

EFFECT OF COCONUT FIBER LENGTH AND CONTENT ON PROPERTIES OF STONE MASTIC ASPHALT

Chandy Chin and Nattaporn Charoentham*

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Abstract

Recently, stone mastic asphalt has been recognized worldwide because of its performance in terms of durability, resistant to permanent deformations, and better in skid resistant. Stone mastic asphalt mixtures require stone to stone contact and this stone to stone contact provides a good strength for pavements. However, stone mastic asphalt mixtures require 4% of air void and it would face with drainage of the binder if this air void is higher than 4%. In this study, the effect of 5-20, 20-40, and 40-60 mm-long coconut fiber and 0, 0.1, 0.3, 0.5, and 0.7% coconut fiber content by mass on 12.5 mm NMAS of stone mastic asphalt properties were investigated. The properties including volumetric properties, Marshall stability, and draindown were studied using Marshall stability and draindown test. The experimental results revealed that the 0.3% of 5-20 mm-long coconut fiber provided the highest stability (7.14 kN) with 0.25% of draindown.

Keywords: Coconut fiber, draindown test, marshall stability, stone mastic asphalt

Introduction

Stone Mastic Asphalt (SMA)

SMA defined as a gap-graded hot mix asphalt is originally developed during the mid-1960s in Germany. Commonly, SMA mixtures consist of 70-80% of coarse aggregate, 12-17% of fine aggregate, 8-13% of filler, 6-7% of asphalt cement, and of stabilizers (the amount of each material is considered by mass of the blended aggregate which is normally 1,200 g). Stabilizers can be either modifiers or fibers (0.3-0.5%) and their purpose is to prevent drainage of asphalt binder from aggregate matrix (Rosli and Hamed, 2012; Shravan, 2017; Kiran Kumar and Ravitheja, 2019). Presently, SMA is widely used because it helps to increase durability and strength as compares to conventional asphalt (Rosli and Hamed, 2012).

Binders in SMA

Being a gap-graded hot mix asphalt, SMA requires air voids approximately 4% and draindown of not greater than 0.3% (Brown and Cooley, 1999). Modifiers and/or fibers are needed in order to fulfill these requirements. Many previous researchers have used modified asphalts such as polymer modified asphalt, natural rubber modified asphalt, and crumb rubber modified asphalt. However, using modifiers alone is not good in draindown prevention. Adding that, modified asphalts are not widely available and it also causes more toxic than conventional asphalts (Hassan and Taha, 2005). This study therefore aims to use the commonly available AC60/70 penetration graded asphalt to reduce these concerns. Using AC60/70 alone, draindown will be out of limitation

School of Transportation Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand. Tel: 086-6481234, 061-7055638, E-mail: ch_natta@sut.ac.th, chin.chandy0612@gmail.com

** Corresponding author*

because AC60/70 is not as stiff as modified asphalts (Kosintra and Witayakul, 2001). Therefore, fiber must be needed in this study.

Natural Fibers in Stone Mastic Asphalt

Fibers have been widely used for many decades to reinforce paving materials. Fibers commonly use in stone mastic asphalt and open graded asphalt to prevent draindown of mixtures. There are many fibers which can be used in SMA including cellulose fiber, waste fiber (tire or carpet), polyester fiber, cotton fiber, asbestos fiber, banana fiber, pineapple fiber, and coconut fiber (Putman and Amirkhanian, 2004; Kiran Kumar and Ravitheja, 2019). Cellulose fiber has been widely used than the other fibers, however this fiber is either costly or not readily available (Awanti *et al.*, 2013; Panda and Giri., 2013). Waste fiber, polyester fiber, cotton fiber, and asbestos fiber are also considered as fiber materials but these fibers are degradable and are not suitable as long-term reinforcement (Busching and Antrim, 1968). Coconut fiber is extensively found in tropical regions and this fiber is not fully used for different purposes therefore it goes as waste. Moreover, as compare to the above-mentioned fibers, coconut fiber has been reported as the best fiber which helps to increase the stability of SMA mixtures, (Kiran Kumar and Ravitheja, 2019). Seeing the certain advantages of coconut fiber, this study therefore aims to use it.

Additionally, fiber dimensions such as length and diameter which mainly depend on fiber specie, location, and maturity do effect to mixture properties (voids space and durability properties). Moreover, fiber properties such as strength and temperature susceptibility are also important for mixtures (Ezekiel and Karlsson, 2011; Panda and Giri, 2013). Furthermore, proportion of fibers using in SMA mixtures is suggested between 0.3-0.5% by mass of the blended aggregate. Vale and Soares (2013) proposed 0.3% and 0.5% of coconut fiber content, Panda and Giri (2013) used 0.3-0.7% (0.2% increment) content of coconut fiber, and Kiran Kumar and Ravitheja (2019) used 0.1-0.4% (0.1% increment) content of coconut fiber. Length and diameter of fiber also need to be considered in order to ensure the proper mixtures and obtain the best performance. The above-mentioned studies utilized coconut fiber which consisted of 30-40 mm-long and 0.2 - 0.6 mm diameter.

Many previous works commonly used 20-40 mm-long of coconut fiber for SMA mixtures (Kiran Kumar and Ravitheja, 2019; Chandy and Nattaporn, 2020). In spite of the extensive research studies, study on the variation of coconut fiber length in SMA has not been found yet. This study therefore aims to use coconut fiber of different lengths (5-20,

20-40, and 40 60 mm-long) and contents (0, 0.1, 0.3, 0.5, and 0.7% by mass of the blended aggregate) to incorporate with the 12.5 mm NMA and AC60/70 (6, 6.5, and 7% by mass of the blended aggregate) for SMA mix. The properties including volumetric properties, Marshall stability and draindown were compared with those of coconut fiber reinforced SMA.

Materials and Methods

Selected Materials

Aggregate Gradation And Its Physical Properties

Base on available materials and specification of SMA gradation outlined by Brown and Cooley (1999), 12.5 mm NMA gradation was selected for this study. To produce this gradation as shown in Figure 1, the combination of four different hot bins including 12.5 mm, 9.5 mm, dust rock, and Portland cement were combined with proportion of 72%, 10%, 10%, 8%, respectively. Portland cement using in this study was found to be passed 0.075 mm (No. 200) sieve of more than 90%. Basic physical properties including bulk specific gravity, water absorption, abrasion, flatness and elongation were tested. These basic physical properties as shown in Table 1 were found within the prescript requirements

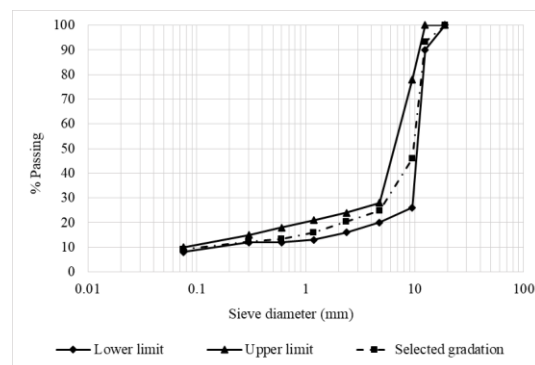


Figure 1 Selected gradation for 12.5 mm NMA SMA (Brown and Cooley, 1999)

Asphalt Cement

For tropical regions, AC60/70 is widely used for pavement construction. Jitsangiam and Nikraz (2013) used AC60/70 as asphalt content to evaluate the suitability of Supperpave and Marshall asphalt mixtures related to Thailand's climatic conditions. Therefore, in this study AC60/70 was selected with the designed content 6-7% (0.5% increment) for SMA mixtures. Basic physical properties (Table 2) including penetration, softening point, flash point,

Table 1 Basic properties of aggregates and filler

Property	Unit	Standard test	Specification	Type of hot bin			
				12.5 mm	9.5 mm	Dust rock	Portland cement
Proportion	%	ASTM C136	-	72	10	10	8
Proportion in 1,200 g	g	ASTM C136	1,200	864	120	120	96
Bulk specific gravity	-	ASTM C128/127	2.7 ^a /3.1 ^b	2.65	2.66	2.65	2.91
Water absorption	%	ASTM C128/127	2	1.18	1.24	1.23	-
Los Angeles abrasion	%	ASTM C131	30	28	28	-	-
Flakiness index	%	ASTM D4791	10	8	10	-	-
Elongation index	%	ASTM D4791	10	7	5	-	-

Note: ^a refers to specification of bulk specific gravity for 12.5 mm, 9.5 mm, and dust rock

^b refers to specification of bulk specific gravity of Portland cement

Table 2 Basic properties of the adopted AC60/70

Property	Unit	Standard test	Specification	Result
Penetration at 25°C	-	ASTM D5	60-70	67
Ductility at 25°C	cm	ASTM D113-07	Min 100	>100
Softening point	°C	ASTM D36	45-55	47.5
Flash point	°C	ASTM D92-12b	Min 232	328
Specific gravity at 25°C	-	ASTM D70-18	1.01-1.06	1.056
Viscosity at:	Pa.s	ASTM D4402	-	
100°C				3.97
135°C				0.44
165°C				0.11
175°C				0.08

Table 3 Physical properties of coconut fiber

Property	Unit	Standard test	Result
Diameter	mm	-	0.2 - 0.6
Tensile strength	N/mm ²	ASTM D3822/D3822-14	120 - 140
Flash point	°C	-	> 200
Fire point	°C	-	> 200
Water absorption	%	-	1.2 - 1.3
PH	-	ASTM D2165-94(2002)e14	5.65

bulk specific gravity, and viscosity were tested and these properties were fallen within requirements.

Coconut fiber

Coconut fiber using in this study was obtained from Sichon district, Si Thammarat Province located in southern Thailand. The lengths of this fiber were between 200-300 mm, therefore they were cut to fit to the designed lengths of 5-20, 20-40, and 40-60 mm-long. Various physical properties including tensile strength, flash point, fire point, water absorption, and PH were tested as shown in Table 3. Length and diameter were measured by venire. Flash and fire point was conducted following to flash and fire point test of AC60/70. The results of these both properties were more than 200°C. Tensile strength (ASTM D-3822/D3822-14) was tested by INSTRON machine with the tensile mode of 5 kN load cell and the cross-head speed of 0.1 mm/min. This test was applied on 10, 30, and 50 mm-long coconut fiber which were the average length of each designed length. Its results were between 120-140 N/mm². PH (ASTM D2165-94,

(2002)e14, 2012) was tested by AOKTON machine and it was 5.65 for all coconut fiber lengths.

Sample Preparation and Experimental Methods

Mixture preparation for Marshall Stability test

Mixtures were prepared according to Marshall method as specified by Brown and Cooley (1999). In this study, at least three samples were tested for each asphalt content. The blended aggregate (12.5 mm NMAS) incorporated with AC60/70 (6, 6.5, and 7% by mass of the blended aggregate) and coconut fiber of various contents (0, 0.1, 0.3, 0.5, and 0.7% by mass of the blended aggregate) of three different lengths (5-20, 20-40, and 40-60 mm-long) were used to prepare for SMA mixtures. Firstly, the blended aggregate (1,200 g) was heated overnight at mixing temperature (160-170°C). After then, coconut fiber was added by content (0, 0.1, 0.3, 0.5, 0.7% of 5-20 mm-long, so on ..., for instance) and thoroughly mixed with the blended aggregate until it became homogenous prior to the presence of AC60/70. AC60/70 after being heated at mixing

temperature was added by content lately. These three materials were thoroughly mixed until the homogenous mixture was obtained. The compaction on the specimen was done by applying 50 blows of a standard hammer (weight of 4.5 kg and a free fall of 45.7 cm) on each side of the specimen in order to obtain a compacted mixture with 63.5 ± 3 mm of height and 101 ± 0.5 mm of diameter after the extraction.

Volumetric Properties

Volumetric properties including air void (AV), void in mineral aggregate (VMA), bulk specific gravity of compacted asphalt mixture (G_{mb}), voids of coarse aggregate in the compacted mixture (VCA_{mix}) were able to determine right after the compacted samples were kept overnight to cool to room temperature. Other required properties such as theoretical maximum specific gravity of mixtures (G_{mm}) and void of coarse aggregate in dry rodded condition (VCA_{DRC}) were tested as well to fulfill the requirements.

Marshall Stability Test

Marshall stability test in accordance with ASTM D6927-06 (2006) was performed right after the determination of volumetric properties were obtained correctly. Compacted samples were maintained at 60°C water bath for 30 min prior to the test. The maximum load in which the sample can withstand with was recorded and determined as the stability of sample.

Draindown Test

Draindown test is a very important test which is a must-do test for SMA mixtures. This test was conducted to insure the holding ability of binder inside SMA mixtures during the production, transportation, and construction time. There are many methods which can be used to evaluate the

draindown characteristic of SMA mixtures. Schellenberg method outlined by ASTM D6390 (2011) was followed in this study. The results of OAC (Figure 2) were used as asphalt content for this test. The specimen of this test was prepared as the preparation of Marshall Stability's specimen but without compacted process. After the performance of this test, Figures 3 and 4 are obtained.

Results and Discussion

Marshall Properties

For the very first step, Marshall samples were prepared with different asphalt contents, different coconut fiber contents, and different variations of coconut fiber with the objective to obtain the optimum coconut fiber content and length required for a mixture. These properties were determined based on 4% air specified by Brown and Cooley (1999). After retested to confirm at their 4% air

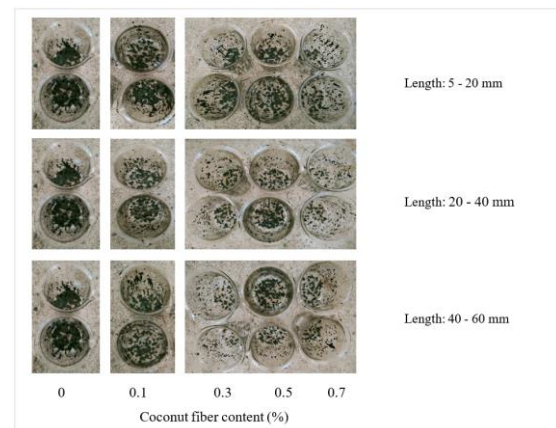


Figure 3. Figure 2.2 Remained mixtures in the glass beaker (ASTM D6390) after testing

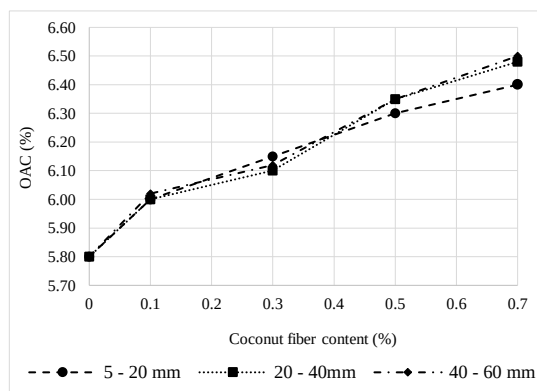


Figure 2. The results of OAC of each mixture

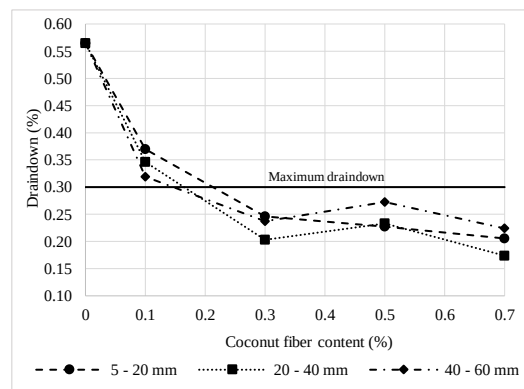


Figure 4. The results of Schellenberg draindown of each mixture

void, the results of such mixtures are presented and discussed as follows.

Marshall properties including AV, VMA, VCAmix, Gmb, Gmm, and stability of each coconut fiber variations are presented through Figures 5-10. According to Figure 5, it is observed that the OAC of any coconut fiber lengths increase when content of coconut fiber increases. This is due to the fact that in every additional coconut fiber content, mixtures need more asphalt content to provide suitable coated area. However, as shown in Figure 6, the stability values are not increased in every additional coconut fiber. It is observed that with increase in coconut fiber content, the stability of a mixture with any coconut fiber length increases up to 0.3% content of coconut fiber, and thereafter decreases. This is due to the fact that homogeneity of mixtures is low at higher coconut fiber content. Moreover, it is due to the fact that at higher additional coconut fiber content, the aggregate contact is reduces and the tendency of compacted mixtures to absorb moisture during curing in water bath at 60°C (30 min) can cause more swelling ability. Furthermore, as seen in Figures 7-8, VMA and VCAmix similarly increase in normal trend. According to the limitation as

specified by Brown and Cooley (1999), VMA of at least 17% is recommended for SMA mixtures. As seen in Figure 7, VMA values of each coconut fiber variation are higher than limitation and it increases in every additional contents of coconut fiber. Moreover, it is also required VCAdrc of not greater than VCAdrc. As shown in Figure 8, these two values are followed to the prescript requirements. The results of VMA and VCAmix of 40-60 mm-long coconut fiber are the highest following by 20-40 and 5-20 mm-long, respectively. It is also seen that the unit weight Gmb and theoretical unit weight Gmm of each coconut fiber variation show the similar decrease trend. These two properties decrease due to further coconut fiber addition. It is also observed that the coconut fiber of 5-20 mm-long provides the highest Gmb and Gmm than the other lengths. It is due to the face that the shorter length provides more homogeneity and its ability of performing to ball shape during mixing is low than the longer length.

Draindown Characteristic

Brown and Cooley (1999) have suggested the draindown of SMA mixtures of not more than 0.3%.

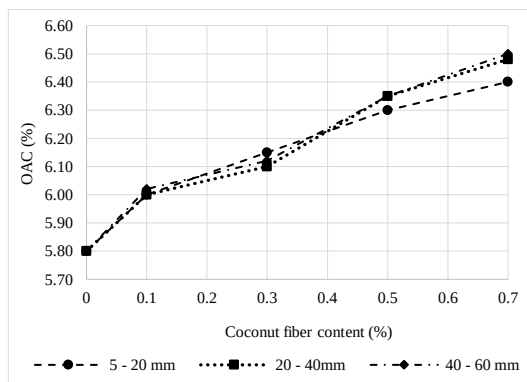


Figure 5. The results of OAC of each mixture

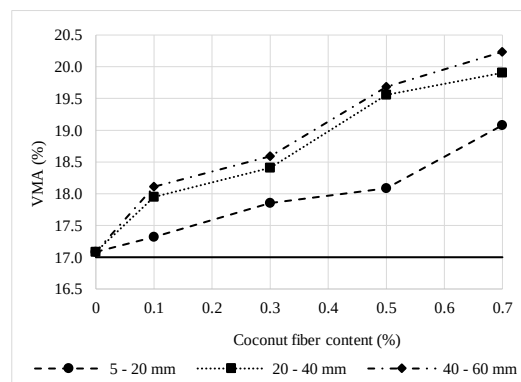


Figure 7. The results of VMA of each mixture

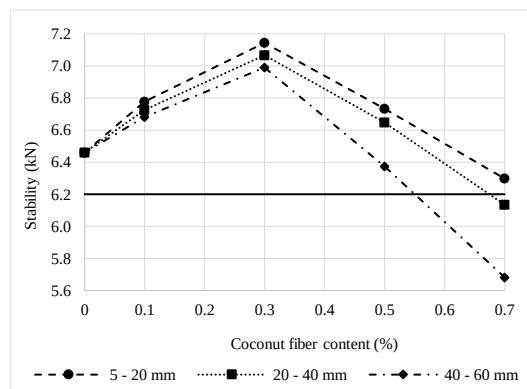


Figure 6. The results of stability of each mixture

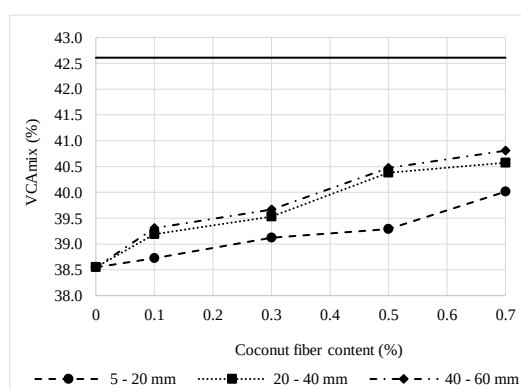


Figure 8. The results of VCmix of each mixture

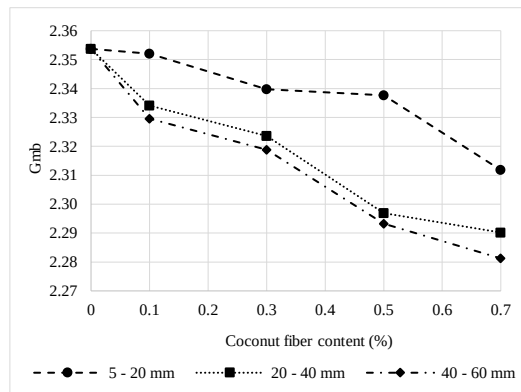


Figure 9. The results of Gmb of each mixture

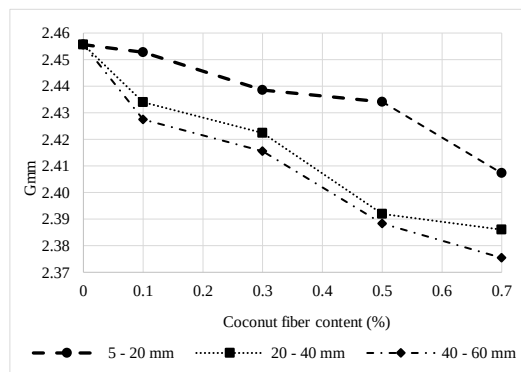


Figure 10. The results of Gmm of each mixture

As shown in Figure 4, draindown of 0 and 0.1% content of coconut fiber of any coconut fiber lengths are out of limitation. This is due to the fact that these both contents of coconut fiber are not able to prevent drainage of AC60/70 from aggregate matrix. On the other hand, draindown of 0.3, 0.5, and 0.7% content of any coconut fiber lengths are within limitation and it shows similar decrease trend.

Optimum Coconut Fiber Content and Length

The optimum coconut fiber including content in % and length in mm were determined based on Marshall Stability values and draindown loss. It is observed from Figure 6 that the draindown loss of 0.3-0.7% coconut fiber content of each coconut variation are within the prescript specification. It is also seen from Figure 6 that the stability value of 5-20 mm-long coconut fiber presents the highest result among other variations. Therefore, the optimum coconut fiber length is 5-20 mm-long and 0.3% content. This is due to the fact that the shorter length provides more workability (easy to mix and compact) and more homogeneity to mixtures. Adding that, the ability of performing into ball shape

during mixing process is lower than the longer length.

Conclusion and Suggestion

In this study, coconut fiber of various contents (0, 0.1, 0.3, 0.5, and 0.7% by mass) of different lengths (5-20, 20-40, and 40-60 mm-long) were added into mixtures to investigate its effect (content and length) on properties of SMA. The results from mixtures mixing with these contents and lengths of coconut fiber were compared in order to obtain the optimum length and content. The following conclusion were made:

- The OAC, VMA, and VCmix of any coconut fiber lengths were increased in every additional content while the Gmb and Gmm of any coconut fiber lengths were decreased in every additional contents.
- The stability of 0.3% content of any lengths of coconut fiber were the highest compared to other contents. Adding that, the stability of 5-20 mm-long coconut fiber was improved up to 2.5% as compared to 20-40 and 40-60 mm-long coconut fiber.
- Draindown was not depended on coconut fiber length but this property was depended on content of fiber adding into mixture.
- The optimum fiber content was found to be 0.3% of all coconut fiber lengths and the optimum coconut fiber length is 5-20 mm-long.
- Mixture containing 0.3% of 5-20 mm-long coconut fiber was the best overall mixture for 12.5 NMA SMA mixing with AC60/70.
- Indirect tensile strength and tensile strength ratio shall be investigated for further study.

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