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Experimental Testing of Natural Fiber on Asphalt Mix Performance

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Abstract: Road materials must have high durability and safety for their users. One solution is to use natural fibers that are abundant in Indonesia in hot asphalt mixtures, as an alternative to asphalt pavement protection materials from damage, especially on surface layers that are unable to withstand traffic loads and temperature changes of 20-50 °C. The study of natural fiber characterization in asphalt pavement is critical point for accurate fiber mixing to improve the performance of asphalt as the road surface layer. This study aims to evaluate the characterization and performance of three natural fibers, namely coconut fiber, rice straw, and palm fiber in a 60/70 penetration asphalt mixture. and recommend the best natural fibers to be used in asphalt mixtures. In this research there were produced asphalt mixtures with natural fibers with a length variation 2-5 mm. Diameter varied from 0.1-0.7 mm. The fiber size variation was conducted to determine its effect on the asphalt characteristics. The addition of 0.1%, 0.2%, 0.3%, 0.4% and 0.5% fibers into asphalt pen 60/70 mixture changed the characteristics of the asphalt with wet process mixing 500 rpm in temperature 110oC. The results of characteristic test demonstrate that tensile strength of natural fiber 2.34 – 217.3 N/mm2. Asphalt concrete with a natural fiber content of 0.2% - 0.3% shows significant Marshall Stability, Marshall Quotient and Marshall Immersion values on the performance of the mixture and this method can improve the quality of the asphalt mixture

Keyword: Coconut Fiber, Palm Fiber, Rice Straw Fiber, Asphalt Mixtures, Marshall Test, Marshall Immersion

INTRODUCTION

Generally, the produced asphalt does not meet the climatic, traffic, and pavement structure requirements, therefore, modification should be used as one of the attractive alternatives to improve asphalt properties. Nowadays asphalt concrete is the most widely used material in pavements, with different applications such as highways, footpaths, runways, port, and parking lots (Piergiorgio Tataranni, 2023). Among various modifiers for asphalt, fibers have gotten much attention due to their improving effects. Fibers have been used in

asphalt mixtures for two main reasons: (1) to increase the toughness and fracture resistance of hot mix asphalt (HMA); and (2) to act as a stabilizer to prevent drain down of the asphalt binder. Furthermore, enable a higher binder content and hence a thicker film around the aggregate, delaying oxidation, moisture penetration and cracking and separation of aggregates.

These advantages serve to protect the asphalt concrete wear. The synthetic fiber has been used frequently as stabilizing additive in asphalt mixture, but they present the drawback of a high cost. There are many benefits that can be gained from using fiber for construction materials, whether natural fiber or synthetic fiber, which will make the components of the material mixture more valuable and this is important for specific applications, including asphalt mixed pavements. The use of natural fibers in asphalt mixtures has attracted attention in the field of highway engineering due to their environmentally friendly nature and potential to improve the performance of asphalt mixtures. Natural fibers, such as coconut, bamboo, and palm fibers, have advantages in strengthening the asphalt structure, reducing permanent deformation, and increasing resistance to cracking and high temperature effects. Recently, some natural fiber has potential to be applied as reinforcement materials to composite products. Natural fibers are cheap and locally available in many countries. Their use as a construction material to improve the properties of the composites costs very little when compared to the total cost of the composites. The natural fibers like coconut husks, palm fiber, and rice straw are plentiful in Indonesia, and taking advantage of these resources could reduce the costs and contribute to regional sustainability. In some areas in Indonesia, the disposal of this waste fibers produced from numerous manufacturing and agricultural processes is an economical and environmental problem for companies and municipalities. These fibers are sometimes used in other applications, but commonly they are disposed of in landfills. Like standard-sized coconut fibers have been utilized in the coir industry, but short waste fibers have not yet been utilized. If these fibers could be beneficially utilized in any application, it would reduce the burden on diminishing landfill space. Also, using such waste materials could be economically beneficial compared to fibers manufactured for a specific application.

Asphalt concrete (AC), is a composite material consisting of aggregate, asphalt binder (mastic), and air void. It has been primarily used as a material in constructing road and airport pavements. However, under the effects of repeated vehicle loading at high temperature, moisture cycling, and low-temperature contraction, AC mixture is susceptible to distresses of rutting (permanent deformation), stripping (separation of asphalts from aggregates), and cracking, etc. Accordingly, additives have been used to alter the engineering properties (e.g. strength) of asphalt binder and improve the performance of AC material for pavement used. The control and fiber-reinforced asphalt mixtures showed high resistance to moisture damage and their ITS improved after being exposed to the moisture damage procedure.

Roads damage in Indonesia mainly caused by environmental factors, overloading, and construction. Environmental factors, such as rainfall and road surface temperature changes, are often difficult to predict. The increasing of road surface temperature is a major problem in Indonesian construction pavements. Grooves in asphalt concrete occur in one of the following types: wear grooves caused by the progressive loss of coated aggregate particles from the pavement surface, structural grooves due to permanent deformation of the subgrade, and instability grooves in asphalt concrete layers [4]. Several investigations have been carried out to improve the performance of asphalt as the road surface layer. One of potential approach is the use of natural fiber additives mixed into the asphalt.

The use of natural fibers in asphalt mixtures has attracted attention in the field of highway engineering due to their environmentally friendly nature and potential to improve the performance of asphalt mixtures. Natural fibers, such as coconut, bamboo, and palm fibers, have advantages in strengthening the asphalt structure, reducing permanent

deformation, and increasing resistance to cracking and high temperature effects. Based on study carried out showed that the addition of 0.75% 5-mm coconut fibers by weight of the asphalt increased the value of the Marshall stability by 10-15% and produced lower penetration-grade bitumen. Similarly, (Oda, Fernandez, dan Ildefonso, 2012) reported that the addition of coconut coir fiber increased the resilient modulus by approximately 14%. The addition of natural fiber in asphalt mixtures not only serves as a reduction of the passive environmental, but also how to improve the performance of such mixtures. Furthermore (Hugo, Silva, Oliviera) reported that coconut fibers have little porous microstructural characteristics preventing runoff from binder and contributing to the hardening of the asphalt mix, their physical characteristics, tensile strength, are similar to other fibers analyzed, in other literatures. Basically, limited investigation is related to addition of natural fibers in asphalt mixtures, in order to improve their performance.

Objectives of the Study

This paper is t aims to characterization of the different natural fiber types and tries to improve for stabilizing and reinforcing asphalt mixture, traffic classification and performance index retained strength of asphalt admixtures and provide pavement with better and more.

METHOD AND MATERIALS

The material used in this study consist bitumen grade 60/70. (Pertamina Asphalt). The aggregate obtained from Rumpin-Bogor West Java aggregate quarry was used for all experiments. In the study using natural fibers from local materials with variations of 2-5 mm long. The diameters vary from 0.1-0.7 mm. Variation of fiber size is done to know the effect on characteristic of asphalt mixture.

Asphalt and Aggregates

Asphalt is a complicated colloidal system of hydrocarbon material made from asphaltenes, resins and oils. Asphalt that serves as an aggregate adhesive in a concrete asphalt mixture it is very important to maintain its ability to stickiness, softening point and flexibility. Asphaltenes of the building-forming material of asphalt and resin affect from the properties of adhesion and ductility, oils affect the viscosity and flow. The asphalt used is asphalt concrete wear layer (AC-WC) with the largest aggregate size of 19 mm taken from the local depot. This type of mixture is suitable for use in Indonesia because it has good mixture properties and characteristics according to conditions in Indonesia. Normal testing with the Marshall Test is carried out to determine the important characteristics in this asphalt mixture to comply with the requirements set out in the Indonesian standard. The asphalt used is asphalt product of PT. Pertamina penetration 60/70. The aggregate component as the main component for the road pavement mixture contains 90-95% aggregate based on volume percentage. The aggregate in AC-WC consists of coarse fractions, medium fractions and natural stone ash or sand, in general the coarse and medium fractions are classified as coarse aggregates and stone ash is classified as fine aggregates.

The aggregates were selected based on the applicable standards in SNI and ASTM then selected based on their properties, and their appropriate gradation so that they can be characterized as factors that influence the deformation resistance of the asphalt mixture and the durability of the asphalt mixture. Physical and mechanical characteristics were determined and tests based on these standards were then carried out to determine the properties of the aggregates as summarized in Table 1, The physical properties of asphalt in Table 2 and aggregates (AC-WC) were selected in this study with a nominal maximum size of 19 mm. used as shown in Table 1.

Table 1. Characteristics of the Aggregates

Property	Test value			Method
	Coarse	Medium	Fine	
Bulk specific gravity, G sb (g/cm3)	2.52	2.52	2.61	AASHTO T84/T85
Surface saturated dry gravity (SSD)	2.58	2.59	2.66	AASHTO T84/T85
Apparent specific gravity, (g/cm3)	2.70	2.69	2.75	AASHTO T84/T85
Absorption (%)	2.66	2.44	1.92	AASHTO T84/T85
Wear by Los Angeles abrasion (%)	22.2	25.9	-	AASHTO T96
Solubility (%)	99	99	-	
Angularity (%)	100/100	100/100	49	DoT's Pennsylvania Test
Toughness (%)	8.42	-	-	BS-812

Table 2. Physical Properties of Asphalt Cement Grade Bitumen 60/70

Test items	Value	Specifications
Penetration at 25ºC (100 g, 5 s, d-mm)	64.3	ASTM D5
Specific Gravity	1.09	ASTM D70
Softening point (º C)	54.25	ASTM D36
Flash point (º C)	275	ASTM D92
Ductility at 25 °C (5 cm/min)	150	ASTM D113
Viscosity (t=135ºC)	518.83	ASTM D2171

Table 3. The Gradation of Aggregates AC-WC

Sieve	Sieve (mm)	Passing (%)	Undesirable range	Lower-upper limits
¾ in	19	99.4	-	100
½ in	12.5	95.8	-	90-100
⅜ in	9.5	83.4	-	max 90
# 4	4.75	44	-	-
# 8	2.36	28.7	39.1	28 - 58
# 16	1.18	20.1	25.6 - 31.6	-
# 30	0.6	14.7	19.1 - 23.1	-
# 50	0.3	10.8	15.5	-
# 100	1.97	7.7	-	-
# 200	0.075	5.2	-	4 - 10

Results from table no.1, table no. 2 and table no. 3 show the aggregate characteristic values can meet the standards required in AASHTO. The mixing method was carried out for ACWC specification by Marshall test and Marshall Immersion Test, Aggregate and asphalt mixed with hot mix system with natural fiber addition as additives. Standard and method refers to the planning of mixture of asphalt SNI regulation (Bina Marga) as show Table 4. as below.

Table 4. Mix Design Criteria AC-WC

Marshall Parameters	Compaction (2 x 75) blows	
	minimum	maximum
VIM (%)	4.9	5.9
VMA(%)	15	-
VFA(%)	65	-
Stability (kg)	800	-
Flow (mm)	2	-
Stability/Flow (kg/mm)	200	-

Source: Bina Marga

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Fibers

Nowadays, fiber materials have been used as additives to modify asphalt. Three types of natural fibers are studied in this paper, including coconut fiber, oil palm fiber and rice straw fiber. Figure 2 shows the raw materials of these fibers. Ripe coconut shells were collected locally, dried and the pure fibers were manually extracted. All the fibers were washed to remove dust and other impurities, and then, dried at room temperature (25-30^{o}C) for two days. Then, these dried fibers were screened to separate the remaining impurities. These fibers were cut into small pieces of 2-5 mm in length to ensure proper mixing with aggregates and binders during the mixing process. The wet process was carried out manually to mix the short natural fibers which were added to the asphalt slowly and then heated to a temperature (110 ^{o} C) to avoid burning of these fibers.

Experimental And Test

Marshall Test

The performance of an asphalt mixture can be checked with the help of the Marshall Test. This test was first introduced by Bruce Marshall, which was further developed by U.S Corps of Engineer. This check is intended to determine the stability and flow of the asphalt mixture. Marshall designs used to make judgments on the Marshall test parameters and analyze the optimum bitumen content for each type of fiber asphalt mixture.

Figure 1. Raw material of three types of natural fibers (A: coconut fiber, B: rice straw, C: palm fiber)
Source : photo documentation

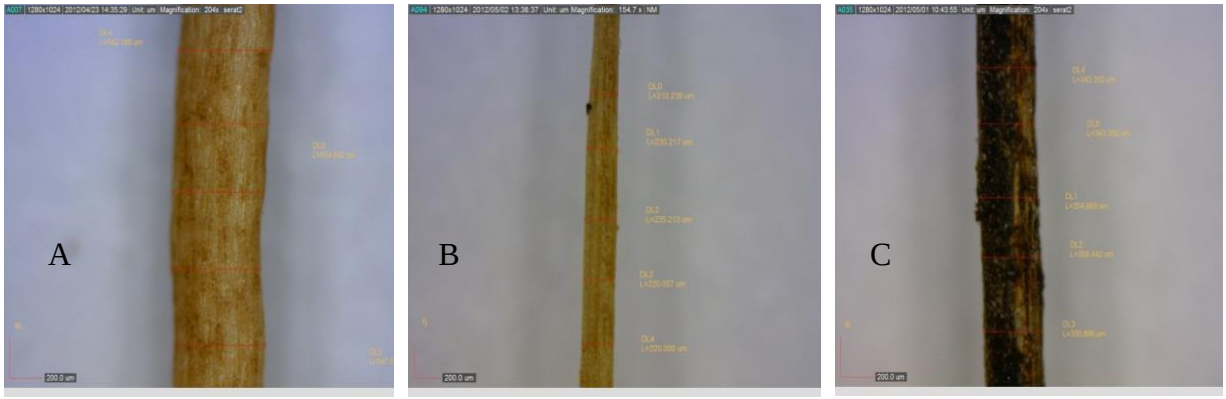
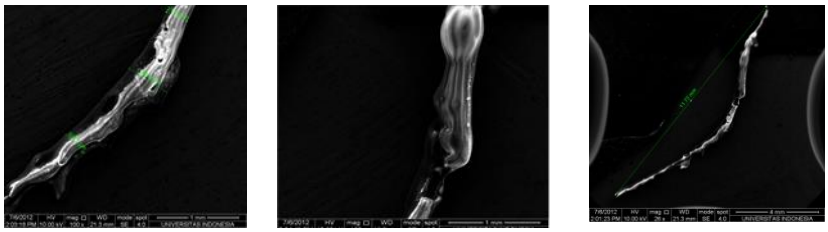


Figure 2. Microstructure of natural fiber (A. coconut fiber B. rice straw C. palm fiber)
Source: photo documentation



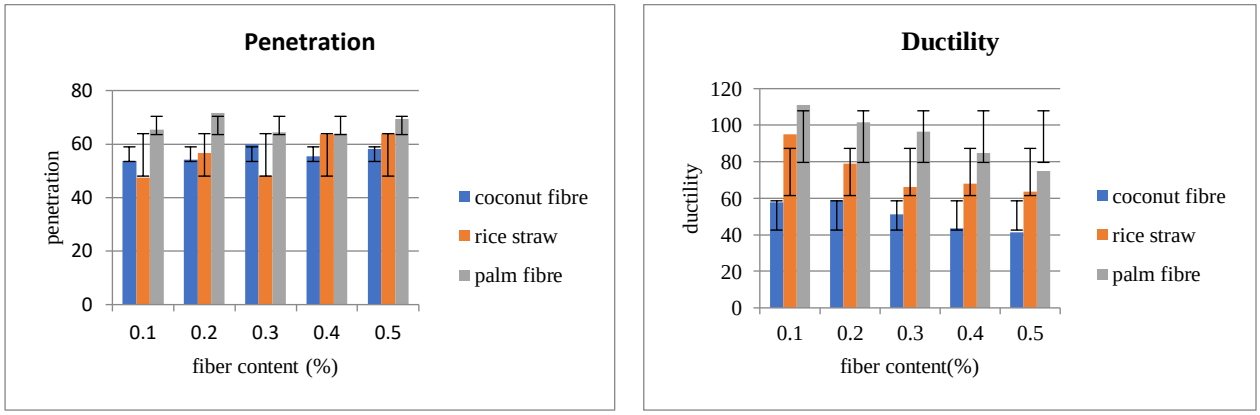
(A) (B) (C)

Figure 3. SEM of natural fiber (A. coconut fiber B. rice straw C. palm fiber)
Source: photo documentation

Tabel 5. Characteristics And Properties Of Fiber

No.	Material	Water Content (%)	Specific Gravity (g/cm3)	Water Absorption (%)	Diameter (mm)	Tensile Strength (N/mm^2)	Modulus Elasticities (N/mm^2)	Elongation at Failure (%)
1	Coconut fiber	16.67	0.54	115.3	0,25-0,70	24,74-217,53	67- 4.819	13,94-94,65
2	Rice straw fiber	16.05	0.44	296.4	0,15-0,48	2,34- 155,69	61-56.411	0,13-5,63
3	Palm fiber	17.07	0.56	48.1	0.20-0.42	10,16-159,98	260-8.456	1,69-68,29

Source: result of research



(a) (b)

Figure 4. (a) Fiber content vs penetration (b) Fiber content vs ductility
Source: result analysis

The results of the penetration and ductility tests shown in Figure 4 show that the asphalt mixture with the addition of 0.2% natural fiber can increase the ability to be more flexible in the asphalt material. Meanwhile, if there is a lack or excess of fiber, it can reduce the tenacity of the asphalt mixture. From of three types of natural fiber materials can be recommended that coconut fiber show more significant results.

RESULT AND DISCUSSION

The three types of natural fiber used is the remainder of the result of a production that has not been utilized optimally. This fiber is passed over the cleaning of dirt and washed and dried for 24 hours at room temperature. The procedure used to Investigate the properties of asphalt concrete made with natural fibers using a mixture ACWC because it has a continuous gradient so as to maintain interlocking. Asphalt is heated to a temperature of 110 ° C and then natural fibers inserted gently until mixed average approximately 10 minutes with a stirring speed of 500 rpm. Manufacture of test specimens of asphalt concrete wearing course natural fiber (ACWCNF) with methodology Marshall tests were performed to investigate whether these three types of fiber can be used and its influence restricted.

The optimum bitumen content used was 6.1% which was used to design the ACWCNF mixture. Can be seen from the picture No. 4. The results of the Marshall Stability (MS), Marshall Quotients (MQ), Index Retained Strength (IRS) showed significant results to the strength and stiffness of asphalt mixture ACWCNF.

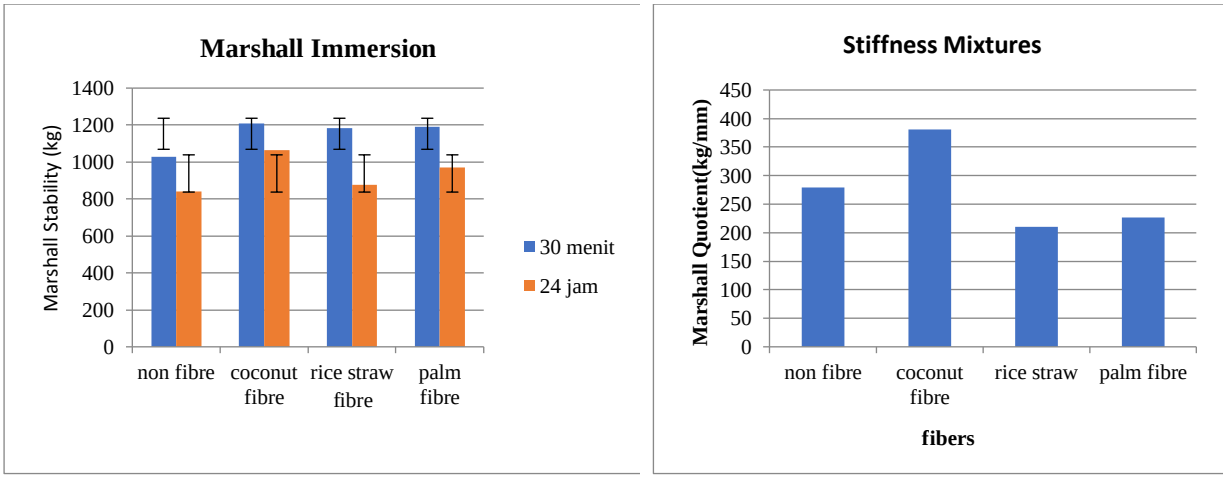


Figure 5. (a) Type of fibers vs Marshall stability and Marshall Immersion
(b) Type of fibers vs Marshall Quotient
Source: result analysis

The third type of natural fiber-based grades Marshall stability and Retained Strength Index (IRS) can meet the standard for traffic load> 1,000,000 ESA. Performance coconut fiber in the mixture hot mix show the value of the largest MQ. Based on the results for Marshall stability / Flow or Marshall Quotient (MQ) is an indicator of stiffness empirically. The higher the value the more rigid MQ possibility of an asphalt mixture and the mixture is more vulnerable to cracking, but on the contrary if it is small then the value of its MQ asphalt mixture will be more flexible

Table 6. The Values of Index of Retained Strength (IRS)

Mixture	Marshall Standard (kg)	Marshall Immersion (kg)	Index Retained Strength (%)
ACWC pen 60/70 Non fiber	1027.90	839.2	81.64
ACWCNF pen 60/70 Coconut fiber	1209.40	1064.4	88.01
ACWCNF pen 60/70 Rice straw fiber	1184.01	878.25	74.18
ACWCNF pen 60/70 Palm fiber	1190.28	970.73	81.55

Source: result of research

Index Retained Strength is a parameter used to measure the resistance of a material to damage or degradation after experiencing a certain loading or damage condition. This index is generally applied to materials used in road construction, such as asphalt or concrete mixtures, to assess how well the material maintains its initial strength after experiencing loads or changes in environmental conditions, such as extreme temperatures, fatigue due to traffic, or humidity. The Table 6. Showed that the addition of fiber in the asphalt mixture gives a tendency to increase the ability of asphalt mixture receive, it is indicated by the increase in the value of stability. Natural fibers have great potential to improve the performance of asphalt mixtures. The use of natural fibers as additives in asphalt mixtures can be a sustainable and environmentally friendly solution in highway construction.

CONCLUSION

The laboratory experiments were designed to study three types of natural fibers' physical properties, reinforcing effects, and mechanisms in asphalt binder, which allows the following conclusions:

1. Research on recycled materials in the form of natural and traditional fibers needs to be carried out because it can optimize the use of fiber from waste, and combine the use of fiber with other sustainable technologies and can also maximize its use to maintain environmental stability by using fiber in asphalt pavement.
2. The percentage of natural fibers of coconut fiber, rice straw, palm-sized fiber short (2- 5 mm) is ideal ranges from 0.2 % to obtain the value of the penetration and ductility and optimum asphalt is still needed if the natural fibers build up or do not need to be seen homogeneities hot mix mixture ACWCNF.
3. The use of natural fibers as additive materials in the mix ACWCNF can be used for traffic over 1,000,000 ESA.
4. Performance characteristics of stability and retained strength index of asphalt mixtures of the three types of natural fibers with the best use being coconut fiber, in other words, coconut fiber in asphalt mixtures has better performance.
5. Economic value studies are needed for further research on the use of natural fibers as asphalt mixtures.

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