การใช้กากใยมะพร้าวในสโตนมาสติกแอสฟัลต์

Utilization of Coconut Fiber in Stone Mastic Asphalt Mixtures

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บทคัดย่อ

ในการวิจัยนี้ได้ศึกษาการใช้กากใยมะพร้าวความยาว 5-20 มิลลิเมตรเป็นส่วนผสมด้วยอัตราส่วนผสม 0 0.1 0.3 และ 0.5% ในวัสดุผิวทางสโตนมาสติกแอสฟัลต์ขนาด NMAS 12.5 มิลลิเมตร โดยพิจารณาคุณสมบัติเชิงปริมาตร ค่าเสถียรภาพของมาร์แชลล์, การไหลแยกตัว และอัตราส่วนกำลังรับแรงดึง จากการศึกษาพบว่าการใช้กากใยมะพร้าวความยาว 5-20 มิลลิเมตร ด้วยอัตราส่วน 0.3% เป็นส่วนผสมในวัสดุผิวทางสโตนมาสติกแอสฟัลต์จะมีคุณสมบัติที่เหมาะสมที่สุด โดยค่าเสถียรภาพของมาร์แชลล์เพิ่มขึ้น 10.52% อีกทั้งการไหลแยกตัวยังลดลง 55.35% เมื่อเปรียบเทียบกับเมื่อไม่ได้ใช้กากใยมะพร้าวเป็นส่วนผสม และให้ค่าอัตราส่วนกำลังรับแรงดึงสูงที่สุด โดยผลการศึกษานี้สามารถใช้เป็นแนวทางในการพิจารณาเลือกใช้วัสดุทางเลือกสำหรับงานทางในระดับท้องถิ่นได้

ABSTRACT

In this study, coconut fiber of 5-20 mm-long with various contents of 0, 0.1, 0.3, and 0.5% incorporated with AC60/70 and 12.5 mm NMAS were used to prepare mixtures for SMA. Properties of mixture including volumetric properties, Marshall Stability, draindown, and TSR were determined and investigated. The results revealed that mixture containing 0.3% of 5-20 mm-long coconut fiber yielded to the optimum requirements. With this coconut fiber content, there was a significant improvement of properties with higher Marshall Stability by 10.52% and lower draindown by 55.35% compared to mixture containing 0% coconut fiber. Moreover, 0.3% of coconut fiber provides the highest. The finding of this study may offer the alternative choices for local authority to have more materials to consider for pavements construction.

คำสำคัญ: กากใยมะพร้าว, สโตนมาสติกแอสฟัลต์, ค่าเสถียรภาพของมาร์แชลล์, อัตราส่วนกำลังรับแรงดึง, การไหลแยกตัว

Keywords: Coconut fiber, SMA, Marshall stability, TSR, Draindown

INTRODUCTION

Stone mastic asphalt (SMA) defining as a gap-grade hot mix asphalt is originally developed in Europe since the mid-1960s. Since then, it is found to have been used successfully in many countries such as United States, Australia, Canada, Japan, Thailand, Indonesia, and many more other countries worldwide (National Asphalt Pavement Association, 2002; Cao et al., 2013; Jitsangiam et al., 2013; Siswanto, 2017). A typical SMA mixture consists of 70-80% of coarse aggregate, 12-17% of fine aggregate, 8 - 13% of filler, 6-7% of asphalt cement, and 0.3-0.5% of fibers and/or modifiers (by mass) (Hainin et al., 2012; Shravan and Prasad Reddy, 2017). As SMA mixture consists of high coarse aggregate, it is therefore applicable for heavy trafficked pavements, high stressed pavement areas, thin overlays, resistance to wear from studded tires as it is a tough, stable, rut-resistant mixture which relies on stone to stone contact. As compared to dense-grade hot mix asphalt, SMA improves durability up to 20%, increases 3-5 times of resistant to fatigue life, reduces 30-40% of permanent deformations, better in skid resistance, and economical for long term. However, SMA may delays to the opening traffic after its lay down and it is time consuming due to additional stabilizing agents (National Asphalt Pavement Association, 2002; Hainin et al., 2012).

There are two types of stabilizing agents including modifiers and/or fibers which can be used to prevent the drainage of the asphalt binder in the aggregate matrix during the production and construction periods (Panda et al., 2013). Modifiers such as polymer modified asphalt (PMA) (Panda et al., 2013), plastic waste modified asphalt (Charoentham and Ngamdee, 2019; Bindu and Beena, 2010), and natural rubber modified asphalt (Mashaan et al., 2013) have been studied successfully. However, these modified asphalt have been reported with the significant increase of toxicity and could expose workers to dangerous health and safety conditions (Charoentham and Ngamdee, 2019; Kriech et al.,2018). Moreover, it is not good in drainage reduction if modified asphalt alone is used (Hassan et al., 2005). Fibers have been used for decade to reinforce properties of pavement materials. Cellulose, mineral, and polymer fiber have been mostly used (National Academies of Sciences, Engineering, and Medicine, 2015). However, these fibers are either costly or not widely available (Panda et al., 2013). Coconut fiber extracted from coconut husk is one among natural fibers and it is extensively found in tropical countries (Panda et al., 2013). This fiber has been reported with the improvement of stability and moisture susceptibility and also reduce the draindown of SMA mixtures as compared to other natural fibers (Shravan and Prasad Reddy, 2017; Awanti et al., 2012; Kumar and Ravitheja, 2019). Therefore, this study attempts to use coconut fiber for SMA mixtures preparation. The proportion of coconut fiber using in SMA mixtures is suggested between 0.3-0.5%. The previous studies indicated that the additional 0.3% of coconut fiber was sufficient and provided the superior results. When coconut fiber content was lower than 0.3%, voids space tended to increase and draindown seemed to be high. On the other hand, asphalt film thickness was insufficient and voids space tended to decrease if there was additional coconut fiber more than 0.3% (Panda et al., 2013; Kumar and Ravitheja, 2019; Vale et al., 2014). This study therefore aims to cover the coconut fiber content of 0, and 0.1-0.5% (0.2% increment). Previous works mostly used coconut fiber length longer than 20 mm which presented difficulties during production (Vale et al., 2014; Chin and Charoentham, 2020). This study therefore aims to use coconut fiber of 5-20 mm-long and various contents incorporated with AC60/70 and local aggregates (12.5 mm NMAS) to prepare for SMA mixtures. Marshall Stability, draindown, and indirect tensile strength (ITS) tests were applied and investigated.

SELECTED MATERIALS

The selected materials including coconut fiber, aggregates and filler, and AC60/70 are presented as follows.

1. Coconut fiber

Coconut fiber was adopted from Sichon district located in the northern part of Si Thammarat province of Thailand. The original coconut fiber lengths as shown in Figure 1(a) were in the range of between 100-300 mm-long. The flash and fire point test were conducted to ensure the safety during the mixing period. It was conducted on approximately 20 g coconut fiber and at least 3 samples were tested. This amount was heated on the hot plate by applying temperature in the rate of 20°C/min until the flash (first occurrence of ignition) and fire (sample supported a flame for a period of at least five seconds) occurred. These both temperatures were found to be higher than 200°C which indicated that coconut fiber could be used without causing fire during the mixing period. The tensile strength was also conducted to ensure that coconut fiber has enough strength to prepare for SMA mixtures. It was tested by INSTRON machine (ASTM D3822/D3822-14) with the tensile mode of 5 kN load cell and the crosshead speed of 0.1 mm/min. As the result, the tensile strength of coconut fiber in this study were found between 120-140 kPa, which were similar to (Vale et al., 2014) and higher than (Panda et al., 2013). To ensure the proper mixing with aggregates, filler and asphalt, the coconut fiber was cleaned and cut into 5-20 mm-long as shown in Figure 1(a).

(a) (b)

Figure 1. The Original (A) and designed (B) length of coconut fiber

2. Aggregates and filler

Three types of limestone (12.5, 9.5 mm and dusk rock) adopted from Roi Et province of Thailand and filler (Portland cement) were used to produce the 12.5 mm NMAS (Brown and Cooley, 1999) as shown in Table 1. The properties including specific gravity, water absorption, Los Angeles (LA) abrasion and flakiness and elongation of each aggregate and filler are presented in Table 2 below. These properties indicated that the aggregates and filler could be used to prepare for SMA mixtures.

Table 1. The adopted 12.5 mm NMAS.

Sieve		Test method	Tolerant limit (%)		Result
mm	inch		Lower	Upper	Passing (%)
19	3/4		100	100	100
12.5	1/2		90	100	93.12
9.5	3/8		26	78	46.02
4.75	No. 4		20	28	24.68
2.36	No. 8	ASTM C136	16	24	20.41
1.18	No. 16		13	21	15.83
0.6	No. 30		12	18	13.28
0.33	No. 60		12	15	12.12
0.075	No. 200		8	10	9.15
Pan	-		Less than 3		0.25

Table 2. Properties of aggregates and filler.

Property	Test method	Specification	Lime stone			PC
			12.5 mm	9.5 mm	DC	
Specific gravity (Gs)	ASTM C128/127	2.5-3.0	2.65	2.66	2.65	2.9
Water absorption, (%)	ASTM C128/127	2	1.18	1.24	1.23	-
LA abrasion, (%)	ASTM C131	30	28	28	-	-
Flakiness and elongation	ASTM D4791	20	16.76	17.93	-	-

Note: DC = dust rock, PC = Portland cement, NMAS = Nominal maximum aggregate size

3. AC60/70

AC60/70 was provided by Thai Lube Base Public Company Limited located in Sriracha, Chonburi, Thailand. The evaluation of the selected AC60/70 was conducted to assure that their significant properties complied with the specification of the provided company above. The properties including penetration, softening point, flash and fire point, specific gravity, and density are shown in Table 3.

Table 3. Properties of AC60/70.

Test item	Test method	Specification	Result
Penetration at 25°C, 5 s, 100 g	ASTM D5	60-70	67
Softening point, (°C)	ASTM D36	45-55	47.6
Flash point test, (°C)	ASTM D92	Min 232	>320
Fire point test, (°C)	ASTM D92	Min 232	>350
Specific gravity at 25/25°C	ASTM D70-80	1.01-1.06	1.05
Density, (kg/m^3)	ASTM D70-80	1010-1060	1047.15

MIXTURE CHARACTERISTIC AND TESTING METHODS

1. Mixture characteristic and Marshall stability test

The blended aggregate using to produce a mixture for SMA was 1,200 g and at least three samples were prepared for each asphalt content. The coconut fiber was cleaned and cut into the designed length and prepared for mixture according to its designed content of 0, 0.1, 0.3, and 0.5% by mass of the blended aggregate. The mixing of mixtures was done into two sub steps (1) the blended aggregate and coconut fiber were thoroughly mixed and (2) the mixture in sub step 1 was then mixed with the AC60/70 by content. Mixtures containing 0% coconut fiber were mixed with 5.5-7% of AC60/70 while those containing 0.1-0.5% coconut fiber were mixed with 6-7% of AC60/70. After the mixture was thoroughly mixed, 50 blows of a standard hammer were applied on each side of specimen in order to obtain a specimen of 63.5±3 mm of height and 101±0.5 mm in diameter after the extraction ASTM D6926-20 [19]. The extracted specimens were kept cooling to room temperature for 24 hours so that the volumetric properties could be determined thereafter. Marshall stability in accordance with ASTM D6927-15 (ASTM, 2015) was tested to determine the strength of the specimens and it was tested after the determination of volumetric properties were obtained correctively.

2. Draindown test

Samples used to determine the draindown were prepared as those of Marshall stability test but without compaction force (ASTM, 2017). At least two samples were prepared and tested following to the illustration as shown in Figure 2 (Jones et al., 2012) and its remained mixture in the glass beakers as shown in Figure 3 are used to determine the draindown of each representative mixture. Generally, the draindown value of not greater than 0.3% in the total mixture is limited (Brown and Cooley, 1999).

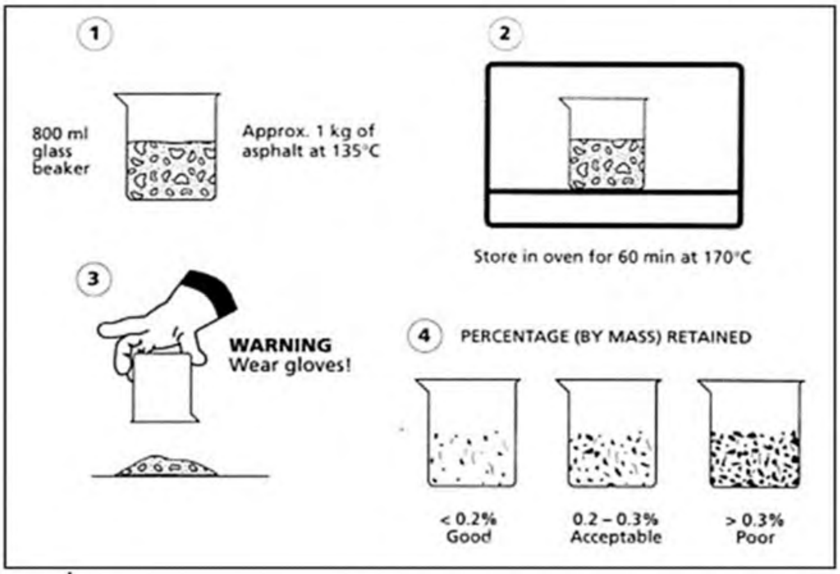

Figure 2 Illustration of draindown test by Schellenberg method (ASTM D6390-11).

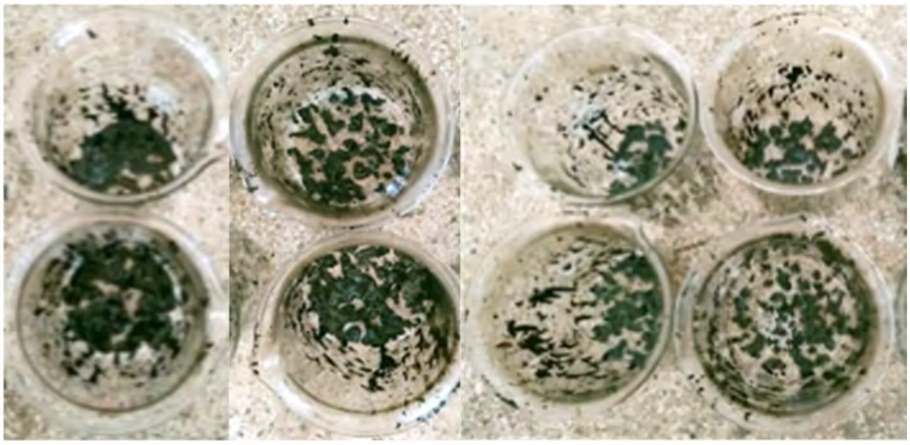

Figure 3 Remained mixture in the glass beaker after the test.

3. Indirect tensile strength (ITS) test

Specimens of ITS test were prepared as those of Marshall stability and three simples were tested for each dry conditioned ITS (ASTM D6931-17) and wet conditioned ITS (ASTM D4867) (ASTM, 2017; ASTM, 2014). Both ITS tests were subjected and the peak loads were averaged and used to determine each ITS as shown in Equation (1) and TSR as shown in Equation (2) (ASTM, 2014).

$$S_t = 2000P / \pi tD \quad (1)$$

$$TSR = S_{tw} / S_{td} \quad (2)$$

where P is the peak load of the specimen expressing in N, t is the thickness of the sample expressing in mm, D is the height of the sample expressing in mm, S_{tw} is the average tensile strength of specimens in wet condition expressing in kPa, S_{td} is the average tensile strength of specimens in dry condition expressing in kPa, and TSR is the tensile strength ratio of the specimens expressing in %.

RESULTS AND DISCUSSION

The results as shown in table 4 were obtained after the determination of OAC, which was based on 4% air voids. To obtain the results of each property, three specimens were prepared at OAC and tested. The results of such mixtures are given and discussed as follows.

Table 4. The results of Marshall properties of SMA mixtures mixing at OAC

Coconut fiber		AV	OAC	VMA	VCA_{drc}	VCA_{mix}	G_{mb}	G_{mm}	Stability
mm	%	%	%	%	%	%			kN
5-20	0	4.15	5.80	17.08	42.61	38.55	2.354	2.456	6.46
	0.1	4.11	6.00	17.32		38.72	2.352	2.453	6.78
	0.3	4.05	6.15	17.86		39.12	2.340	2.439	7.14
	0.5	3.96	6.30	18.09		39.29	2.338	2.434	6.73
Specification (Brown and Cooley, 1999)		4	6 - 7	Min 17	VCA_{drc} > VCA_{mix}		-	-	Min 6.2

Note: AV = air voids, OAC = optimum asphalt content, VMA = voids of mineral aggregate, VCA_{drc} = voids of coarse aggregate in dry rodded condition, VCA_{mix} = voids of coarse aggregate in the compacted mixture, Max = maximum value, Min = minimum value

It is seen that the volumetric properties including AV, OAC, VMA, and VCAmix of mixtures are within the prescript specifications except the OAC of mixture containing 0% coconut fiber. It can be seen that the OAC increases when the additional coconut fiber content increases. This is due to the fact that the additional coconut fiber content leaded mixtures to need more asphalt content in order to provide the suitable coated area. Moreover, SMA mixtures require VMA of at least 17% in the total compacted mixture and the VCAdrc higher than the VCAmix. It is seen that the VMA of all mixtures are higher than the required value except those containing 0% coconut fiber which VMA is almost equal to the minimum required value. It is also seen that the VCAdrc values are greater than the VCAmix for all mixtures. This could be indicated that the mixtures have enough voids of coarse aggregate which is able to provide the suitable stone to stone contact. However, these both properties are not enough to judge the strength of mixtures. It is needed to include the Marshall Stability and TSR to prove the strength of mixtures. According to table 4, stability of all mixtures are higher than the required value (6.2 kN). The stability increases up to 0.3% coconut fiber content, and thereafter decreases. This is due to the fact that the bituminous mixture is the sticky materials so that the mixtures mixing in high coconut fiber content tend to have low uniformity as the disorder of coconut fiber inside the mixtures increases. Moreover, it could be simply noticed that the presence of coconut fiber helped to improve the stability of mixtures. Other volumetric properties such as Gmb and Gmm are also able to describe the characteristics of mixtures. It is seen that the Gmb and Gmm of all mixtures decrease when the additional coconut fiber content increases. The Gmb was determined based on the weights of mixture in dry, water, and saturated surface dry condition (SSD). When mixtures contained high coconut fiber content, its weight in water was lower as compared to those mixing with low coconut fiber content. According to the investigation during the test, it could be the reason that the air bubbles were likely trapped to the mixtures containing high coconut fiber content. Adding that, the Gmm which was determined on the loose mixtures are also related to the weight of specimens in water condition. This therefore could be indicated that the air bubbles are likely to happen to mixtures consisting of high coconut fiber content.

Other requirements such as TSR and draindown as shown in table 5 are also required in order to determine the characteristics and suitable coconut fiber content for SMA mixtures.

Table 5. The results of draindown and TSR of SMA mixtures mixing at OAC.

Coconut fiber		OAC	Draindown	S_{td}	S_{tw}	TSR
mm	%	%	%	kPa	kPa	%
5-20	0	5.80	0.56	-	-	-
	0.1	6.00	0.37	-	-	-
	0.3	6.15	0.25	737.60	664.84	90.13
	0.5	6.30	0.23	680.85	603.00	88.57
Specification (Brown and Cooley, 1999)		6 - 7	0.3 Max	-	-	70 Min

It is seen that the draindown slightly decreases when the coconut fiber content increases. Normally, a SMA mixture permit to have the maximum draindown of 0.3% (Brown and Cooley, 1999). It is therefore seen that the draindown meets to the prescript requirement at 0.3% coconut fiber content. Moreover, it is able to indicate that the presence of coconut fiber could help to reduce the drainage of the asphalt in the mixtures during the production period. It is also seen that the S_{td} and S_{tw} (determined on mixtures passing the draindown requirement only) decrease when the additional coconut fiber increases. This is due to fact which shares similar conclusion as that of stability. The TSR, another requirement obtained from the ratio of the S_{tw} to the S_{td}, is the important value used to indicate the characteristic of moisture susceptibility (the extension of moisture damage occurred due to the presence of moisture in mixture) (Tayfur et al., 2007). It is seen that the TSR shows the highest value at 0.3% coconut fiber content, and thereafter decreases. This could be simply indicated that the additional coconut fiber of only 0.3% brings the best improvement for moisture susceptibility. This finding shares similarity to (Panda et al., 2013; Beena and Bindu, 2011), which also stated that the presence of coconut fiber provided significant increase in stability and TSR (moisture susceptibility).

The results of Marshall properties, draindown, and TSR are then used to determine the optimum coconut fiber which is suitable for a SMA mixture [18]. According to the results as shown in table 5, it is seen that the draindown of mixtures containing 0 and 0.1% coconut fiber content are higher than the required maximum value. It is also seen from the results as shown in table 4 and 5 that mixtures containing 0.3% coconut fiber provide the highest stability and TSR. Therefore, the optimum coconut fiber content is decided to be 0.3%. Additionally, the SMA mixtures yielded to the optimum results (7.14 kN stability and 90.13% TSR) when they were mixed with this optimum coconut fiber content. To sum up, the additional 0.3% coconut fiber could bring significant improvement of volumetric properties, increased up to 10.52% stability and up to 2.5% TSR.

CONCLUSION

The following conclusion are made based on the laboratory experiment of using coconut fiber incorporated with 12.5 mm NMAS and AC60/70 for SMA mixture according to compacted hammer method. The results including Marshall properties, draindown, and TSR were used to describe the characteristics of SMA mixtures and also used to determine the optimum coconut fiber for a SMA mixture. It can be concluded that (1) The OAC increases when the additional coconut fiber content increases. Contrary, the Gmb and Gmm decrease when the additional coconut fiber content decreases. (2) The mixtures containing 0.3% coconut fiber content (optimum coconut fiber content) provided the highest stability and TSR, and consisted of acceptable draindown of 0.25%. To sum up, it could be simply indicated that the 0.3% of 5-20 mm-long coconut fiber was able to use with the selected local materials for making the SMA mixtures.

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