asphalt (PA) is used to control the effects of storm water and reduce runoff. However, due to high air void content, it decreases the volumetric properties and tensile strength of PA. Thus, this study aims to investigate the inclusion of bamboo fiber enhances the volumetric properties of PA and contributes to the resolution of the low tensile strength problem. Stability, flow, density, and stiffness are some variables considered. Other considerations include the use of a void filled with bitumen (VFB) with two separate gradations of polyacrylonitrile (PA) and four different percentages of bamboo fiber (0.2 percent, 0.3 percent, 0.4 percent, and 0.5 percent). In addition, the permeability, binder drain-down, and Cantabro loss tests are used to analyze the modified PA's physical qualities. According to the findings, including bamboo could contribute considerably to improving the inner structure of PA for both grades. Besides, additional bamboo fiber significantly reduces the abrasion value by 80%, whereas the binder drain down improved the volumetric properties and preserved the permeability characteristics of PA. Therefore, it can be concluded that the existence of bamboo PA can significantly improved the mechanical performance of PA.

Keywords: **Bamboo fiber, Porous Asphalt, Volumetric Properties, Physical Properties**

Introduction

Porous asphalt (PA) is distinguished from conventional thick asphalt by a higher air void content (typically between 18 and 22 percent) and a gap aggregate gradation. The higher air void quantity helps prevent erosion, enhances wet protection, and lowers spray due to its porous construction. Also, this construction makes it possible for rainwater to run away from the road in the opposite direction of the road, which reduces runoff. After a downpour, the PA pore network, which contradicts to dense-graded asphalt, becomes saturated with water and draws more moisture from the surrounding air (Salih *et al*., 2018). Since 1950, PA has increased the aggregate composition of pavements, making them more porous. Within the context of this model, PA is used relatively often as

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia. E-mail: khairilazman@umpsa.edu.my
* *Corresponding author*

DOI: https://doi.org/10.55766/sujst-2024-01-e01698

a non-structural wear mechanism in both the United States and Europe. On the other hand, the history of this kind of asphalt in the United States has been a bit of a mixed bag, with some states claiming that it has high performance while others prohibiting its usage owing to poor performance (Slebi-Acevedo *et al*., 2020; Yang *et al*., 2021).

The PA combination's strength and durability needed to be improved since the mixture had many pore structures. This was the cause of the problem. The degree of wear and tear inflicted on the asphalt binder is crucial in deciding how long PA mixtures will remain functional. The potential for loose disintegration of the mix due to degradation of the asphalt binder is the primary focus of the study on the adhesion mechanism of PA mixed. It is well known that the Cantabro test is the primary tool responsible for defining the bonding degradation of practical pavement when exposed to repeated axial stress (Huang *et al*., 2022).

Despite this, PA improves storm water drainage, eliminates scraping and blowing on vehicles and pedestrians, boosts skid resistance, decreases noise and rutting resistance, and offers a range of other benefits for the environment and public safety. In addition, Kusumawardani and Wong *et al*. (2020) discovered that when PA was compared to different types of pavement, it was shown that PA has a former surface layer temperature during the day and a subordinate surface layer temperature during the night. PA's lower surface layer temperature demonstrated this during the day. The results showed this when the temperature was taken at the top of the pavement. The performance of the PA may be significantly influenced by a broad number of parameters, just two of which are the qualities of the asphalt binder and the shape in which the aggregates are packed. However, these two elements alone may have a significant influence.

The interaction of individual particles inside the coarse aggregates is responsible for most of the aggregate packing in PA. This particular packing has a negligible amount of fine aggregates as a fraction. It has been shown that PA has a lower extensive base rutting tolerance than ordinary dense-graded asphalt, which is notably not beneficial during the summer months when rutting is the most critical stress. This is due to the high air void content of PA, causing the reduction of its mechanical properties. PA use is acceptable in Malaysia due to the tropical atmosphere and continuous rainfall throughout the year in this Southeast Asian nation. This is particularly true for low-strength pavements like pedestrian and bicycle lanes. The presence of rust poses a risk not only to the security of the highway but also to the permeability of the PA and the PA's useful life Kusumawardani and Wong *et al*. (2020).

Problems with PA may include one or more combinations of ravelling, cracking, and pitting due to the large voids, stone-to-stone interlocking structures, frequent traffic loads, and complicated environmental conditions. These factors all contribute to the instability of PA. It is also possible for these problems to develop simultaneously with one another. Ravelling was the most prominent issue with PA, as it caused aggregate to slide off the top surface of the pavement and was the primary factor that led to a significantly decreased service life for the pavement. In addition to ravelling, clogging is another problem connected to PA that must be considered. The probability of PA being clogged is increased, which is one of the most detrimental consequences of less water penetration on the system. In addition, the presence of water harms the production of dense-graded asphalt (for instance, it may produce moisture damage), which is a prelude to the evolution of some types of loss, such as rutting, and speeds up the process.

The most effective technique for ravelling is one that involves the application of PA by aggregate stripping. It is generally accepted that aggregate stripping is a significant limitation on the long-life duration of PA, and the expectation of achieving the most excellent possible service life for PA can only be realized if aggregate stripping can be circumvented. In other words, if aggregate stripping can be avoided, PA will have longer long-life duration. As a consequence, an effort was made to revitalize the asphalt's curing ability by spraying rejuvenators over PA to stop aggregate ravelling, increase the asphalt's service life, and fulfil the purpose of the desired maintenance effect (Xu *et al*., 2018). To be effective in terms of their penetration capacity and their ability to minimize noise, Pavements need to have their clogs cleared regularly. Only then will they be able to fulfil their potential. Vacuuming the pavement or washing it with water under high pressure is two methods that may be used to do this task at least once a year. Which way is used will depend on the specifications of the area.

A study by Fediuk and Ali (2022) developed and organized the present new developments in the field of environmentally friendly built construction and building materials. Thus, this study focuses on the utilization of natural fiber such as bamboo fiber for the potential improvement of PA performance. Based on the findings of several laboratory studies show what effect the addition of fibers has on the PA. The results of this study, derived from laboratory testing and an examination of the gathered information, indicate that fiber-modified

PA pavement outperforms regular PA pavement in terms of its overall performance.

The present study examines the physical and morphological features of two distinct gradations in PA pavement. Before this, several investigations had been carried out using other types of fiber-like materials (such as steel fiber, cellulose fiber, glass fiber, aramid fiber, and polypropylene fiber) in conjunction with PA. However, there has been little research conducted on the integration of bamboo fiber with PA. The deficiency in this research is in the selection of the precise method for integrating bamboo fiber into PA pavement. Nevertheless, the integration of natural components such as Bamboo fiber into research activity is still significantly far from practical implementation. Another concern about PA is aggregate gradation since the size of the aggregate might provide challenges in terms of pavement bonding. Although design considerations may be flawless, the performance of pavement might be compromised because to variations in aggregate size and shape. This research aims to determine the total performance of PA by integrating bamboo fiber, taking into account all the aforementioned difficulties.

Materials and Methods

Bamboo fiber (Gigantochlea cotechino) that ranges in age from three to four years is obtained from Raub, Pahang. In addition, three to five years are the mature phase for bamboo plant where it reaches its maximum density. The culms of the bamboo were cut into splints with dimensions of 1500 millimeters, 20 millimeters, and 10 millimeters, respectively. In this project, the penetration-quality bituminous binder with a grade of PEN 60/70 or above followed the Malaysian Public Works Department's Road Work Specification. In this work (JKR/SPJ/2008-S4, 2008), the reinforcing impact of fibers in PA was investigated using a binder with more conventional chemical makeup. Despite the extensive use of polymer-modified asphalt in Pennsylvania, which was the focus of the research, this was nevertheless accomplished.

This investigation utilized PA aggregates of two distinct gradations, denoted by the letters A and B in Figure 1. These gradations are shown in the figure. When making the PA mixture, a nominal maximum of 10 millimeters of aggregate was used for the grade. In contrast, a maximum of 14 millimeters of the sum was used when making the grade B mixture.

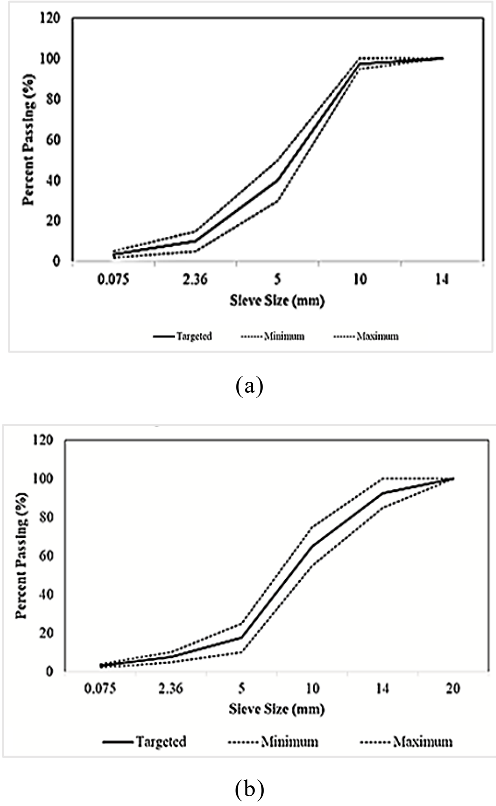

Figure 1. PA gradation. Grading A- 10 mm (a) and Grading B- 14 mm (b)

Methods

Permeability

The permeability of a rock's surface allows water or other fluids to flow through. Permeability is measured in Darcy (d) or Millidarcy (Md). A formation's relative permeability is a dimensionless ratio of its capacity to flow liquid, water, or gas compared to a single-phase fluid, usually water. A single fluid traveling through rock has a proportional permeability of 1.0. Often two or more fluids are two or more fluids that obstruct rock passage instead of simply one (Ma *et al*., 2021).

The constant head and decreasing head permeability tests determine a material's permeability. This study uses the falling head permeability test. Its main advantages are the falling head permeability test's simple equipment, clear process; inexpensive costed head permeability test's simple equipment, clear process, and inexpensive cost are its main advantages. This study has been evaluated by (Radzi *et al*., 2020).

After soaking the sample, it was immersed for less than 24 hours. Seal the cylinder test piece's side with Vaseline and preserve it with a thin rubber coating. After placing the ready-made test sample on the bottom of the sleeve, place it on the bracket with the clear acrylic sleeve and close the gap between the top half of the test piece and the rubber putty sleeve. Label the start time outside the acrylic pipe to monitor it. Find the water pipe at the sample's top and 10 centimeters above it to determine a head difference of 10 cm. Use a jar to swiftly inject water into the cylinder before it reaches the required level. Do this before the water cylinder's selected level. Stop recording time on the stopwatch when the water level drops and start again when it rises. Start timing when the water reaches the higher mark. Equation 1 was used to get the permeability coefficient.

$$K_F = \frac{\alpha l}{At} 1n\ (h_1 / h_2) \qquad (1)$$

Binder Drain-down

When working with restricted aggregate surface mixtures, particularly porous asphalt, binder drainage is a significant challenge (PA). The Transport Research Laboratory created the Binder Drainage Experiment in the United Kingdom. This experiment is commonly used to establish an upper limit on the suitable binder amount for a porous mixture (Syafiqah *et al*., 2021).

The sample of the PA mixture that has yet to be compacted should first be placed in a tarred wire basket that was fabricated in the lab as shown in Figure 2 and Figure 3. The whole mixture should be placed in the wire basket. After transferring the mixture into the basket, you should avoid merging it, or you will mess it up. Determine the mass of the combination down to the nearest 0.1 gram. After that, determine the mass of a paper plate to an accuracy of 0.1 gram, register it, and write down the result. Put the basket on the paper and bake it for at least three hours at a temperature higher than 28 degrees Celsius. After the mixes have been in the oven for three hours, remove the basket and paper plate, recalculate the mass of the paper plate to the nearest 0.1 gram, and then register it.

Cantabro Loss

During this stage of the research procedure, the Los Angeles Abrasion Machine is used to do calculations on the fragmentation of the specimens that have been compacted. PFC, LRA, and hot-mix cold-laid consistency are all assessed in terms of weight loss percentage, also known as cantabro loss. This value is directly proportional to the amount of asphalt binder used as well as its specific composition (Dong *et al*., 2013).

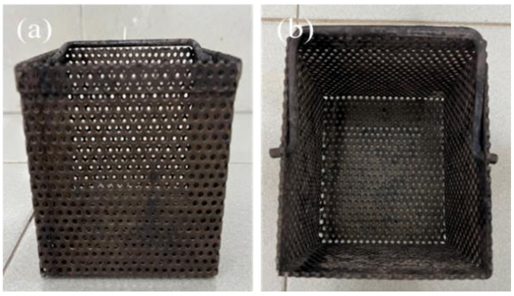

Figure 2. Binder drain-down basket side (a) and top view (b)

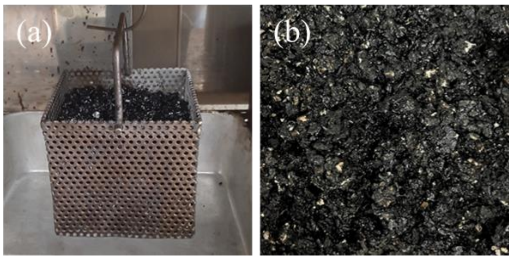

Figure 3. Binder Draindown loose sample before (a) and after test (b).

The specimens were allowed to air dry at room temperature for two days. After that, the samples are kept for at least three hours at a temperature of 25 degrees Celsius, the test temperature, before being tested as shown in Figure 4 and Figure 5. After the required time has passed since the specimens were last housed, they should be weighed (M0) and immediately placed into the Los Angeles drum that does not contain abrasion loads (ball). After that, the drum is turned for three hundred rotations at speeds ranging from 188 to 208 rad/s. After the test, the specimen will be weighed (M1). Stone loss, or attrition resistance, is calculated for each specimen.

$$L = \frac{M_0 - M_1}{M_1} \times 100 \qquad (2)$$

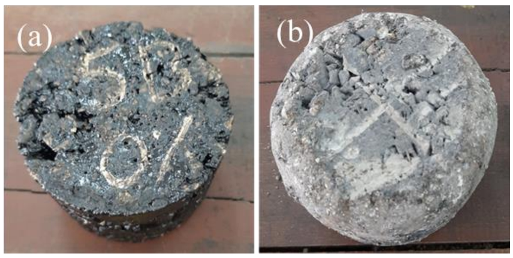

Figure 4. Cantabro loss sample before (a) and after test (b).

Marshall Stability

The Marshall stability test measures a bituminous material's maximum strain at a 30.8 mm/minute loading rate. Until it reaches its limit, the test load will be increased. After then, the loading is stopped, and the maximum load, such as the Marshall stability, is documented. After then, the burden only decreases. The specimen's plastic flow is measured using a dial gauge during the loading test. It helps interpret test findings. The flow value will match the vertical deformation after maximum load (Chu and Fwa *et al*., 2019). The aggregate mix form and traffic intensity determine the best binder material for this test. This study may link Marshall stability and bitumen percentage, and this study may connect bitumen percentage may be bound by this study (Ogundipe *et al*., 2016).

The specimens will be cooked in a water bath at 50-0 degrees Celsius for 30-35 minutes or in an oven at 150-200 degrees Fahrenheit for 1.5-2 hours. After removing the samples from the range or water bath, they were put in the lower breaking head. After that, an upper specimen splitting headpiece piece was installed, and the assembly was installed on the testing machine. After programming, the flow meter will reset to zero. The load was applied at 30 mm/min to produce an accurate measurement. The work in Newton matched the weight carried. The flow meter counted millimeters while recording. Simultaneously, this measurement was taken (Masri *et al*., 2016).

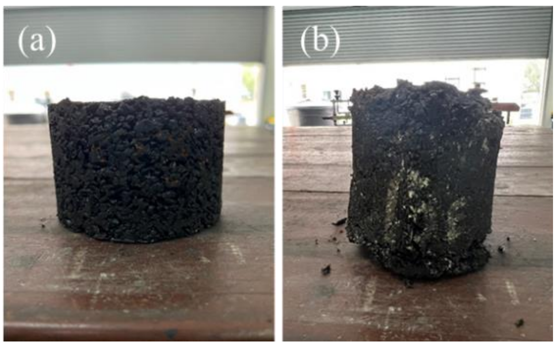

Figure 5. Marshall stability sample before (a) and after test (b).

Results and Discussion

Scanning Electron Microscope

SEM images at different magnifications are shown in Figure 6. Soaking bamboo strips before crushing did not change the extraction technique. Whether the material was soaked before crushing or crushed immediately after washing, each age group produced roughly the same amount of fibers. Despite this, visual examination showed that 0-1-year-old bamboo fibers created more short fibers than 2-4-year-old bamboo fibers, but this was not tested (Rocky and Thompson *et al*., 2018). The pieces of bamboo were put through a cleaning procedure that consist of soaking them in a plain water at room temperature for several lengths and then be dried before use. Figure 6b revealed that the fracture occurred in two separate places when seen at a magnification of 100 millimeters. Figures 6a and 6c depict the fracture of bamboo at two distinct magnification levels, while Figures 6d and 6g exhibit xylem at two magnification levels. In this collection of SEM images, the fiber pull-out is seen in Figures 6c and 6f at magnifications of 30 m and 200 m, respectively. These figures were created using a 30 m and a 200 m resolution. But none of the bamboo fiber SEM photographs ever revealed any other significant flaws, such as matrix traces, bonding between the fibers, or breaking of the fibers. To acquire photos of this kind, testing with FESEM will need to be carried out since, in contrast to SEM, FESEM can produce more accurate images.

It is vital to understand the chemical components that makeup bamboo fiber to choose chemicals that are more effective for degumming and to select acceptable processing procedures. The removal of lignin, pectin, hemicellulose, and extractives from fibers is accomplished by degumming. During the production of fibers, this procedure is carried out (Rocky and Thompson *et al*., 2018). Figure 7 displays an electron image of bamboo fiber, and this specific fiber was chosen for further investigation. Figure 8 shows EDX photographs that reveal chemical compositions in carbon (C), oxygen (O), and sodium (Na), and EDX analysis identifies carbon as a built-up layer of carbon. These chemical compositions were detected in carbon, oxygen, and sodium. Carbon, oxygen, and sodium each have a unique chemical makeup, as seen in Figure 8. The percentage of oxygen is 42.533, whereas the percentage of sodium is 0.818. The atomic proportion of carbon is 56.469, while the share of oxygen is 42.533. In this criterion, the balance of carbon is higher than the other two criteria, oxygen and sodium, when both depth and speed rate are constant.

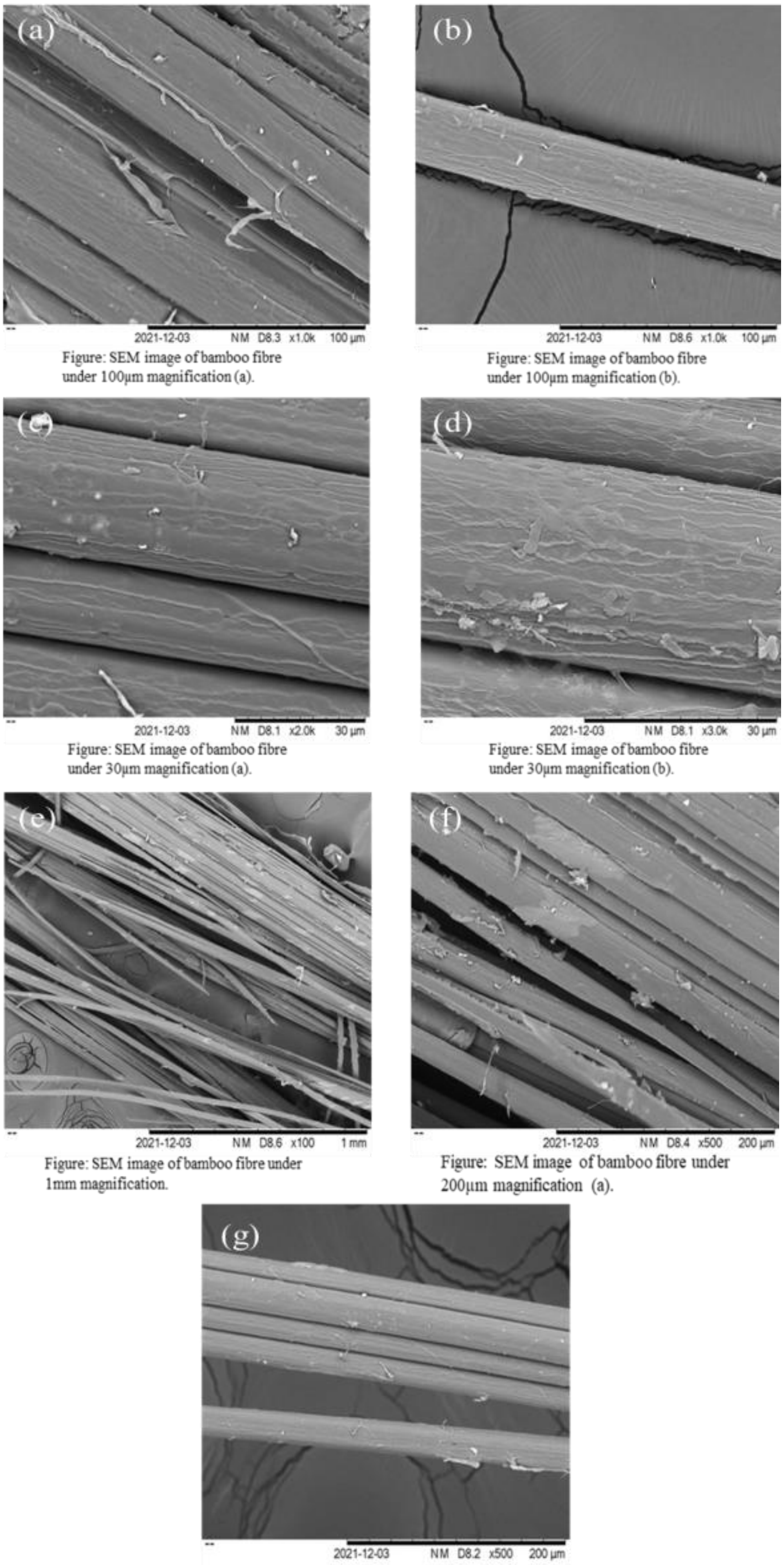

Figure 6. SEM images of bamboo fiber under 100µm magnification (a, b), 30µm magnification (c, d), 1mm magnification (e), and 200µm magnification (f, g)

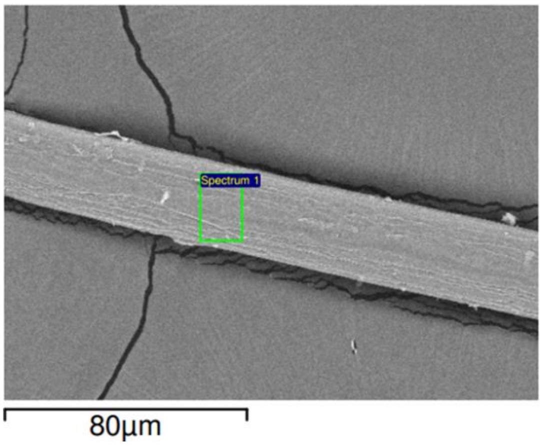

Figure 7. SEM image of single bamboo fiber under 80µm magnification

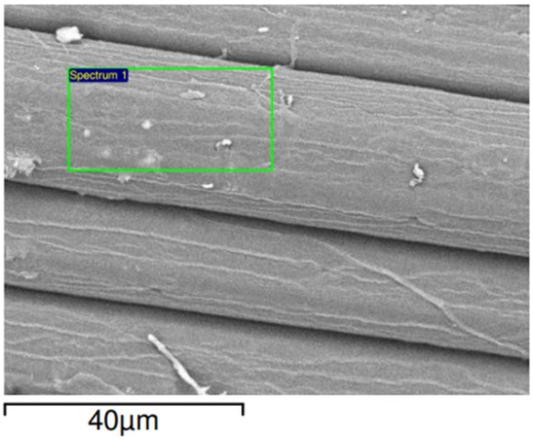

Figure 9. SEM image of single bamboo fiber under 40µm magnification

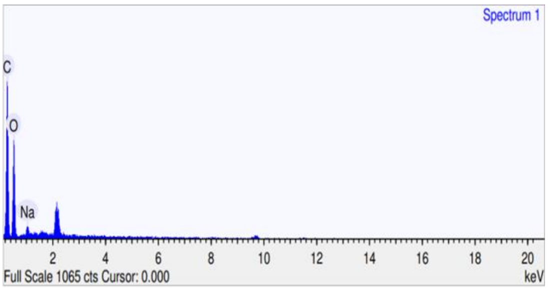

Figure 8. Chemical compositions found in bamboo fiber, including C, O, and Na

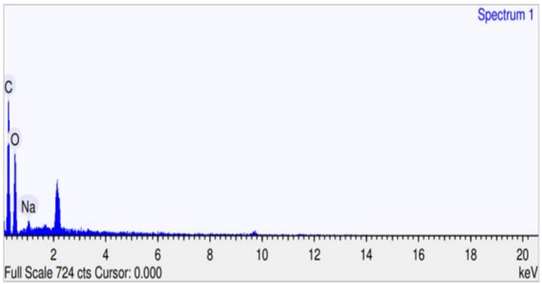

Figure 10. Chemical compositions found in bamboo fiber, including C, O, and Na

The electron photograph of bamboo fiber seen in Figure 9 was the one that was chosen for closer inspection. These EDX chemical compositions were recognized as including carbon, oxygen, and sodium, and the EDX analysis revealed that carbon was present as a built-up layer. The EDX is seen in Figure 10. In comparison, the atomic percentage of oxygen is 42.057, whereas the atomic percentage of sodium is 1.026. The percentage of carbon is 56.017. With the exception of sodium, the proportion of carbon and oxygen in this sample is much lower compared to the one that was found in the earlier collection of data at the same depth and speed rate.

Permeability

The falling head permeability test measures PA's permeability, which may be moderate to low (less than 0.0001 m/s). Similar samples and design mixes were utilized in this test. The falling head technique determines permeability for PA low discharge. The continuous head permeability test was used for conventional asphalt that discharges satisfactorily after a while.

According to Figure 11, both controls PA have a higher permeability average value than the experimental PA (1.155 m/s and 1.265 m/s, respectively). Combining bamboo fiber at respective percentages ranging from 0.2 percent to 0.5 percent with PA of both grades achieved the maximum permeability coefficient average value at grade B (1.41 m/s). At 0.3 percent, both maximum and minimum permeability coefficient average values were achieved at grade (1.235 m/s and 0.81 m/s). Above all other percentages, 0.3 percent of grade B was found to have the lowest permeability rating. This is something that can be mentioned. It indicates that water moved through the PA sample gradually and steadily, which caused the strength of the PA sample to decrease. However, as the particles are reduced, the spaces between them become more condensed. Because of this, there is an increase in the resistance to the flow of the water, which leads to a fall in permeability-this is why a 0.3 percent PA sample has a lower concentration of permeability than a 0.2 percent PA sample.

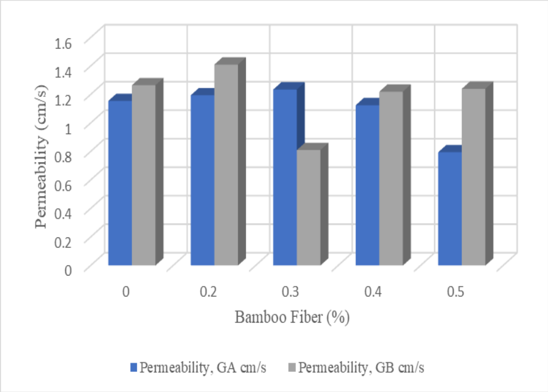

Figure 11. Permeability average graph

Because the holes between the solid particles in the PA are linked, water can move freely through the PA. This shows that the change in aggregate size repeatedly impacts the decrease in permeability. It also brings a decline in the permeability strength of PA pavement and the involvement of other environmental elements, such as weather and severe rainfall. As a direct consequence, previous research has shown an absence of evidence that can be relied upon to estimate permeability consistently. Field investigations revealed that PA exhibits a diminishing degree of permeability with each passing period (Akhtar *et al*., 2021). Furthermore, as compared to the control PA mixture, the PA mixture with a finer gradation exhibits worse drainage efficiency due to the increased likelihood of fine aggregate particles obstructing internal pores and reducing the air void contents of the PA mixture. The addition of fiber has a minor influence on the permeability coefficient at both gradations, which the changing pore microstructure should also cause (Ma *et al*., 2021). The incorporation of bamboo fiber in a certain proportion of PA pavement yields optimal results in terms of both gradations.

Binder Drain-down

A binder drain-down test with a loose sample was used for data collection. A control sample and four various percentages of bamboo fiber that were added to justify the test are shown in Figure 12. According to the figure, the aggregate and bitumen bonding of the control sample was much better than those of grade A. Incorporating 0.2 percent to 0.4 percent bamboo fiber into PA will often decrease the average value, except for the 0.4 percent area. In this region, grade A has the highest average percentage, and both average values are practically similar. Compared to 0.2 percent to 0.4 percent, the enhanced bamboo fiber concentration of 0.5 percent has a much higher average value. In contrast, a proportion of 0.5 percent is the sweet spot when mixing with PA samples. Furthermore, it shows that both the control and the bamboo fiber addition boost the binder drain-down capacity of the PA sample.

The quantity of binder material that evaporated changed visibly in response to the different amounts of bamboo fiber used. The binder and tiny particles were expelled into the sample that served as the control. According to the findings of several investigations, the binder could drain alongside the tiny aggregates since the binder basket had a hole of 3 millimeters in diameter. However, the quantity of drained binder was reduced when the fiber content rose to higher levels (Masri *et al.*, 2016). In addition to this, increasing the maximum aggregate size resulted in a slight reduction in the maximum binder content.

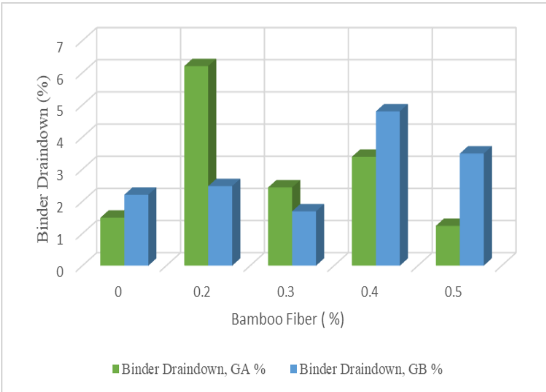

Figure 12. Binder Drain-down average graph

Cantabro Loss

Twenty different PA samples were used to conduct the cantabro loss test and assess its results. Four samples of the control PA included no bamboo fiber, but each of the sixteen samples treated with bamboo contained between 0.2 and 0.5 percent of bamboo fiber. In addition to that, the Marshall Mix design technique was used in this test. Figure 13 show that the control group (zero percent) had the highest value of cantabro loss, six percent for grade A and seven percent for grade B. This was determined by comparing the control group to the experimental group. On the other hand, when bamboo fiber was combined with porous asphalt, 0.2 percent produced the lowest cantabro loss average, which was 2 percent for grade A and 3 percent for grade B. The grade B equivalent is comparable to 0.3 percent, although it is a little bit higher than the grade B equivalent of 0.2 percent, which was 4 percent in the previous phase (Masri *et al*., 2016).

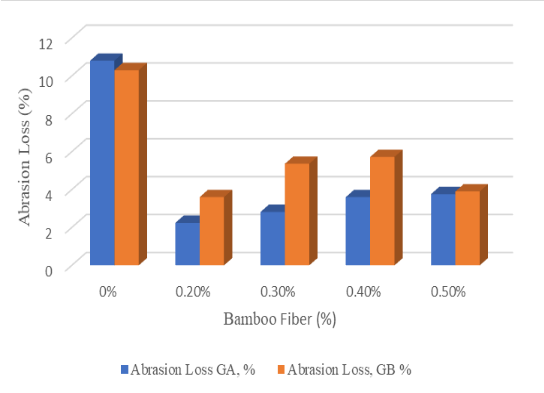

Figure 13. Cantabro Loss average graph

There is a rising pattern in the cantabro loss value for grades 0.5 and 0.4 percent bamboo-modified PA compared to grades 0.2 and 0.3 percent. This is shown by the fact that these percentages have a bamboo component. It was shown that adding less bamboo fiber to PA does not enhance its abrasion resistance because the value of cantabro loss increased when bamboo-modified PA was at a concentration of 0.2 percent. For grade A, bamboo-modified PA at a concentration of 0.3 percent achieved a cantabro loss value of 66 percent. In contrast, bamboo-modified PA at a concentration of 0.5 percent obtained a cantabro loss value of 42 percent. The cantabro loss value with the highest percentage, 51%, was acquired at 0.2 percent, while the cantabro loss value with the lowest percentage, 30%, was obtained at 0.4 percent. Both of these grades were given a B. Cantabro loss is the factor that defines the durability of pavement; a high loss percentage indicates that the pavement is becoming less durable, while a low loss percentage indicates that the pavement is becoming more durable. It has been discovered that every percentage of fiber-modified PA samples obtains a lower percentage of cantabro loss than the standard PA samples. Consequently, the typical PA sample has a shorter service life than the fiber-modified PA sample. The Cantabro test is widely used globally as a measurement indicator for pavement durability. Based on these tests' findings, adding bamboo fiber to PA pavement enhances its longevity. In addition, the abrasion values for modified specimens are ranging from 2% to 6%, compared to abrasion loss for control specimen (unmodified) reaching 10%. This shows by addition of bamboo fiber, it could significantly reduce the abrasion by 80%.

Volumetric Properties

Stability

The capacity of an asphalt mix to withstand persistent deformation is measured when we talk about stability. The stability reaches its highest value, as shown in Figures 14 and 15, at around 10 KN 0.4 percent for both PA-GA and PA-GB. Both gradations have values that differ from one another compared to specimens that have not been altered. However, compared to untreated specimens, the stability values of every transformed specimen are much more significant. This suggests that the incorporation of bamboo fiber into PA may significantly strengthen the material's resistance to the permanent deformation of its shape (Masri *et al*., 2016). Alterations to the stability value are also dependent, to a certain extent, on the aggregate ratio. This suggests that the variation in aggregate size significantly impacts the structural integrity of PA. In addition, PA grading A consists of nominal maximum aggregate size (NMAS) of 10mm, while for grading B is 14mm. Thus, these variations of sizes can also the contributing factor that affect the stability of PA specimen. By using fewer amounts of bamboo fiber, it may be possible to improve the stability of the mixes, particularly their stability, without causing a reduction in the permeability coefficient (Akhtar *et al*., 2021). As shown in Figures 16 and 17, adding 0.4 percent more bamboo fiber results in a more stable product than the other amounts of bamboo fiber.

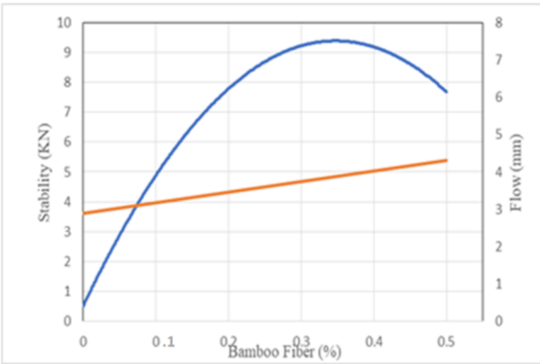

Figure 14. Stability and Flow PA-GA

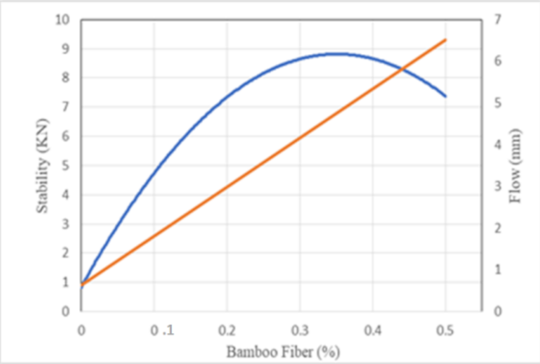

Figure 15. Stability and Flow PA-GB

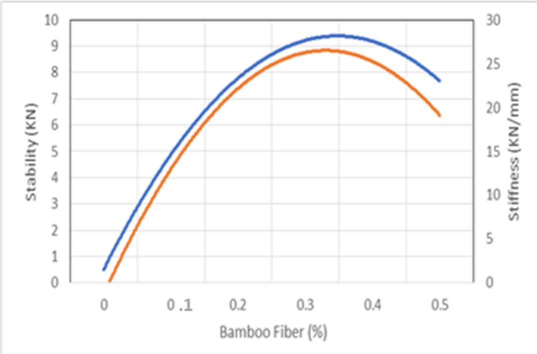

Figure 16. Stability and Stiffness PA-GA

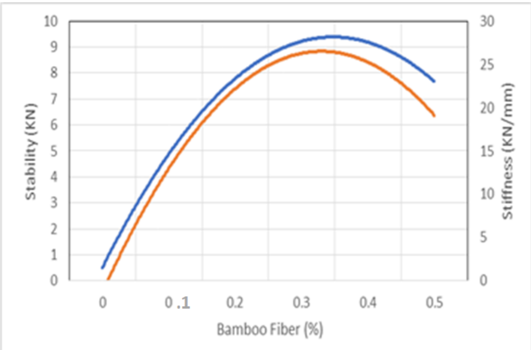

Figure 17. Stability and Stiffness PA-GB

A distinct pattern for both metrics showed that stability and density would climb to a peak level at a quantity of fiber equal to 0.4 percent before beginning to decrease. This pattern showed that stability and density would climb to a peak level at a quantity of fiber equal to 0.4 percent. Some data implies that increasing a material's stability and density will increase the material's resistance to deformation. The most excellent densities for PA-GA and PA-GB are 2.19 and 2.24, respectively, in the absence of any fiber, while the stability for both gradations is in the range of 6 to 7 KN. On the other hand, when just 0.4 percent of fiber is present, the maximum stability is 10,000 N, and the maximum density is 2,246 g/mm3. The increase in stability is roughly 30 percent more than the density increase, which is around 2 percent. However, increasing the amount of fiber by more than 0.4 percent did not increase any of the measured measures. There is compelling evidence that raising the percentage of fiber utilized in the PA mixture up to 0.4 percent was more helpful in boosting the material's density and stability. Figures 14 and 15 provide the results of comparing flow and stability. The orange lines representing the stability data while the blue lines representing flow and stiffness. It was evident that increasing the amount of fiber employed led to a more extraordinary rise in flow value for both of the gradations. The Malaysian Public Work Department for Road works (JKR/SPJ/2008-S4, 2008) suggests that the flow should be at most 4 mm. Although the increment has grown, it is still within what is considered acceptable (Abdul *et al.*, 2021).

Flow

The flow performance of the asphalt mix is shown in Figures 18 through 21 for a range of different percentages of the total amount of fiber. The adjusted PA combination produced flow values inconsistent with one another when the amount of fiber was increased. The flow numbers averaged out in the neighborhood of two to four millimeters. According to the Malaysian Public Works Department Road works Standard, the flow values for surfaces and pavement under the heavy traffic category should be 3 mm to 5 mm. This is defined in the roadwork standard (JKR/SPJ/2008-S4, 2008). As a direct consequence of this, each specimen that was used in this inquiry fulfilled the requirements that were specified for the standard. Both Figures 20 and 21 demonstrate a connection between the proportion of bamboo fiber present in the sample mixture and an increase in the density of the samples as a whole. The blue line represents stiffness value while the orange lines representing flow and density. The sample with the most significant proportion of bamboo fiber has the lowest bulk density of 2.17 g/mm (GA) and 2.22 (GB). Still, the sample mixture that contains 0.4 percent glass fiber has a maximum density of 2.246 g/mm (GB). It is feasible to make an educated guess about the air volume present in the spaces between the aggregate particles in a full mix. When there is a more significant percentage of bamboo fiber, the flow rate decreases slightly, as seen in Figures 20 and 21. This is visible evidence of what happens. The sample that consisted of 5 percent bamboo fiber had the lowest value for VFA, which was 0.617 percent, while the sample that consisted of 1 percent bamboo fiber had the highest value, which was 0.996 percent. This illustrates that the particles of bamboo fiber do not fill the spaces between the aggregates when combined with bitumen. As a direct consequence, an increasing number of spaces devoid of bitumen may be seen.

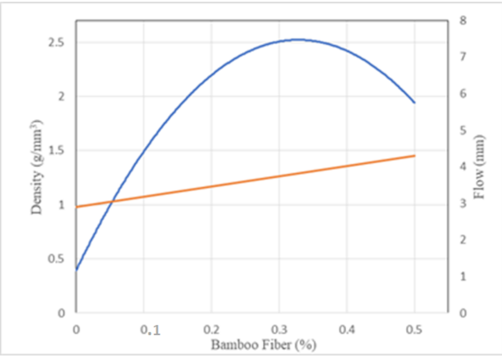

Figure 18. Density and Flow PA-GA

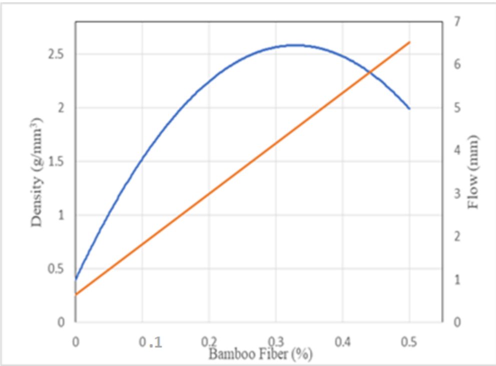

Figure 19. Density and Flow PA-GB

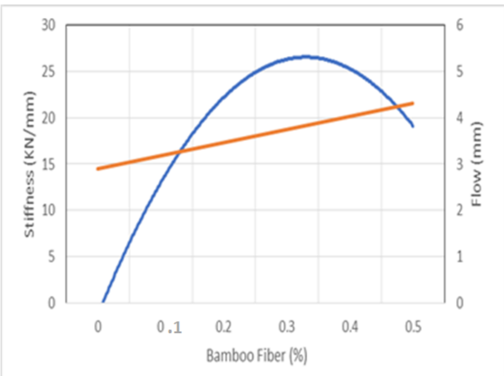

Figure 20. Stiffness and Flow PA-GA

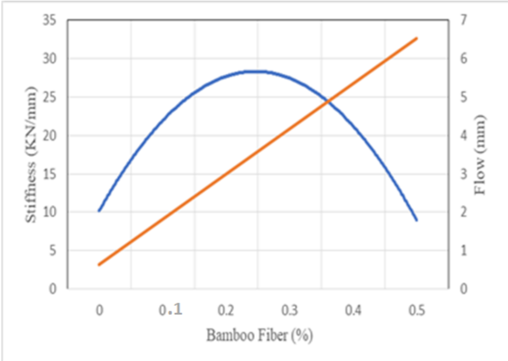

Figure 21. Stiffness and Flow PA-GB

Stiffness

The PA mixture's stiffness values of the stiffness of the PA mixture are shown in Figures 22 through 25. These values, which vary based on the quantity of fiber, are displayed. Theoretically, an asphalt mixture with a higher stiffness would have more excellent resistance and extended durability than a lower one. If the asphalt is blended to a stiffer consistency, surface damages to flexible pavements, like raveling and bleeding, will be far less severe. Examples of these types of damage are bleeding and bleeding. It is clear from the graphs that increasing the amount of fiber added to the PA mixture to a level of 0.2 percent would result in the highest possible level of stiffness for both grades. When compared to the control specimen, which only has 8 KN/mm (GA) and 36 KN/mm (GB) of stiffness, the value of stiffness at 0.2 percent quantity of fiber is approximately 30 KN/mm (GA) and 40 KN/mm, respectively. This is in contrast to the fact that the control specimen only has these values for stiffness. The addition of bamboo fiber likely resulted in an enhancement in the PA mixture's rigidity. From the results, the findings are consistent with a study by Akhtar *et al*. (2021).

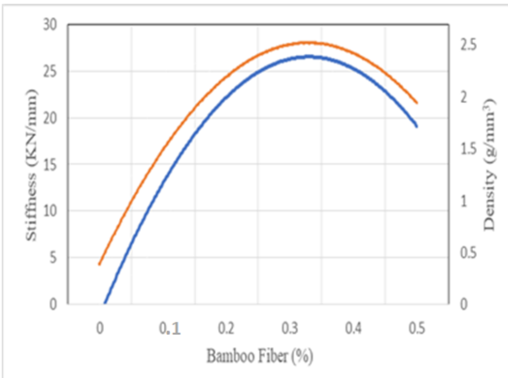

Figure 22. Stiffness and Density PA-GA

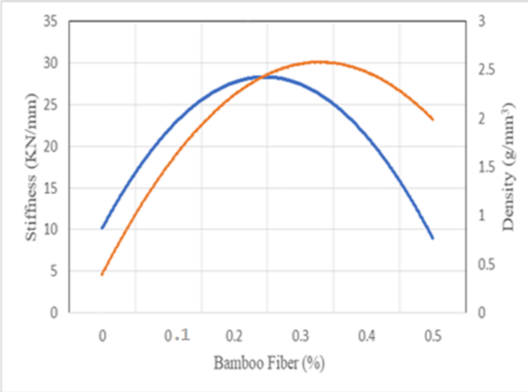

Figure 23. Stiffness and Density PA-GB

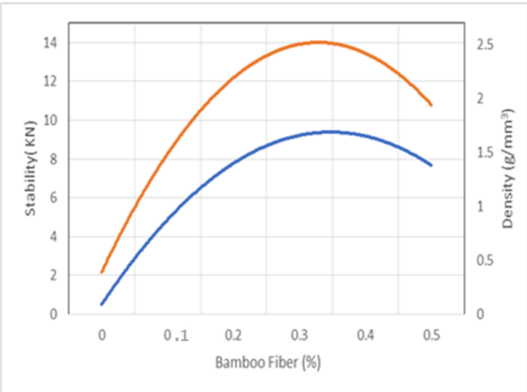

Figure 24. Stability and Density PA-GA

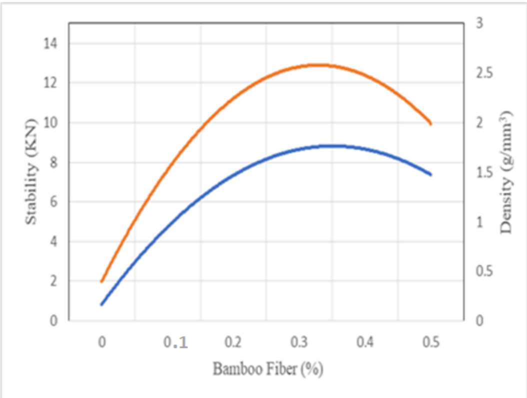

Figure 25. Stiffness and Flow PA-GA

Conclusions

The binder drain-down test evaluates a porous mix's ability to retain binder without draining. The binder drain-down control sample's ideal drainage capacity is greater than the modified PA sample's. The fiber percentage minimizes binder drainage. The principal binder component was evaluated using it. However, the modified PA sample's increased fiber content (0.5 percent) indicates higher binder drainage. The mix's permeability was investigated. All samples had adequate permeability. A modified PA sample with 0.2 percent material had the best permeability average value, and increasing the fiber content decreased it. This suggests that a smaller fraction of altered PA has smooth water flow, which increases permeability. Particle loss was similar across all modified PA mixes when experimental bitumen was tested for its effect on PA mix abrasion resistance. The control sample loses more particles than the modified PA sample. Thus, the bamboo fiber in PA mixes significantly reduces abrasion loss.

Marshal testing assessed volumetric uniformity in the produced samples. The generated materials had good stability ratings, from the control sample (containing 0 percent) to the 0.5 percent fiber-modified polyamide (PA) sample. The generated materials had good stability ratings, from the control sample (containing 0 percent) to the 0.5 percent fiber-modified polyamide (PA) sample. For example, the sample with 0.4 percent fiber-modified PA had the highest average value for both gradings (aggregate size 10 mm, 5 mm, 2.36 mm, and 0.075 mm for grading A and 14 mm, 10 mm, 5 mm, 2.36 mm, and 0.075 mm for grading B and sample thickness 71 mm and 70.63 mm) and the highest average stability of 9.8425 kN and 9. Bamboo fiber alters a PA mixture's air void and asphalt content.

PA-GB specimen's physical and volumetric qualities are much more significant than PA-GA specimens. This difference may be seen when comparing PA-GB to PA-GA. This suggests that the aggregate's nominal size may impact the overall performance of PA in terms of its resistance to a variety of pavement distresses. This is due to the NMAS of grading B is 14mm, while for grading A is 10mm, which clearly shows that higher NMAS size of PA specimen can contribute significantly towards the overall performance.

The usage of bamboo fiber is also promising in designing more eco-friendly and durable porous asphalt pavement. For the purpose of extending the lifespan of porous asphalt pavement, it is suggested that the incorporation of bamboo fiber into roadways, parking lots, or walkways would have a significant influence.

Acknowledgement

The authors would like to acknowledge Universiti Malaysia Pahang Al-Sultan Abdullah for funding this study under internal grant number RDU210303.

References

Abdul, M.M., Muslich, H.S., Madzlan, N., Nur Izzi M.Y., Rizwan, A.M., Abdulnaser, M.A., and Mujahid, A., (2021). Physicochemical, rheological and morphological properties of bitumen incorporating petroleum sludge. Construction and Building Materials, 297:123738. https://doi.org/10.1016/j.conbuildmat.2021.123738

Akhtar, M.N., Al-Shamrani, A.M., Jameel, M., Khan, N.A., Ibrahim, Z., and Akhtar, J.N. (2021). Stability and permeability characteristics of porous asphalt pavement: An experimental case study. Case Studies in Construction Materials, 15:e00591. https://doi.org/10.1016/j.cscm.2021.e00591

Chu, L. and Fwa, T.F. (2019). Functional sustainability of single- and double-layer porous asphalt pavements. Construction and Building Materials, 197:436-443. https://doi.org/10.1016/j.conbuildmat.2018.11.162

Dong, Q., Wu, H., Huang, B., Shu, X., and Wang, K. (2013). Investigation into Laboratory Abrasion Test Methods for Pervious Concrete. Journal of Materials in Civil Engineering, 25(7):886-892. https://doi.org/10.1061/(asce)mt.1943-5533.0000683.

Fediuk, R. and Ali M. (2022), Recyclable Materials for Ecofriendly Technology. Materials 2022, 15(20):7,133. https://doi.org/10.3390/ma15207133

Huang, W., Yu, H., Lin, Y., Zheng, Y., Ding, Q., Tong, B., and Wang, T. (2022). Energy analysis for evaluating durability of porous asphalt mixture. Construction and Building Materials, 326:126819. https://doi.org/10.1016/j.conbuildmat.2022.126819

Jalan, C., (2008). Standard specification for road works Malaysia. SCRIBD, 4:1-187.

Kusumawardani, D.M. and Wong, Y.D. (2020). The influence of aggregate shape properties on aggregate packing in porous asphalt mixture (PAM). Construction and Building Materials, 255:119379. https://doi.org/10.1016/j.conbuildmat.2020.119379

Ma, X., Jiang, J., Zhao, Y., and Wang, H. (2021). Characterization of the interconnected pore and its relationship to the directional permeability of porous asphalt mixture. Construction and Building Materials, 269:121233. https://doi.org/10.1016/j.conbuildmat.2020.121233

Masri, K.A., Arshad, A.K., and Samsudin, M.S. (2016). Mechanical properties of porous asphalt with nanosilica modified binder. Jurnal Teknologi, 78(7-2):139-146.

Ogundipe, O.M. (2016). Marshall Stability and Flow of Lime-modified Asphalt Concrete. Transportation Research Procedia, 14:685-693. https://doi.org/10.1016/j.trpro.2016.05.333.

Radzi, N.A.M., Masri, K.A., Ramadhansyah, P.J., Jasni, N.E., Arshad, A.K., Ahmad, J., Mashros, N., and Yaacob, H. (2020). Stability and Resilient Modulus of Porous Asphalt Incorporating Steel Fiber. IOP Conference Series: Materials Science and Engineering, 712(1). https://doi.org/10.1088/1757-899X/712/1/012027

Rocky, B.P., and Thompson, A.J. (2018). Production of natural bamboo fibers-3: SEM and EDX analyses of structures and properties. AATCC Journal of Research, 5(6):27-35. https://doi.org/10.14504/ajr.5.6.4

Salih, S., Gómez-Meijide, B., Aboufoul, M., and Garcia, A. (2018). Effect of porosity on infrared healing of fatigue damage in asphalt. Construction and Building Materials, 167:716-725. https://doi.org/10.1016/j.conbuildmat.2018.02.065

Slebi-Acevedo, C.J., Lastra-González, P., Indacoechea-Vega, I., and Castro-Fresno, D. (2020). Laboratory assessment of porous asphalt mixtures reinforced with synthetic fibers. Construction and Building Materials, 234:117224. https://doi.org/10.1016/j.conbuildmat.2019.117224

Syafiqah, S.N.Z., Masri, K.A., Jasni, N.E., and Hasan, M. (2021). Performance of Stone Mastic Asphalt incorporating Kenaf fiber. IOP Conference Series: Earth and Environmental Science, 641(1):012001.

Xu, B., Li, M., Liu, S., Fang, J., Ding, R., and Cao, D. (2018). Performance analysis of different type preventive maintenance materials for porous asphalt based on high viscosity modified asphalt. Construction and Building Materials, 191:320-329. https://doi.org/10.1016/j.conbuildmat.2018.10.004

Yang, B., Li, H., Zhang, H., Sun, L., Harvey, J., Tian, Y., Zhu, Y., Zhang, X., Han, D., and Liu, L. (2021). Environmental impact of solid waste filler in porous asphalt mixture. Construction and Building Materials, 303:124447. https://doi.org/10.1016/j.conbuildmat.2021.124447