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Effect of Bagasse and Coconut Peat Fillers on Asphalt Mixture Workability

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Abstract: Workability is of importance during asphalt construction, which plays a role in increasing stability and other performances. Using different mineral fillers can result in different asphalt workability in the same mix design. While fillers can increase stability, viscosity with regards to asphalt mastic needs to be considered for working in the field. Nowadays, waste natural materials can allow agriculturists to get more income by recycling in many industries. In this study, the objective is to determine the effect of using bagasse and coconut peat as filler on mastic viscosity and the resistance to failure performances. Findings show that the viscosities of asphalt mastic with coconut peat and bagasse fillers are relatively similar to those with limestone filler for all temperatures at 20 percent filler content. Additionally, the stabilities and flows of asphalt mixtures mixed with waste natural fillers were close to those mixed with mineral fillers at equivalent temperatures. In conclusion, the mastic viscosity is vital for determining the workability of asphalt mixture. The waste natural fillers including bagasse and coconut peat give similar mastic viscosity to limestone filler and higher than granite filler, which shows less difference to performance results.

Keywords: asphalt mastic; mastic viscosity; bagasse; coconut peat; Marshall Stability Index

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1. Introduction

Most roads have been built by asphalt, because it can offer better driving efficiency and less maintenance than concrete roads. Asphalt is an easy to find, low-cost and highly flexible material obtained from crude oil refining. In a hot mixed asphalt (HMA) construction process, the workability is of importance to be considered before paving. Workability is defined as a function accounting the ease of mixing and compaction of HMA. This definition offers the concept of HMA movement, HMA handling and road compactivity via road equipment. Mixing aggregates with asphalt binder is an important task in the production of asphalt pavement. The mixing consistency can have a significant impact on the performance of asphalt surfaces on many features of asphalt mixtures such as the thickness and homogeneity. Many parameters, including the temperatures of processing, the mineralogy of aggregates, the gradation of the aggregates, the size or shape of the aggregates and the type of asphalt binder used, affect the workability of asphalt mixtures [1,2]. While some factors may be more dominant than others, their influence depends on specific mixture characteristics and may also range from case to case. The guidelines and standards that support paving engineers in the design and production of materials should therefore be sufficient for a broad range of materials and boundary conditions.

The mixing and compaction temperature of asphalt mixtures was typically calculated by the test of an asphalt binder viscosity [3,4]. However, even for ordinary mixtures, there may be some challenges as to the correlation between the asphalt binder and mixture behaviors, when more complex material types are used.

Since the mineral filler fraction has a rather large surface area relative to the coarser aggregates in the mixtures, the physio-chemical interaction between asphalt binder and fillers can be a significant parameter in the mixture performance. It was in the 1870s that we began using asphalt fillers putting into asphalt mixtures [5]. Several researchers subsequently investigated the use of asphalt mastic stiffening fillers and found that fillers were the key factors [1,6,7]. The characteristics of fillers including the shape of the fillers, their size and size distribution, the nature of their surface texture, their adsorption intensity and the chemical composition of the fillers are of importance on long-term performance of asphalt mixtures [2,8–10]. Additionally, several experiments have shown that the Rigden voids have an effect on the geometric properties of the filler. Fractional voids are, thus, an important measure of how filler properties interact with the reinforcement of binders [8,11–23]. These essential studies show that fillers have a major effect on mastic efficiency. Nonetheless, workability and efficiency outcomes with the same asphalt mixture design are still unknown with different fillers. The decreasing optimum content of asphalt is associated with the presence of the filler [2,24,25]. Higher filler rates result in more resistance to deformation due to an increase in asphalt cohesiveness and internal consistency in the filler [2,24,26]. However, an excessive number of fillers can weaken the asphalt mixture by increasing asphalt required for aggregate coverage, thereby affecting the workability of the asphalt mixture [25,27]. If asphalt and aggregates are combined during a mixing process, the fineness of the filler can be attributed to the mastic asphalt. Interactions between asphalt and filler create certain properties that affect the asphalt mixture's efficiency. Due to its different filler surface area, it can absorb asphalt differently causing different results on the mixture of asphalt [28–30].

Nowadays, waste natural materials have been adopted in many industries. In this study, coconut peat and bagasse are chosen as fillers because they have a relatively large amount waste natural materials in Thailand. They have been produced about 4,500,000 (bagasse) and 50,000 (coconut peat) tons a year, while the aggregate fillers used for asphalt road construction are about 2,000,000 tons/year. Thus, the volume of waste natural materials is considered to be reduced by replacing mineral fillers with agricultural waste disposal fillers. Some researchers have found that replacement of asphalt by bagasse ash can improve the HMA stability of Marshall [31,32]. The application to improve the viscosity and performance of the asphalt filler was chosen for reducing the disposal and increasing the value of natural materials, bagasse, and coconut peat, which were easily discovered.

The objectives of this study are to determine the effect of using bagasse and coconut peat as fillers on mastic viscosity and to determine the stability and flow of asphalt mixture mixed with bagasse and coconut peat fillers. It is hypothesized that bagasse and coconut peat crushed as filler are able to increase viscosity and performance of asphalt.

2. Materials and Methods

For the asphalt blending process, four different types of fillers from various quarries and fields were chosen including limestone, granite, bagasse, and coconut peat. These four fillers displayed substantially different densities, as shown in Table 1. In this study, 15–30 percent by volume of fillers were added in the asphalt binder. The controlled asphalt binder was AC 60–70.

Table 1. Type of filler using in this study.

Factor	Filler Type	Density (g/cm^3)
Mineral fillers	Granite	2.58
	Limestone	2.62
Waste natural fillers	Bagasse	0.38
	Coconut peat	0.29

Table 1 shows that the density of bagasse and coconut peat (0.38 and 0.29 g/cm^3, respectively) were much lower than those of limestone and granite (2.62 and 2.58 g/cm^3, respectively). It is revealed that waste natural fillers' density was approximately 7–10 times smaller than the mineral filler, thus the use of bagasse and coconut peat by weight in asphalt mixture would be less than that of mineral fillers. Two waste natural fillers were separated by the grinding machine: coconut peat (Figure 1a) and bagasse (Figure 1b). They were subsequently sieved to obtain fillers with a sieve number of 200 (0.075 mm). The asphalt binder AC 60–70 used in this analysis was obtained from TIPCO Asphalt PCL. Two aggregates, including limestone and granite, were used. The aggregate gradation was based on the Superpave specification with large traffic volumes (Figure 2).

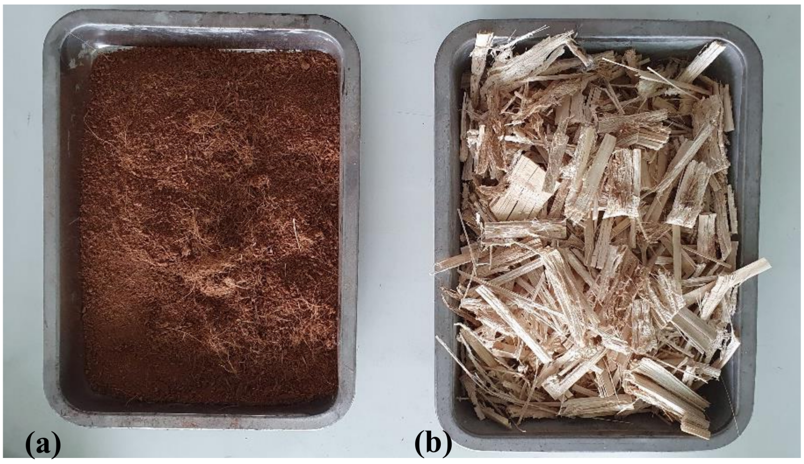


Figure 1. Waste natural materials (**a**) coconut peat and (**b**) bagasse.

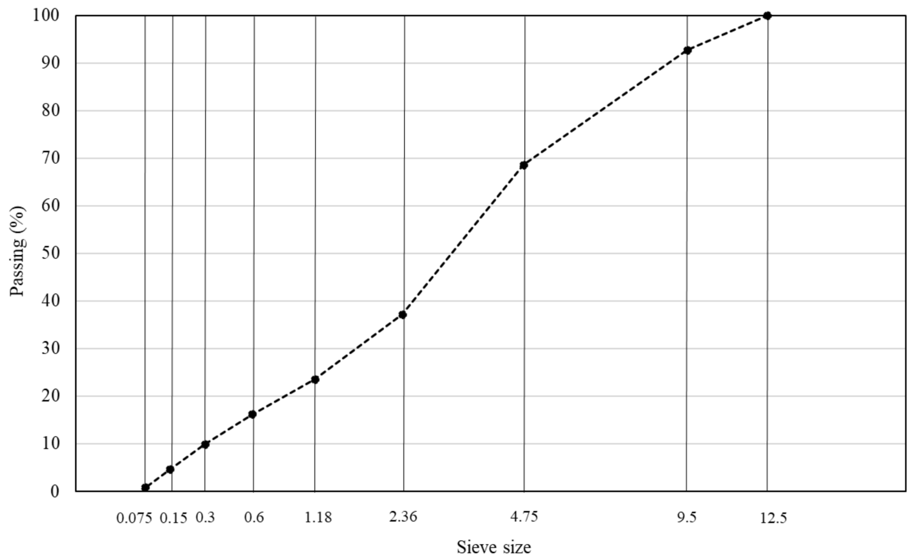
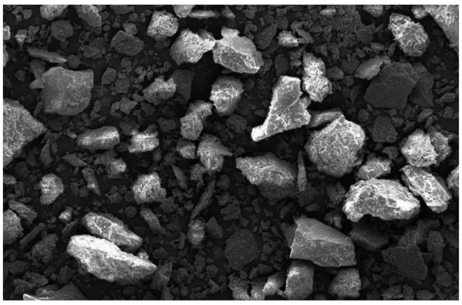


Figure 2. Aggregate gradation.

Typically, filler-to-asphalt ratio (F/A) is in between 0.6–1.6 depending on the density of mineral filler. The ratios can be converted as percent by asphalt volume in which the estimated minimum filler content is 20% by volume of asphalt, while 40% by volume of asphalt is estimated as maximum filler content. Due to the low density of coconut peat and bagasse fillers, the filler content may be varied depending on the workability of asphalt mastic. Therefore, in order to determine the optimum content and effect of waste natural filler with asphalt, asphalt mastic viscosities should be determined.

Mineral filler particles have the micro-surface texture characteristics of which influence the interfacial contact between the filler and the asphalt binder [33]. The four fillers' surface micro morphological characteristics were observed with FEI Quanta 250 scanning electron microscope (SEM) used for structural and chemical analysis of metallographic specimens with magnification up to

×1,000,000 and down to a resolution of 3 nm as shown in Figure 3. SEM operational parameters were 20 kV accelerating voltage, 15 mm working distance and stage tilt angles of 8°.



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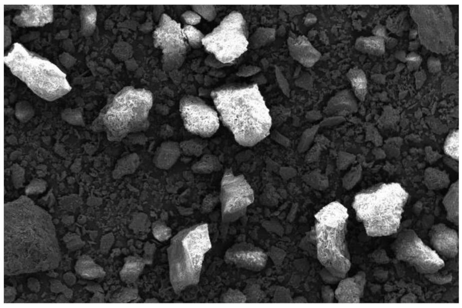

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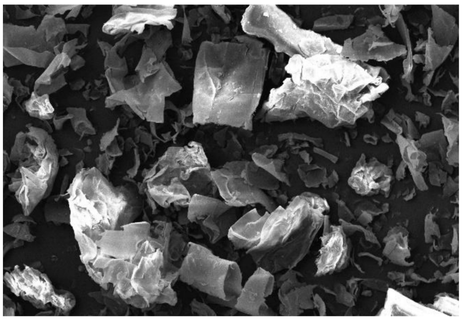

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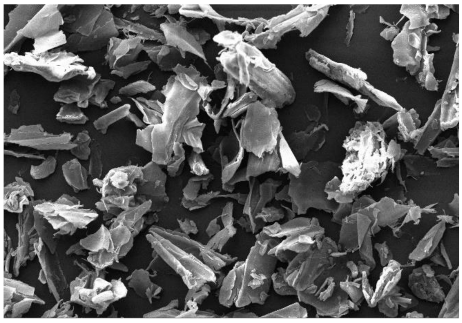

(**d**)

Figure 3. Micro surface texture morphologies of the mineral filler particles. (**a**) Limestone filler; (**b**) granite filler; (**c**) coconut peat filler; (**d**) bagasse filler.

The figures show that the micro surface textures of the coconut peat and bagasse filler particles were alike sheets, while those of the limestone and granite filler particles were more uneven. The shape of coconut peat, bagasse and limestone fillers were more angular than the granite filler that can be created the weakest interfacial adhesion among the four studied fillers.

From Table 2, it is shown that the SEM surface area of limestone, bagasse, and coconut peat fillers (i.e., 3437, 3494 and 3973 µm^2, respectively) are among the similar sizes which yield higher values than that of granite filler (i.e., 2253 µm^2).

Table 2. The estimated surface area through SEM imaging.

Filler Type	Surface Area (µm^2)
Granite	2253
Limestone	3437
Coconut peat	3973
Bagasse	3494

The mixture was made of asphalt and aggregate depending on the method of Marshall. Two series of Marshall specimens were created for each blend. The first series of asphalt specimens that had a particular asphalt content was used for optimum asphalt content of the blends. The optimum content of asphalt was identified by selecting the asphalt content in the asphalt range that fulfills the design criteria identified in the Department of Highway (DOH). The second series with an optimum asphalt content was developed for the mechanical efficiency determination of the respective mixtures for each filler.

In accordance with ASTM D6926 (ASTM 2010a) [34], every material was prepared. The aggregates were heated overnight at 100 °C to insure moisture-free conditions. Due to increasing viscosity of the asphalt mastic and a constant temperature of 150 °C, the mixture samples were heated over 2 h. For compacting specimens measuring 101.6 mm in diameter and 65–75 mm in height, the Marshall hammer compaction (2 × 75 blows) was used. For all specimens' volumetric measurements were performed after a 24 h curing time for the Marshall specimens. Following the required conditioning, the Marshall stability test was carried out in accordance with ASTM D6927-15 [35]. The specimens were then tested indirect tensile strength (ITS) according to the AASHTO T283.

The experiments were divided into two phases including the viscosity test of the asphalt mastic by rotational viscometer and the performance tests.

2.1. Experimental Method of the Effect of Waste Natural Fillers on Asphalt Mastic Viscosity

During the first phase of the experimental design, apparent viscosity experiments were conducted at temperatures between 100 and 220 °C. This involved asphalt mastic produced with AC 60–70 and four types of fillers (i.e., limestone, granite, bagasse, and coconut peat). Asphalt mastics were prepared using estimated minimum and maximum filler contents, which equal to 20 and 40% by asphalt binder volume with three replicates of each sample. The asphalt mastics were blended using laboratory devices including a heating mental and a vertical blender with a spindle. The blending process for the asphalt mastics consist of the following steps: heating of the asphalt into the heating mental up to the mixing temperature (i.e., 155 °C); placing the spindle in the center of the asphalt, then blending with an addition of filler with the rotational speed of 1000 rpm for 1 h. A total of 24 samples were tested. The studied asphalt and fillers were blended by a high shear blending machine. Preliminary tests have shown that the blended between asphalt binder and filler content of 40% for bagasse and coconut peat were impracticable because of the excessive quantity of these two waste natural fillers. As a result, the 40% by asphalt binder volume was removed from the experiments. The results, highlighting the impact of filler types and dosage on the viscosity of asphalt mastics, have enabled investigators to define the compaction temperature's (iso-viscosity) effects.

In this study, preliminary asphalt mastics viscosities display a Newtonian behavior between the shear stress and shear rate as their filler concentration was low, thus the rotational viscometer was adopted to use for determining the asphalt mastic viscosities. A standard viscosity (or Brookfield) viscometer (RV) was used in the viscosity test, in accordance with the AASHTO T316 standard or with standard ASTM D4402 [36]. With the precision of ±1 percent and repeatability of ±0.2 percent, the viscometer system measures viscosities between 100 and 40 million cP. The device is compatible with a wide range of spindles including an integrated temperature resistance detector to measure samples from 9 to 260 °C. The rotational viscometer used in this study. Viscometer measures the torque as the spindle rotates at a constant speed through an asphalt tube. The dynamic viscosity is proportional to the torque of the rotational viscosity. The RV criterion for calculating non-Newtonian viscosity fluids is prevalently used in the chemical and food industry. RV can be tested at high temperatures and suited for non-Newtonian fluids (such as asphalt binder and modified asphalt binder). RV is used in asphalt technology primarily to measure asphalt binder viscosity; however, some studies have used RV to assess asphalt mastic viscosity [37]. In a straightforward way, such a viscometer consists of a cylindrical chamber that controls temperatures, in which the test fluid is inserted and a 27-size spindle that is operated by a power motor. While the spindle is spinning, a calibrated spring, attached to the dial, records the fluid resistance to rotation. Although viscosity (measured by the rotational viscometer) is not an absolute feature of bituminous binders, as it can often show non-Newtonian behavior, it can be used for comparative purposes where, as with the present analysis, temperatures, share rate, torque, etc. Therefore, through the entire investigation, the shear rate kept at 20 rpm and the torque at 100% ± 3%. The shear rate of 20 rpm was used, since the shear rate in binder experiments is the most widely used. Several experiments to determine the effect of shear rate on the viscosity of mastics have been performed. While shear dependence on the mastic was found, the relative classification of the mastics did not change according to the shear rate covered in the test. Viscosity tests were performed with a spindle of SC4–27 and a sample of 10 ± 0.5 g.

In this study, asphalt mastic viscosity determines asphalt viscosity at 20, 40, 60, 80, 100, 150 and 200 rpm following AASSTO T316 specifications to calculate the impact of different speeds and temperatures on the mastic viscosity at 4 different temperatures of 150, 160, 170 and 180 °C.

2.2. Experimental Method of the Assessment of Asphalt Concrete Mixed with Bagasse and Coconut Peat Filler Performance

During the second phase, the findings from the first phase of the analysis were verified, when asphalt blends with unmodified binder (AC 60–70) and 20% of filler content used was prepared for the preparation of the asphalt mastic. A comparative analysis was also conducted of these asphalt blends. The compacted specimens were comparable with scientific literature temperatures [38] and iso-viscosity temperatures obtained in the first phase of the analysis across a variety of measures, namely Marshall stability and IDT tests specified in ASTM D6927-15 and AASHTO T283, respectively. The Marshall stability and IDT results obtained from Humboldt HM–5120A including the load capacity of 50 kN, speed range of 50.8 mm/min, platen size of 254 mm/100 mm and 1000 tests and up to 3000 readings per test data storage.

The composition of the asphalt mixtures was determined according to current specification for wearing course of the Department of Highway, Thailand. Therefore, a different value of asphalt content based on the equivalent void of 4% by asphalt mixture volume was chosen to prepare the mixtures.

In the second phase, mastic viscosities in which were corresponding to testing temperatures were prepared for testing Marshall stability and tensile strength ratio (TSR) in the conditions of mixing and compacting at the same temperature and those at different temperatures, as shown in Table 3.

Table 3. Conditions of asphalt concrete mixture design.

Condition	Description
Not considered mastic viscosity	Mixing at 155 ± 3 °C for all samples Compacting at 142.5 ± 2.5 °C for all samples
Considered mastic viscosity	Mixing at 0.17 ± 0.02 Pa.s of mastic viscosity Compacting at 0.28 ± 0.03 Pa.s of mastic viscosity

The number of mixtures tested in this phase were total 32 samples including 16 for stability test (i.e., 4 asphalt filler types, 2 temperature conditions, and 2 replicates), and 16 for moisture damage resistance test (i.e., 4 asphalt filler types, 2 moisture conditions, and 2 replicates).

3. Results

3.1. Results of the Effect of Waste Natural Fillers on Asphalt Mastic Viscosity

The findings from the viscosity tests have been processed in order to emphasize the stiffening effects of the fillers in asphalt binder at the mixing and compaction temperatures of the respective mixtures. In this respect, the compaction temperature of a standard asphalt mixture is defined as the temperature that produces an asphalt viscosity of 0.28 ± 0.03 Pa.s the area-specific technical literature [38]. However, it is believed that the effects of all the other components of an asphalt mixture (e.g., filler and aggregates) are not considered [39,40].

To confirm that the asphalt mastics with low filler concentration show Newtonian behavior, the mastic viscosities were performed in a different shear rate.

Figure 4 displays the relationship between mastic viscosity and shear rate and shear stress and shear rate at 150 and 170 °C. When applying different shear rates, mastic viscosities displayed constant values through the same temperature. Likewise, the relation between shear stress and shear rate show a linear mastic viscous behavior. This is to confirm that the mastics with low filler concentration exhibit Newtonian behavior.

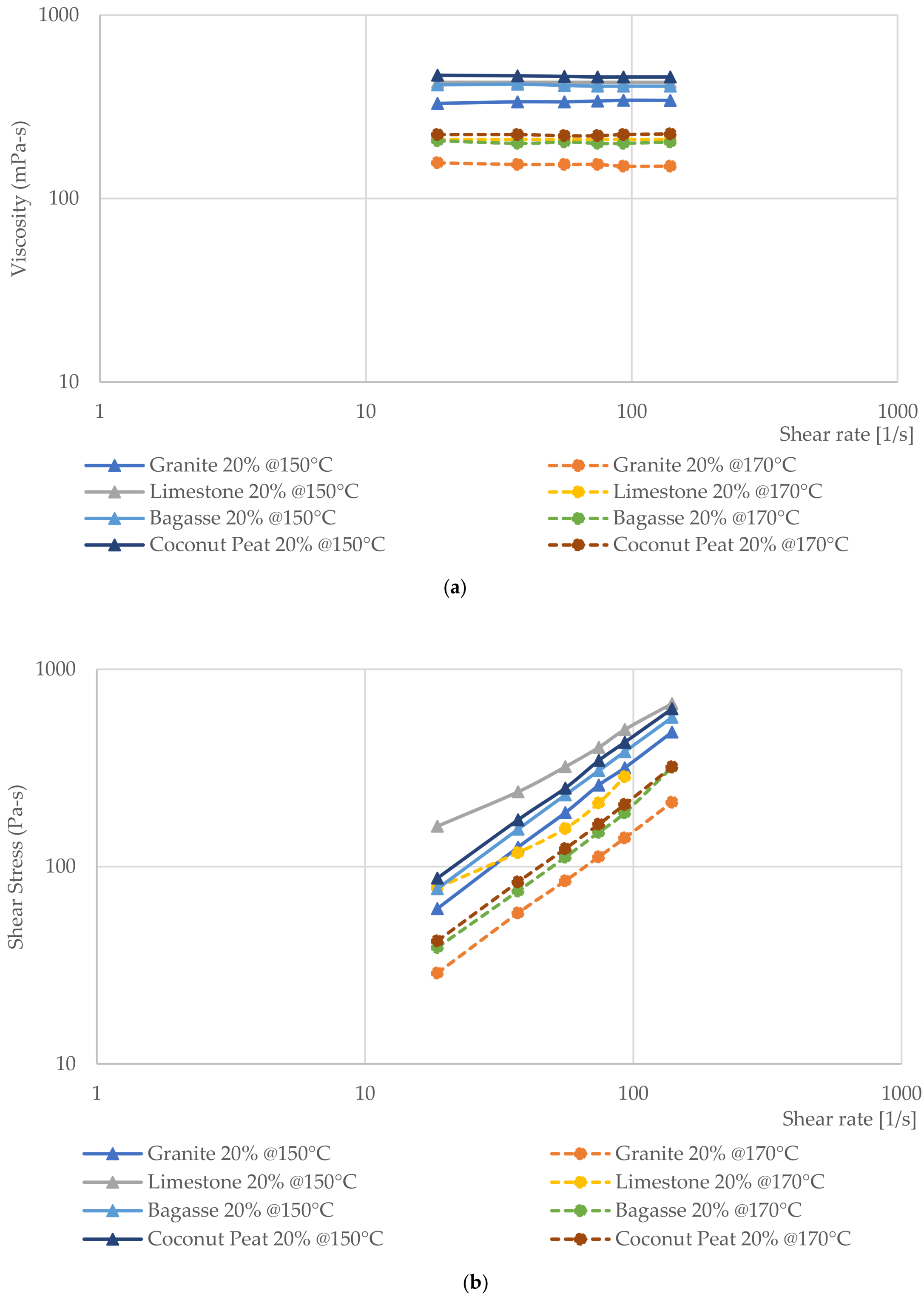

Figure 4. The relationship of asphalt mastic (**a**) viscosity and shear rate and (**b**) shear stress and shear rate at 150 and 170 °C.

The results of viscosity test by rotational viscometer can show relation of mastic viscosity and temperature of each sample, which mixed with different filler types and different filler ratios, as well as the viscosity of AC 60–70, as shown in Figure 5.

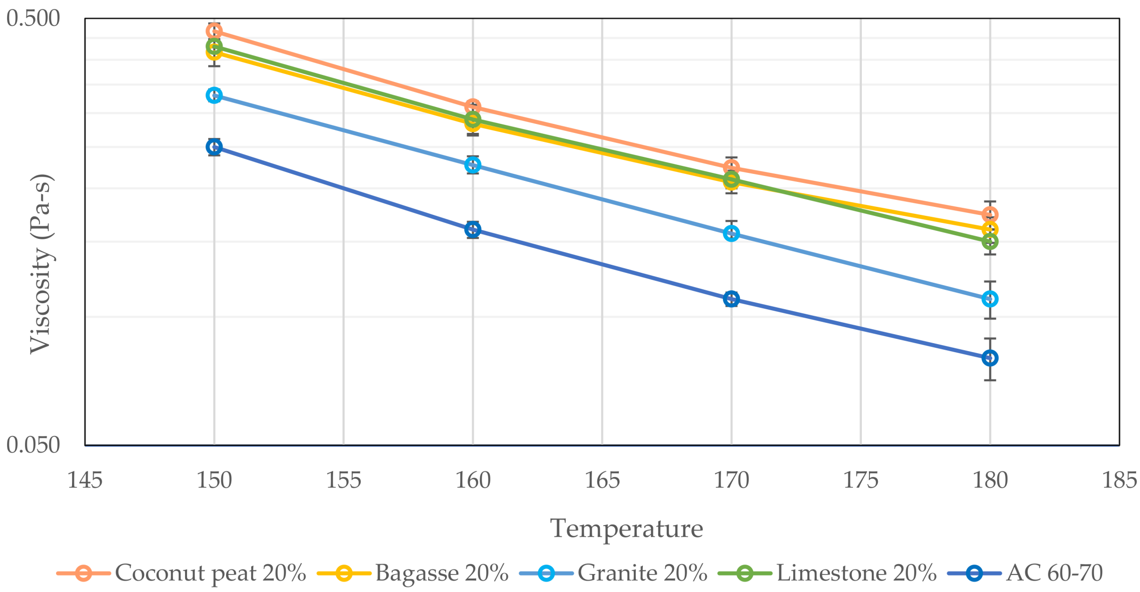

Figure 5. The viscosities of asphalt binder and asphalt mastics at 20 rpm with different temperatures.

Figure 5 shows that increasing content of filler led to increasing the asphalt mastic viscosity. The results show that in the same filler content at 20%, the viscosities of asphalt mastics with coconut peat and with bagasse fillers were relatively close to those with limestone filler for all temperatures. The viscosities of asphalt mastics of coconut peat, bagasse and limestone fillers were in between 0.417–0.467, 0.283–0.316, 0.207–0.223 and 0.150–0.173 Pa.s at 150, 160, 170 and 180 °C, respectively, while those with granite filler showed lower than other fillers presenting 0.33–0.11 Pa.s from 150–180 °C. As a comparison with the asphalt binder, the viscosities for all of the asphalt mastics were higher than those from the asphalt binder for all temperatures.

Table 4 presents the sensitivity of viscosities relative to asphalt mastic with limestone filler. Results indicate that viscosities of asphalt binder were much lower than those of asphalt mastic with limestone filler about a half. This indicates that adding filler resulted in increasing viscosities for all temperatures. If the viscosities criteria calculated from 0.17 ± 0.02 Pa.s for mixing temperature and 0.28 ± 0.03 Pa.s for compaction temperature were employed, the findings of mixing and compaction temperatures for each asphalt mastic type would be different, as shown in Table 5. The mixing and compaction temperatures according to the criteria of asphalt binder viscosities were much higher than that of asphalt binder. The calculated mixing and compaction temperatures subjected to asphalt mastic viscosity were at least 167 and 153 °C, respectively. Therefore, these results hypothesize that using the chart of calculating the mixing and compacting temperatures using asphalt binder viscosities might not be the right way to be obtained, as all viscosities of asphalt mastics represent different results with the same filler content.

Table 4. The sensitivity of viscosities relative to asphalt mastic with limestone filler.

Temperature °C	Granite	Bagasse	Coconut Peat	AC 60–70
150	23%	3%	–9%	42%
160	22%	2%	–7%	45%
170	25%	2%	–6%	48%
180	27%	–7%	–16%	47%

Table 5. Mixing and compaction temperature of asphalt mixture with different asphalt mastic type using the asphalt binder viscosity criteria.

Filler	Mixing Temperature (°C)	Compaction Temperature (°C)
Coconut peat 20%	179.37	164.25
Bagasse 20%	176.37	160.78
Granite 20%	166.38	152.89
Limestone 20%	175.22	160.96
AC 60/70	155.00	142.50

3.2. Results of the Assessment of Asphalt Concrete Mixed with Bagasse and Coconut Peat Fillers Performance

From the results of the first phase, this phase was experimented in two cases in order to determine the effect of filler in asphalt mixture on failure performance with different temperatures and the same temperature. With the hypothesis that if the asphalt mastic viscosity was taken to determine the optimum temperature for mixing and compaction according to asphalt binder viscosity specification, the asphalt concrete performances would be better. In this study, as the asphalt mastic viscosity has not yet been standardized for determining the temperature for mixing and compaction of asphalt concrete, using the standard value for asphalt viscosity as a determinant was applied. To set up the testing temperatures, the mixing and compaction temperatures that meet the specification of asphalt binder viscosity including 0.17 ± 0.02 Pa.s and 0.28 ± 0.03 Pa.s, respectively, were used. The materials of verifying the performance of this effect included granite aggregates with coconut peat, bagasse, granite and limestone fillers.

The asphalt mixtures were prepared using short-term aging. The fillers were introduced during the mixing processes at the same time the binder was added. The mix design used 20% filler by volume for the graded mixes. When adding different fillers in the mix, the amount was adjusted to equate the volume of 20% filler included in the mix design. This ensured that any change in the mix performance is due to the mineral filler type and not the change in mix components' volumetrics. The asphalt content for the asphalt mixtures was 5% by weight of total mix for bagasse, coconut peat and granite fillers and 5.5% for limestone filler. In this section, the effects of using different asphalt mastics on asphalt mixture performance were evaluated.

3.3. Volumetric Properties of the Mixture

The amount and type of filler in a mixture greatly affects the volumetric properties. The theoretical maximum density (G_{mm}) and the bulk density (G_{mb}) of the mixture was measured using ASTM D2041 (ASTM 2011). To investigate the effect of different fillers on the volumetric properties of the mixtures, the properties were examined at specified asphalt content of 5% for bagasse, coconut peat and granite fillers and 5.5% for limestone filler to meet requirement of the void in the mix (AV) of 4% ± 0.5 (Table 6).

Table 6. The volumetric designs for granite, limestone, bagasse and coconut peat fillers.

Fillers	G_{mm} (g/cm^3)	G_{mb} (g/cm^3)	AV (%)
Granite	2.26	2.17	4.19
Limestone	2.30	2.20	4.13
Bagasse	2.24	2.15	4.01
Coconut peat	2.23	2.14	4.19

With the optimum asphalt content, the G_{mm} for all mixtures shown in Table 6 were in the small range of 2.23–2.30. The design asphalt content for each mixture was established to meet the design criteria specified by the Department of Highway (DOH) (Marshall stability > 8 KN, flow between 2–4 mm, VTM of 3–5%, and VMA of >14%). Therefore, all asphalt mixtures met the requirement of volumetric design criteria. Then, Marshall stability and moisture susceptibility resistance tests were conducted on each mixture at optimum asphalt content. At the respective optimum asphalt content, it is assumed that the mixtures are likely to have similar aggregate asphalt structures, air voids, and effective asphalt film. Theoretically, the optimum asphalt content is greatly affected by the properties of constituent materials and mix design. Given the same mix design, gradation, aggregate type, and asphalt type, the differences in the optimum asphalt content among mixtures incorporating different fillers were attributed to the underlying properties of the respective filler.

3.4. Evaluation of Asphalt Mixture Performances

3.4.1. Marshall Stability

Condition 1: All samples were mixed at 155 ± 3 °C and compacted at 142.5 ± 2.5 °C following the viscosity of asphalt binder AC 60–70 without considering the asphalt mastic viscosity. This result can be shown if the bagasse and coconut peat fillers can be replaced by granite and limestone fillers for improving the stability in asphalt mixture with the same mixing and compaction temperatures. The results are shown in Table 7.

Table 7. Result of Marshall stability and flow test (not considered mastic viscosity).

Fillers	Stability (KN)	Coefficient of Variation (CV)	Flow (mm)
Granite 20%	9.26	9.07%	2.59
Limestone 20%	8.83	0.7%	2.87
Coconut peat 20%	9.66	4.13%	2.77
Bagasse 20%	8.69	6.53%	2.62

Results show that the mixture mixed with coconut peat fillers gave the highest stability of 9.66 KN with the flow of 2.77 mm, while that with bagasse yielded the lowest stability of 8.69 KN with the flow of 2.62 mm. These results indicate that with the equivalent temperatures based on the asphalt binder viscosity, stability and flow for asphalt mixtures mixed with waste natural fillers were close to the samples mixed mineral fillers. All mixtures' stability and flow values were above the specification of DOH.

Condition 2: It is hypothesized that if the asphalt mastic viscosity was taken into account to determine the optimum temperature for mixing and compaction according to asphalt binder viscosity specification, the asphalt concrete performances would have been better. Therefore, in this condition, mastic viscosity was considered through the values of asphalt binder viscosity specification determining the mixing temperature at 0.17 ± 0.02 Pa.s and compaction temperature at 0.28 ± 0.03 Pa.s. The temperatures of each mixture were calculated as shown in Table 5.

Table 8 shows the same trend as the first condition which the highest stability was the mixtures mixed with coconut peat fillers (i.e., 11.21 KN) with the flow of 3.33 mm, while others showed the stability in the range of 9.21 to 11.21 KN and 3.19 to 3.56 mm for flow. This indicates that even though the temperatures change, the Marshall stability and flow trends still remained the same. Increasing temperatures directly affected the stability and flow.

Table 8. Result of Marshall stability and flow test (considered mastic viscosity).

Fillers	Stability (KN)	Coefficient of Variation (CV)	Flow (mm)
Granite 20%	10.91	9.12%	3.19
Limestone 20%	10	1.50%	3.56
Coconut peat 20%	11.21	4.52%	3.33
Bagasse 20%	9.21	6.54%	3.21

3.4.2. Marshall Stiffness Index (MSI)

MSI is the ratio of Marshall stability kN to the flow of the sample in mm. Stiffer mixtures suggest higher MSI values, providing greater resistance to permanent deformation [41]. This definition is well known and used by some European engineers and many transport companies, including the Ministry of the Works of Malaysia and the National Roads Agency of South Africa, which have adopted 2000 and 2500 N/mm, respectively, as a minimum allowable MSI for the mixture of asphalt cement [42,43]. Lees (1987) considered that MSI should be at least 2.1 kN/mm [44], which has resulted in many researchers taking this value into account [45,46]. The results of the MSI are shown in Figure 6.

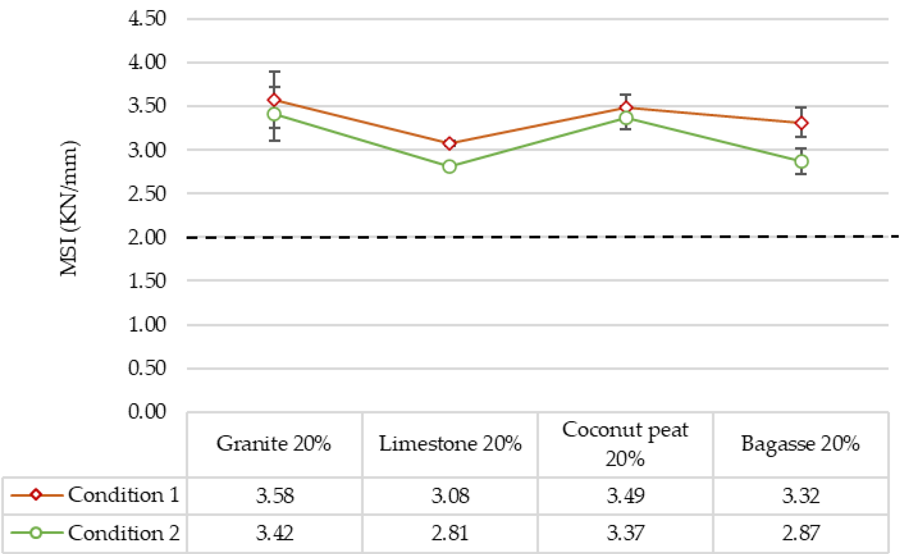

Figure 6. Marshall Stiffness Index of asphalt mixtures.

Figure 6 shows that MSI from the condition 1 were higher than those from condition 2 for all mixtures. The MSI for conditions 1 and 2 were in between 2.87 to 3.58, which are higher than the minimum allowable MSI specification. This indicates that using the mixing and compaction temperatures determined by asphalt binder viscosity leads to higher MSI than using the mixing and compaction temperatures determined by asphalt mastic viscosity. Thus, the mastic viscosity affected the stability and flow.

3.4.3. Moisture Susceptibility

Mineral fillers contribute towards the stiffening of the asphalt binding system and thus have greater resistance to rutting at high temperatures. The fillers can, therefore, also affect the bond of asphalt with aggregates, thereby increasing the sensitivity to asphalt mixtures' moisture content. Previous study [47] found that the resistance to moisture damage affected by the type of mineral fillers. However, the effect of various mastic volumes of asphalt on moisture damage resistance has not been examined. Mixing and compaction temperatures of the asphalt binder viscosity have been applied in this section. Table 9 presents the ITS values for all four fillers types in dry and wet conditions on asphalted mixtures with a granite aggregate and equivalent filling material (i.e., 20 percent by volume). The results indicate that the ITS value of the limestone filler mixture in wet conditions resulted in higher ITS values in the dry state than that of the waste naturally, followed by bagasse, granite and coconut peat fillers, respectively.

TSR was calculated as the predictor from the ITS testing to assess the possible impact of filler types on moisture damage resistance. Figure 7 indicates the strength ratio of asphalt mixture for all types of fillers following wet conditioning. For all filler types, TSR shows lower values than 0.7, the standard TSR specification. Bagasse usage (i.e., 0.62) could lead to higher TSRs (i.e., 0.54 granite and 0.60 limestone fillers) relative to mineral fillers.

Table 9. Indirect tensile strength (ITS) of dry and wet conditions on asphalt mixtures with granite and different filler content.

Type of Fillers	Dry Condition (MPa)	CV	Wet Condition (MPa)	CV
Bagasse	0.26	3.12%	0.16	0.43%
Coconut peat	0.27	2.01%	0.14	1.34%
Granite	0.30	1.24%	0.16	2.09%
Limestone	0.30	5.00%	0.18	2.32%

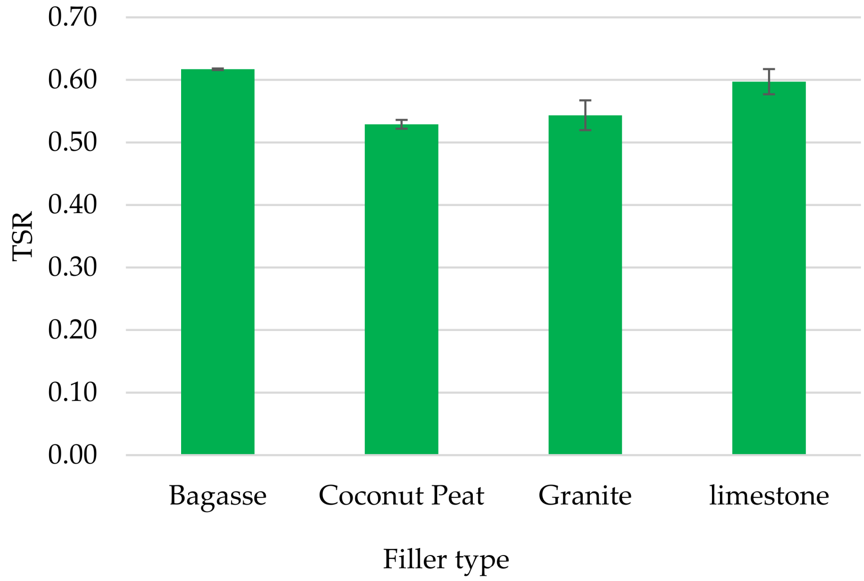

Figure 7. TSR of ITS test after moisture of asphalt mixtures with granite aggregate for all filler types.

This indicates that the TSR was dependent on filler type. In this study, results preliminarily confirm that bagasse can be an alternative filler replacing mineral fillers for moisture damage resistance.

4. Summary of Findings and Discussions

In this study, the researchers have chosen bagasse and coconut peat replacing mineral fillers to evaluate the effect of bagasse and coconut peat as a mastic viscosity filler and to assess asphalt mixtures mixed with bagasse and coconut fillers, which are expected to increase the viscosity and performance of asphalt mixtures.

There were two experimental stages, including viscosity mastic through the rotational viscometer and stability of Marshall and resistance to moisture damage. The following points summarize the main findings of the study.

1. Findings show that the viscosities of asphalt mastics with coconut peat and bagasse fillers were relatively similar to those with limestone filler for all temperatures at 20 percent filler content by volume but were higher than those with granite filler. This result can be addressed by the shape of the microparticle in which the granite filler particle was more rounded than the rest of studied fillers. This finding is logical, as it corresponds to the results from previous research that showed a lower viscosity for the rounded filler particles [48]. Additionally, this result can be addressed from the SEM surface area in which the viscosities correspond to the SEM surface area for each filler.
2. The viscosity, the stability and the flows of asphalt mixtures mixed with waste natural fillers were similar to the mixed mineral filler samples at equal temperatures based on the asphalt binder.

3. Using the mixing and compaction temperatures determined by asphalt binder viscosity led to higher MSI than using the mixing and compaction temperatures determined by asphalt mastic viscosity. This affected the stability and the flow of the mastic viscosity.
4. The TSR depended on the type of filler. Preliminary findings confirm that an alternative filler can be used to substitute mineral fillers for resistance to moisture damage. This finding corresponds to the results of previous research that the mineral fillers can be replaced by coconut peat and bagasse fillers [49].

5. Conclusions

This study can be concluded that the mastic viscosity is vital for determining the workability of asphalt mixture. The waste natural fillers including bagasse and coconut peat give similar mastic viscosity to limestone filler and higher than granite filler.

It also can be concluded that asphalt mastic viscosity affects the Marshall stability and flow values. Preliminary results show that although the MSI irrespective of asphalt mastic viscosity samples gave better results than those with considering asphalt mastic viscosity, the values were close, and the determining of mixing and compaction temperatures was not based on the value set of mastic viscosities. Therefore, bagasse and coconut peat fillers are deemed to be the potential materials used in asphalt mixture.

Further studies on different factors such as binder type, aggregate type and aggregate gradation should be considered to verify the performance of using waste natural fillers as an alternative to asphalt mixture. Other failure performance tests for testing the mixtures of bagasse or coconut peat fillers should be considered for future work. The non-Newtonian behavior for the high concentration of fillers needs to be considered.

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