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Laboratory investigation of stone mastic asphalt mixtures containing coconut fiber

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Abstract

Coconut fiber has been widely used in many applications especially in the pavement purposes. In this study, the properties of stone mastic asphalt (SMA) mixtures mixing with three different lengths (5 - 20, 20 - 40, and 40 - 60 mm-long) and contents (0.1, 0.3, and 0.5% by mass) of coconut fiber were investigated. The properties including Marshall stability, draindown, indirect tensile strength, and tensile strength ratio were carried out on 12.5 mm NMAS of SMA mixed. The optimum asphalt binder content was determined for each mixture. The experimental results revealed that SMA mixtures containing 0.3% of 5 - 20 mm-long coconut fiber provided the optimum properties based on SMA specifications for Marshall compacted design and had better performance as compared to other mixtures.

Keywords: Coconut fiber, Draindown, Indirect tensile strength, Marshall stability, Stone mastic asphalt (SMA)

1. Introduction

SMA, which is a gap-graded hot mix asphalt has been recognized worldwide because of its durability, resistant to permanent deformations, and capable of being applied in thin layers. Typically, the required components of SMA mixtures are aggregates, asphalt cements, and stabilizing agents. As SMA mixtures require stone to stone contact, it is therefore needed 70 - 80% of coarse aggregate, 12 - 17% of fine aggregate, and 8 - 13% of filler. Furthermore, SMA mixtures require 6 - 7% of asphalt cements and 0.3 - 0.5% of fibers and/or modifiers [1-3].

Stabilizing agents including fibers and/or modifiers are required to fulfil the draindown requirement of SMA. Modifiers such as polymer, crumb rubber, natural rubber, plastic wastes, etc. have been used to modify the conventional asphalt [4, 5]. Beside modifiers, there are many type of fibers including cellulose fiber, banana fiber, sisal fiber, waste fibers, pineapple fiber, and coir/coconut fiber which can be used in SMA [3, 6, 7]. Fibers permit a higher asphalt content that would make a thicker asphalt film around the aggregate. With the thicker asphalt film, it helps to retard the oxidation, counter to moisture penetration, and it's good at aggregate separation which benefits in improving the wearing resistance of the surface courses of the pavements [4]. Fibers are also good in draindown reduction as compared to polymer modifiers [8]. Coconut fiber has the highest toughness which is capable of improving stability and moisture susceptibility of SMA mixtures among all known natural fibers [7]. Kumar and Ravitheja [3] investigated on the characteristic of SMA mixtures containing three different type of natural fibers (coir/coconut, sisal, and banana fiber). The results indicated that the stability of mixtures mixing with coconut fiber were 10% greater than those mixing with sisal and banana fiber. In another study, Vale *et al.* [9] compared the behavior of natural fibers (coconut and cellulose fiber) in SMA mixtures. These two fibers were compared by several properties including draindown, indirect tensile strength (ITS), resilient modulus, fatigue life, and moisture susceptibility. Coconut fiber was cut into 30 - 40 mm-long and its contents were 0.5% and 0.7% by mass while the content of cellulose fiber was 0.3% by mass. These two fibers were mixed with 5.5% - 7% (0.5% increment) of AC50/70. The experimental results indicated that the optimum fiber content (OFC) for mixtures containing cellulose and coconut fiber were 0.3% and 0.5%, respectively. Moreover, the results of draindown, stability, and moisture susceptibility of mixtures mixing with coconut fiber were excellent as compared to those mixing with cellulose fiber. Beside the improvement of SMA properties, it is also reported that SMA mixtures containing coconut fiber were economical (cheaper and also abundantly available) as compared to those containing cellulose fiber [10]. By seeing the certain advantages of coconut fiber, therefore this study aims to investigate the properties of SMA mixtures containing coconut fiber.

Previous works commonly used 20 - 40 mm-long of coconut fiber to prevent draindown and also used to investigate the other properties effected toward SMA mixtures. Chandy and Nattaporn [11] studied on using of coconut fiber in SMA mixtures. The coconut fiber length and contents using in this work were 20 - 40 mm-long and 0.1 - 0.7% (0.2% increment), respectively. The properties including volumetric properties, Marshall stability, and draindown of mixtures mixing with and without coconut fiber were compared. The results indicated that the addition of 0.3% coconut fiber reached to the optimum requirements of SMA. To be able to see the effect of coconut fiber on properties of SMA, this study therefore aims to differentiate the length of coconut fiber into three different lengths. The results also showed that the stability of mixtures containing 0.7% coconut fiber was out of prescript requirement. Therefore, this study aims to use 0.1, 0.3, and 0.5% content of coconut fiber. In this study therefore

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Table 1 Basic properties of aggregates

Property	Unit	Standard test	Specification	Result		
				12.5 mm	9.5 mm	Dust rock
Specific gravity	-	ASTM C127	2.5 - 3.0	2.65	2.66	2.65
Water absorption	%	ASTM C127	2 Max	1.18	1.24	1.23
LA abrasion	%	ASTM C131	30 Max	28	28	-
Flakiness	%	ASTM D4794	10 Max	8	10	-
Elongation	%	ASTM D4794	10 Max	7	5	-

Table 2 Basic properties of AC60/70

Property	Unit	Standard test	Specification	Result
Penetration at 25°C, 100g, 5s	-	ASTM D5	60 - 70	67
Ductility at 25°C, 5cm/min	cm	ASTM D113-07	Min 100	> 100
Softening point	°C	ASTM D36	Min 46	47.6
Flash and fire point	°C	ASTM D92	Min 220	> 328
Solubility in Trichloroethylene	%	ASTM D2042-15	Min 99	99.98
Specific gravity at 25/25°C	-	ASTMD70-80	1.02 - 1.06	1.056
Complex shear modulus at 64°C	kPa	ASTM D7175-15	Min 1	1.11
Viscosity at 135°C	cP	ASTM D4402	-	110.17
Viscosity at 165°C	cP	ASTM D4402	-	42.01

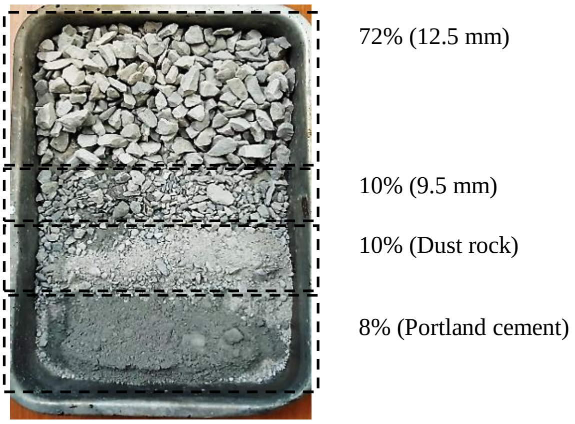


Figure 1 The combination of aggregates and filler for 12.5 mm NMAS

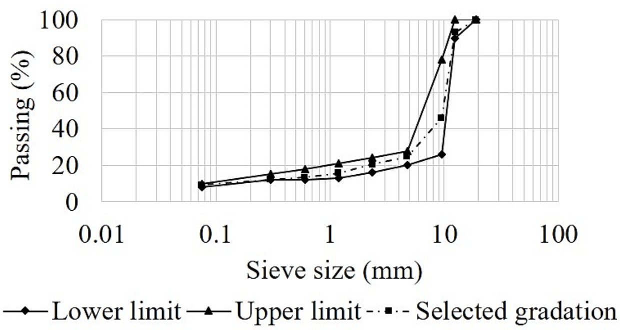


Figure 2 Gradation selection for 12.5 mm NMAS

coconut fiber of three different lengths (5 - 20, 20 - 40, and 40 - 60 mm-long) and contents (0.1, 0.3, and 0.5%) mixing with AC60/70 were incorporated into 12.5 mm NMAS to study its various properties for SMA mixtures. Marshall stability, draindown, ITS, tensile strength ratio (TSR), and moisture susceptibility are discussed in detail.

2. Materials and experimental methods

2.1 Basic properties of aggregates and filler

Three sizes of lime stone aggregate (12.5 mm, 9.5 mm, and dust rock) adopted from Roi Et province (Thailand) were used to prepare all SMA mixtures throughout the study. Specific gravity, water absorption, Los Angeles (LA) abrasion, flatness and elongation properties of these aggregates were tested as shown in Table 1.

Portland cement passing 0.075 mm sieve of more than 90% was also used in this study. Its laboratory specific gravity (ASTM C188) was 2.97. The combination (Figure 1) of 12.5 mm (72%), 9.5 mm (10%), dust rock (10%), and Portland cement (8%) was made for 12.5 mm NMAS (Figure 2) according to specification of SMA mixtures for Marshall Hammer compacted design [12].

2.2 Basic properties of AC60/70

AC60/70 using to prepare the SMA mixtures in this study was provided by Thai Lube Base Public Company Limited located in Sriracha, Chonburi, Thailand. Various properties as shown in Table 2 were tested.

2.3 Basic properties of coconut fiber

Coconut fiber using to prepare SMA mixtures in this study was adopted from Sichon district located in the northern part of Si Thammarat province of Thailand. The colour of this fiber was brown and its lengths ranged between 200 - 300 mm-long. It was cleaned and cut into three different designed lengths including 5 - 20, 20 - 40, and 40 - 60 mm-long as shown in Figure 3.

The tensile strength conducting on the average of each length was tested by INSTRON machine (ASTM D3822/D3822-14) with the tensile mode of 5 kN load cell and the cross head speed of 0.1 mm/min. The above three mentioned lengths gave similar average tensile strength of 135 N/mm^2. To ensure that it can be used and prepared for SMA mixtures at mixing temperature, flash and fire point test were performed. The average result of flash and fire point were greater than 200°C. Moreover, other properties such as diameter, water absorption, and PH were tested as well. Diameter was measured by a standard venire. Water absorption was tested by curing 20 g coconut fiber (3 samples) at 25°C water for 24 hours, and the samples were then kept overnight in oven (110°C). PH was tested (curing 10 g coconut fiber (3 samples) at 25°C water overnight) by AOKTON machine (ASTM D3822/3822-14). These properties are provided in Table 3.

Table 3 Physical properties of coconut fiber

Property	Unit	Test method	Result
Diameter	mm	-	0.2 - 0.6
Flash and fire point	ºC	-	> 200
Water absorption	%	-	1.2 - 1.3
PH	-	ASTM D2165-94(2002)e14	5.65
Tensile strength	N/mm2	ASTM D3822/D3822-14	120 - 140

Table 4 Specifications of SMA mixtures of Marshall Hammer compacted design [12]

Property	Unit	Specification
Air void	%	4
VMA	%	17 Min
VCAmix	%	Less than VCAdrc
Stability	kN	6.2 Min
TSR	%	70 Min
Draindown	%	0.3 Max

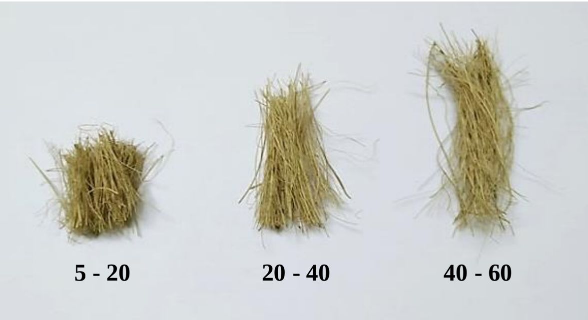


Figure 3 Different lengths of coconut fiber in mm-long

2.4 Design of SMA mixtures

Coconut fiber after being cut to fit the designed lengths (5 - 20, 20 - 40, and 40 - 60 mm-long) was added by content (0.1, 0.3, and 0.5% by mass) and mixed with 1,200 g of heated blended aggregate (160 - 170ºC) until sufficiently homogenous. AC60/70 was also added by content (6, 6.5, and 7% by mass) and the mixture was mixed until sufficiently homogenous again. The final mixture was compacted by 50 blows of a standard hammer with free dropped height in order to get a sample of 63.5 ∓ 3 mm of height and 101 ∓ 0.5 mm in diameter after the extraction. After 24 hours, weight of samples in air, in water, and in saturated state were determined in order to find the volumetric properties. Marshall stability test was performed right after the determination of volumetric properties were done correctly. The peak load being able to withstand by the sample was recorded as the stability value according to ASTM D6927-06 [12, 13].

There are two methods used to determine the optimum asphalt content (OAC) including NAPA procedure and AI method, [14]. In this study, NAPA procedure was followed in order to obtain the OAC of all mixtures. To determine the OAC, 3 samples were prepared for each asphalt content (6, 6.5, and 7%). It was proposed by Brown and Cooley [12] that at the target OAC, the air voids shall be 4%. Thus, the OAC of all mixtures were chosen to be evaluated depending on 4% air voids. The requirements of SMA mixtures for Marshall Hammer compacted design are provided in Table 4.

2.5 Draindown test

Draindown test following by ASTM D6390-11 [15] was used to determine the draindown characteristic of mixtures. Samples preparation for this test were prepared as those of Marshall stability test but without compaction process. Mixture after being mixed well was pour into 1,000 ml glass beaker and then kept for 1 hour at mixing temperature. After that 1 hour, mixture was pour out off the glass beaker with no shaking force. The remained mixtures sticking inside the glass beaker as shown in Figure 4 were used to determine the draindown. In this test, 2 samples of each OAC were tested and the average values were recorded.

2.6 ITS test

The static ITS test was conducted to those mixtures passing the requirement of stability and draindown only. To be able to obtain moisture damage of SMA mixtures, 6 samples were prepared and divided into three each of unconditioned ITS (ASTM D6931) and conditioned ITS (ASTM D4867). Samples of unconditional ITS were maintained at least 1 hour but not more than 2 hours at 25ºC while those of conditioned ITS were maintained at 25ºC within the vacuum suction such as 5 minutes in order to get the samples to reach to its degree of saturation (volume of water have to between 55 - 80 % of the volume of air). After samples reached to its degree of saturation, they were maintained 24 hours more at 60ºC water bath and then proceed another 1 hour in 25ºC water bath. After the above mentioned criteria were met, static ITS test of each group were subjected and their peak loads were recorded. The sample before and after the test (failure) were shown in Figure 5.

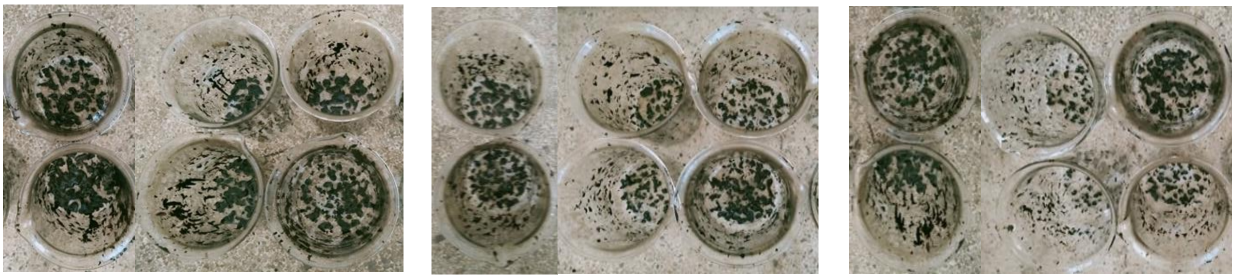
3. Results and discussion

3.1 The effect of coconut fiber on OAC and volumetric properties

The OAC and volumetric properties including air void (AV), void in mineral aggregate (VMA), void of coarse aggregate in the compacted mixture (VCAmix), void of coarse aggregates in dry rodded-condition (VCA_{drc}), specific of compacted (Gmb) and umcompacted mixture (Gmm) of various contents and lengths of coconut fiber are shown in Table 5.

Table 5 shows the results of OAC and volumetric properties of mixtures mixing with various contents and lengths of coconut fiber. It is seen that the OAC of mixtures increase in every additional content of all lengths of coconut fiber. This is due to the fact that mixtures need more asphalt content to provide suitable coated area. This finding is in the agreement with the study of Panda et al. [4] and Wo [16]. It is also seen that the results of VMA of mixtures are greater than the requirement (17% Min). These VMAs also increase in every additional content of coconut fiber. It is also seen that Gmb and Gmm decrease in similar trend. The coconut fiber of 40 - 60 mm-long has the highest VMA but lowest Gmb and Gmb. This is due the fact the longer length provides less homogeneity and workability. It also seen that the results of VCAdrc are greater than the VCAmix (within requirement) of all contents and lengths of coconut fiber. It is also seen that volumetric properties of controlled mixture (0% coconut fiber) fall in specifications. However, the OAC (5.8%) of this mixture is lower than the designed content (6 - 7%) and its VMA almost equals to minimum value. The finding of such mixtures share similarities with the study of Beena and Bindu [17]. However, the results of OAC in this study are quite lower than those of Beena and

Length: 5 - 20 mm Length: 20 - 40 mm Length: 40 - 60 mm



0.1% 0.3% 0.5% 0.1% 0.3% 0.5% 0.1% 0.3% 0.5%

Coconut fiber content

Figure 4 Remained mixtures in the glass beaker (ASTM D6390-11) after testing

Figure 5 Samples before (a) and after (b and c) the ITS test

Table 5 The OAC and volumetric properties of mixtures

Coconut fiber		*OAC*	*AV*	*VMA*	*Gmb*	*Gmm*	*VCAmix*	*VCAdrc*
mm	%	%	%	%			%	%
0	0	5.80	4.15	17.08	2.354	2.456	38.55	42.61
	0.1	6.00	4.11	17.32	2.352	2.453	38.72	42.61
5 - 20	0.3	6.15	4.05	17.86	2.340	2.439	39.12	42.61
	0.5	6.30	3.96	18.09	2.338	2.434	39.29	42.61
	0.1	6.00	4.10	17.95	2.334	2.434	39.19	42.61
20 - 40	0.3	6.10	4.08	18.41	2.324	2.422	39.53	42.61
	0.5	6.35	3.97	19.56	2.297	2.392	40.38	42.61
	0.1	6.02	4.03	18.11	2.330	2.427	39.31	42.61
40 - 60	0.3	6.12	4.00	18.59	2.319	2.416	39.67	42.61
	0.5	6.35	3.98	19.69	2.293	2.388	40.48	42.61

Bindu’s. The reason is that they used fine aggregate (30% by mass) and filler (11% by mass) higher than those (10% by mass for each type) of this study. The fine aggregate consists of particles passing through 4.75 mm sieve, it is therefore required more asphalt for absorption [14].

3.2 The effect of coconut fiber on Marshall stability

After the first experiment of all mixtures were done and evaluated based on 4% air voids, the second experiment were retested at the same OAC of the first experiment to verify. The results of Marshall stability of mixtures mixing in various lengths and contents of coconut fiber are shown in Figure 6.

Figure 6 is used to present the Marshall stability results of SMA mixtures of this study. It is observed that the stability of all lengths of coconut fiber increase up to 0.3% content of coconut fiber, and thereafter decrease. This finding is similar to [17] who stated that bituminous mixture is a non-uniform which consists of aggregates, filler, and sticky binder. It is therefore the excessive fiber could lead the mixture to have less uniformity so that the weak points may happen inside the mixture. It is also seen that the controlled mixture provides the lowest stability compared to other contents. This could be indicated that the presence of coconut fiber significantly brings the improvement of stability [17]. Adding that, it is also observed that the stability results of 5 - 20 mm-long coconut fiber show the highest among other lengths. This is due to the fact that the shorter length is easy to mix, compact, and also provides more homogeneity to mixture. The requirement of stability is required to be at least 6.2 kN [12], it is therefore seen that these results are greater than the minimum requirement.

3.3 The effect of coconut fiber on draindown characteristic

Draindown of SMA mixtures were conducted right after the determination of OAC. Draindown results of mixtures containing various contents and lengths of coconut fiber are shown in Figure 7.

Figure 7 presents the draindown results of SMA mixtures mixing with various coconut fiber lengths and contents. It is observed that the draindown results at 0 and 0.1% of any lengths of coconut fiber are higher than the maximum value (0.3%). In contrast, the draindown results of mixtures having 0.3 and 0.5% of any lengths of coconut fiber are lower than the maximum value. According to specification taken from [12], driandown is specified to be lower than 0.3%. Therefore, it is seen that the

Table 6 The IDT results of SMA mixtures

Coconut fiber		***Unconditioned ITS***	***Conditioned ITS***
mm	**%**	***kPa***	***kPa***
5 - 20	0.3	737.60	680.83
	0.5	680.85	603.00
20 - 40	0.3	720.86	651.60
	0.5	676.67	549.49
40 - 60	0.3	705.47	630.47
	0.5	631.13	506.58

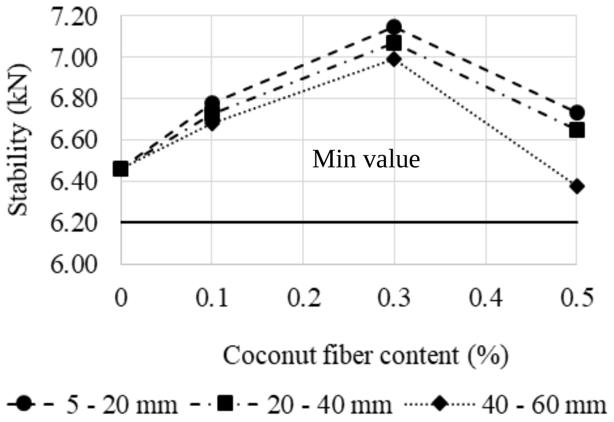


Figure 6 The results of Marshall stability of each mixture

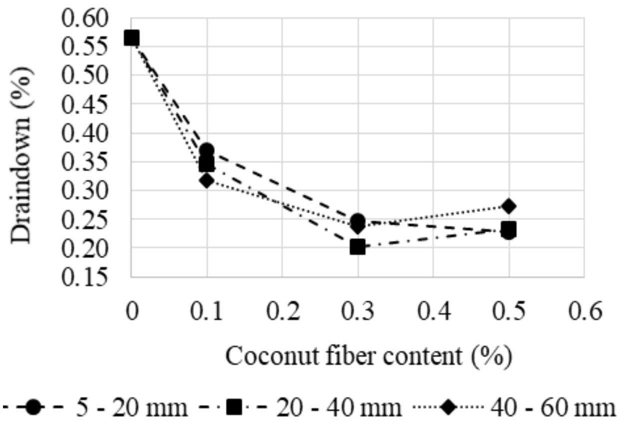


Figure 7 The results of draindown

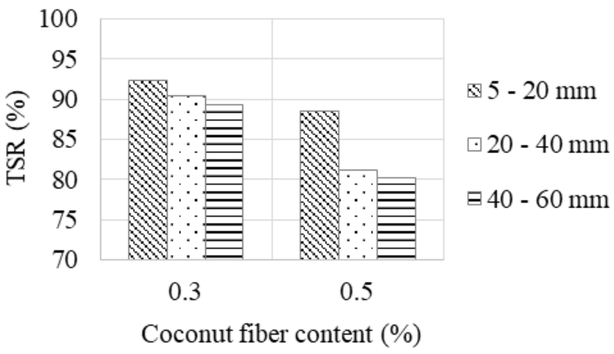


Figure 8 Results of TSR

draindown of 0 and 0.1% of any lengths of coconut fiber are out of the prescript specification. This is due to the fact that the ability to absorb AC60/70 at these contents is lower as compared to other contents. Adding that, it may be due to the fact that the AC60/70 is not viscous enough (its adhesive force is not as strong as modified asphalt) to make these two contents meet the requirement. Modified asphalt such as polymer modified asphalt (PMA) [4] shall be used to make these contents applicable. The viscosity of AC60/70 in this study was 42.01 cP (165^{o}C) while that of PMA requires at least 300 cP (165^{o}C) [5]. The higher the viscosity value, the greater the adhesive force will be [14]. This could be indicated that the mechanism characteristic of PMA at high temperature is better (more adhesive force) than AC60/70. However, experiments shall be conducted and investigated when these contents are used with the other binder to prepare for SMA mixtures. This finding shares similarity with the study of Beena and Bindu [17].

3.4 The effect of coconut fiber on indirect tensile strength characteristic

The ITS results of SMA mixtures mixing with different coconut fiber lengths and various contents for both unconditioned and conditioned samples are given in Table 6.

Table 6 shows the results of ITS of mixtures passing draindown and Marshall stability requirements. It is seen that the unconditioned and conditioned ITS at 0.3% content of any lengths of coconut fiber provide the highest result. It is also seen that the unconditioned and conditioned ITS of 5 - 20 mm-long coconut fiber of any contents present the highest results following by 20 - 40 and 40 - 20 mm-long. This is due to the fact that the shorter length brings more homogeneity but the longer length is likely to stick together and the ability of performing to ball shape (it is not good because it could lead mixtures to have less bonds between fiber, binder, and, aggregate) is also high. Moreover, these both results could indicate that the presence of coconut fiber provides the improvement of strength to mixture as compared to controlled mixtures. This finding shares similarity to the study of Beena and Bindu [17] and Mohammadzadeh et al. [18].

3.5 The effect of coconut fiber on TSR and moisture susceptibility

The results of TSR of mixtures mixing in various coconut fiber lengths and contents are given in Figure 8.

It is seen that the results of TSR at 0.3% content of coconut fiber are greater than those of 0.5% content. It is also seen that the results of TSR of 5 - 20 mm-long coconut fiber present the highest value following by 20 - 40 and 40 - 60 mm-long. This is due to the fact that the conditioned samples which consisted of higher coconut fiber content incorporated with longer length increased the ability of water absorption (during maintained at 60^{o}C for 24 hour). This finding which shares similarity to the study of [9] and [18] could indicated that the TSR yields to the optimum value when both conditioned and unconditioned samples consist of optimum amount of coconut fiber (0.3%) with the shorter length. SMA mixtures are required to have TSR at least 70% [12], it is therefore indicated that the above TSR results are greater than the prescript requirement.

Moisture susceptibility is defined as the extension of moisture damage (occurs due to the presence of moisture) in bituminous mixes and it is evaluated based on the results of TSR [19]. Therefore, moisture susceptibility is reflected by TSR. Additionally, it is able to indicate that the addition of only 0.3%

content of any lengths of coconut fiber could significantly bring advantage in terms of improving the moisture susceptibility characteristics. This finding is similar to the study of [4] and [17].

4. Conclusions

The conclusions based on laboratory investigation on the properties of 12.5 mm NMAS SMA mixing with coconut fiber were made based on the result of OAC and volumetric properties, stability, draindown, ITS, and TSR. It's indicated that the OAC was effected by content of coconut fiber rather than length of coconut fiber. Adding that, mixtures containing 5 - 20 mm-long coconut fiber provided greater volumetric properties compared to other lengths. Furthermore, the results of draindown test could reveal that the coconut fiber length had no effect on draindown but its content and material such as AC60/70 were the things playing the important role in the effecting on this property. Moreover, mixtures containing 5 - 20 mm-long coconut fiber provided greater stability, ITS, and TSR following by 20 - 40 and 40 - 60 mm-long. Adding that, the stability, ITS, and TSR of mixtures were found to be the highest at 0.3% of all lengths of coconut fiber. The additional 0.3% content of coconut fiber improved TSR of mixtures up to 2.1% compared to other contents. Furthermore, the results of TSR were improved up to 12.1% when this content incorporated with 5 - 20 mm-long coconut fiber. Moreover, the best overall moisture susceptibility improvement went to mixtures containing 0.3% content of 5 - 20 mm-long coconut fiber. Additionally, the best overall results were found on mixtures containing 0.3% of 5 - 20 mm-long coconut fiber.

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