International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.11 No.03, pp 52-63, 2018

The Performance of Asphalt Concrete Mixture and Fiber Reinforcement Using Seawater Immersion Model to Indirect Tensile Strength

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Abstract : The objective of this research was to analyze the indirect tensile strength of the asphalt concrete mixture with fiber reinforcement that was immersed on the sea water. The method of research was an experimental testing on the mechanical properties of fibers and indirect tensile strength of the mixture with a variation of length were 5 mm, 6 mm, 8 mm, 10 mm, 12 mm, 14 mm and the variation of fiber content for each composition was respectively 0.2%, 0.4%, 0.6%, 0.8%, 1.0% and 1.2% with the optimum diameter of fiber was 0.3 mm. Each composition of the mixture was tested for each variation of length and fiber content with the optimum asphalt content of 5.9%. The seawater-immersed fibers with the immersion duration of 3 weeks gave high tensile strength and strain. The 0.3 mm diameter fibers with 3 weeks immersion had a maximum stress = 130.45 N / mm^2, and maximum strain of 14.24% while those in control had a maximum stress = 13.71 N / mm2 and maximum strain of 13.89%. While the indirect tensile strength (ITS) test results on five variations of length and percentage of fibers in the asphalt concrete mixture, the 0.6% fiber content composition provided ITS value of a maximum stress = 26795.84 kPa and maximum strain in the fiber length of 8 mm was 0.01486 and an elastic modulus was 2318478.25 kPa. The composition yield a Poisson ratio = 0.44. The Poisson number is an indicator of the ductility of a mixture.
Keywords: elastic modulus, indirect tensile strength, strain

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DOI : http://dx.doi.org/10.20902/IJCTR.2018.110308

1. Introduction

One of the functions of the pavement surface is to provide safety and comfort for the road users and reduce the risk of accidents particularly in wet surface conditions[1]. To ensure resulting mixture has a robust performance towards plastic deformation, rutting, fatigue and tensile strength, thus it is necessary to provide fiber reinforcement as a composite material to asphalt binder of the mixture. The function of fiber in the mixture is expected as a reinforcement material that provides tensile strength with lower stiffness modulus[2]. The fiber in the asphalt concrete mixture is intended to improve the properties of the mixture, for instance by increasing the strength of the material and the characteristic of fatigue, and increasing the ductility[3,4]. Furthermore, it is known that fiber may contribute to avoid crack formation and propagation[5,6], increasing the cohesive strength and tensile mixture, provide physical changes to the asphalt mixture[7], the absorption rate and surface area depending on fiber type[8]. Basically, fiber contributes to the change of the viscoelasticity in the modified asphalt, improves the dynamic modulus[5], temperature sensitivity[9], creep resistance, rutting resistance[10], and reduces the reflective cracking of asphalt on the asphalt mixture and structure. The concrete asphalt layer is reinforced by the fiber that currently is an alternative to repair and strengthen pavement structures[11].

Some fibers have high tensile strength to the asphalt mixture, it was found that the fibers have a great potential to increase the cohesive strength and tensile of the asphalt mixture and are believed to provide physical changes to the asphalt mixture[7]. For the efficiency, the asphalt mixture that was mixed with fiber showed a slight increase in optimum asphalt content[6]. The objective of this research was to analyze the indirect tensile strength of the asphalt concrete mixture and fiber reinforcement using seawater immersion model.

2. Experimental

This research used experimental method by doing some experiment conducted to test some hypothesis to find the relation of dependent variable and independent variable, then controlled in a scientific experiment as the comparison.

2.1 Research Stages

This research was conducted experimentally with four stages of examination and testing. Stage 1 was the preparation of materials; Stage 2 at this stage was done for two material testing and fiber characteristics. Stage 3 was planning of asphalt mixture based on standard asphalt content (s) with five variations of asphalt content as -1%. -0.5%, s, + 0.5%, + 1% which aimed to obtain the optimum asphalt content (OAC). Furthermore, the mixture design with variation of fiber length (0.5 mm to 14 mm at 0.2 mm intervals) and percentage variation of fibers (0.2% to 1.2% with 0.2% intervals) based on OAC. Stage 4 was indirect tensile strength test based on length and percentage of optimum fiber.

2.2 Mixing method

In this study there were two initial mixing methods used to obtain characteristic mixtures of elements and specifications: mixture-I formula which the fiber was composited with aggregate and mixture-II formula which the asphalt is composed with asphalt. Each mixture formulation was mixed and tested to determine the fiber treatment model in the mixture which yielded mixed characteristics that fulfill all the parameters and mixed requirements.

2.3 Fiber material

a. Fiber

Fiber obtained from South Sulawesi with the age of palm trees above the age of 5 years with black fibers as reinforced, fibers was selected at the lower and upper ends of the diameter of between 0.20 to 0.30 mm because it had a solid part and there was no hole in it while at the base was perforated and it contained of a little cork. (Figure 1).

Figure 1. Palm Fiber (a) raw material (b) chopped fiber

b. Binder: Pertamina Co. Ltd asphalt penetration 60/70

c. 1. Crushed stone of maximum size 19.05 mm, 12.7 mm, and 9.53 mm based on requirement of AC - WC mixture specification;

2. Ash stone (size pass Screen No. 4 (4.75 mm)

2.4 Testing Method

a. Single fiber tensile test

The tensile test was performed in accordance with ASTM 3379-02 using the size and model of the test specimen as shown in Figure 9.

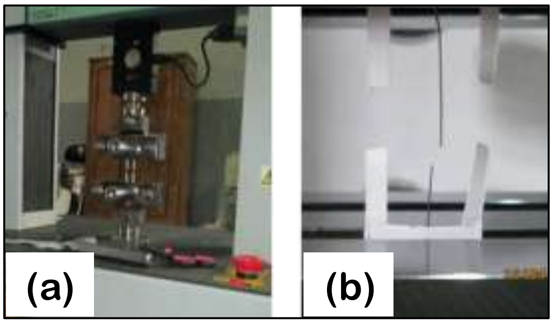


Figure 2. (a) Single-fiber tensile test apparatus; (b) break fiber when being pulled

b. Scanning electron microscopy (SEM) to observe the microstructure of the materials used.

The microcosmic system of lignocellulose composite pavement fibers to strengthen the performance of the asphalt mixture as a pavement material and its characteristic properties were analyzed. A Hitachi S-3000N scanning electron Microscope was used under 15 kV acceleration voltages.

c. Indirect tensile strength test, (ITS) test

The low tensile bond property of the asphalt mixture was an important indicator for the evaluation of anti-crack pavement capabilities (Fig. 3). One of the most commonly used testing models to investigate the performance of asphalt mixtures at low temperatures[12].

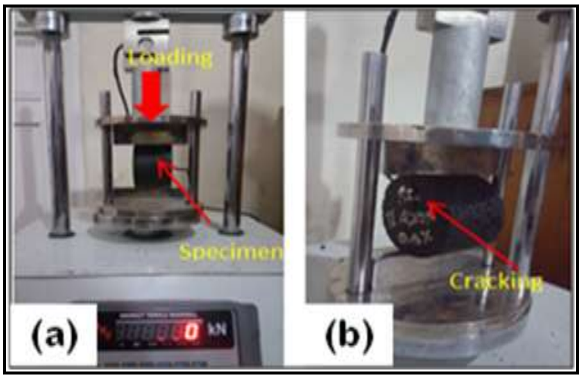


Figure 3. Indirect tensile strength test. (a) Before testing, (b) Cracking condition after the test

According to Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011), the test was performed at a temperature of 200° C[13]. The specimen was compressed 75 times on each side; the specimen size was 9.85 mm x 65.5 mm in diameter. The specimen was placed in a room at 200 ° C for 4 hours before the test.

d. Marshall test

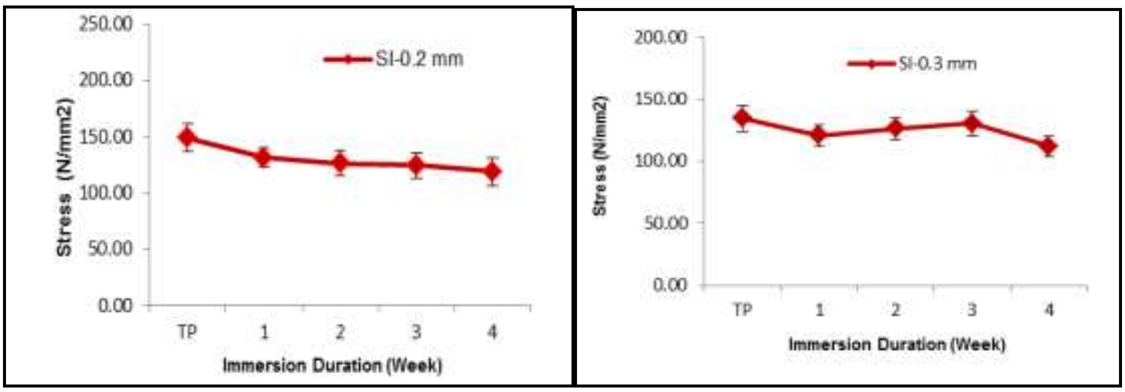
This test aimed to know the characteristic of the asphalt concrete mixture with five variations of asphalt content based on standard asphalt content (-1, -0.5, S, + 0.5, 1.0). Determination of optimum asphalt content (OAC) based on Marshal Parameters that met the required mixed specifications that were included.

2.5 Data Analysis

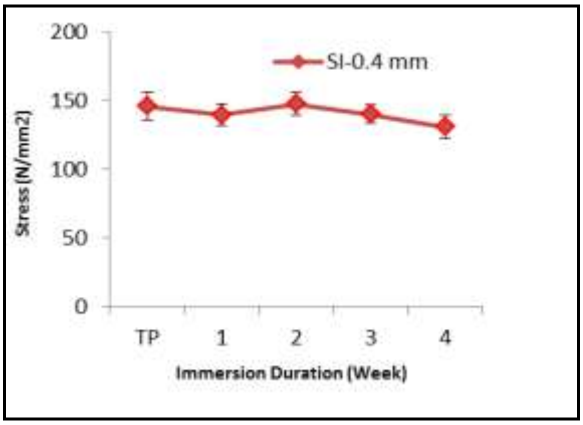
The data obtained in this study were analyzed qualitatively and quantitatively. The process and data analysis was done manually and using computer using Microsoft Office Excel program and SPSS 24. All data that is described in matrix of the relationship between data source and data analysis method is intended to answer the objectives in this research.

3. Results and Discussion

The effect of the immersion by using seawater on the percentage of fiber strain had decreased significantly. Figure 4 a showed that the fibers with the diameter of 0.2 mm decreased significantly from 1 week to 4 weeks, while the fibers with 0.3 mm and 0.4 mm diameter decreased the percentage of strain until 2nd week and increased in 3rd week of the immersion. The increase in the percentage of this strain value was due to the increase in cellulosic elements and the increase in tensile stress. This condition indicates that the larger diameter of fibers led to the decrease of stress and strain values, in which the fibers that had diameters greater than 0.3 mm were brittle and fragile.



(a) **(b)**



(c)

Figure 4. The relation between the stress and the duration of immersion for fiber diameter of (a) 0.2 mm, (b) 0.3 mm, and (c) 0.4 mm.

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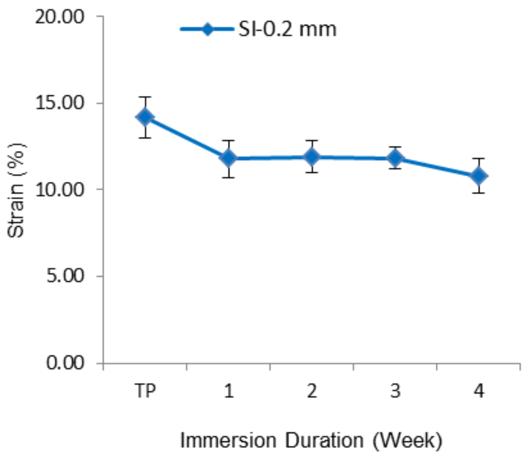
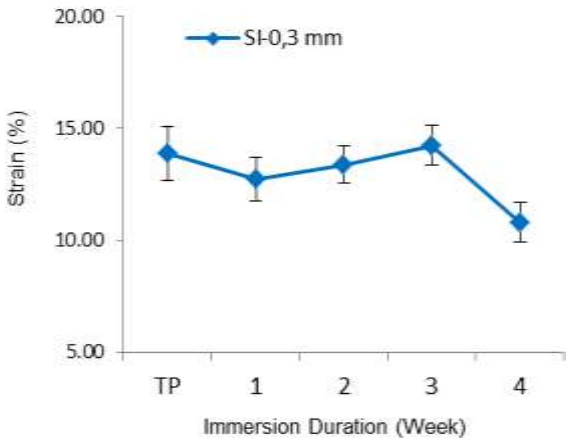


(a)



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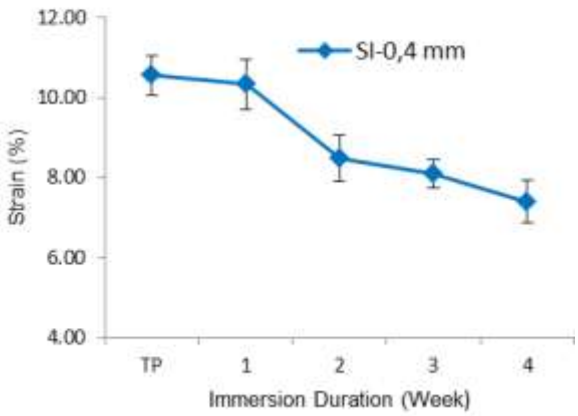


(c)

Figure 5. The strain value percentage relation between fiber diameter and immersion duration. (a) The percentage of fiber strain with diameter of 0.2 mm, (b) The percentage of fiber strain with diameter of 0.3 mm, (c) The percentage of fiber strain with diameter of 0.4 mm.

The Marshall Test results showed the mixed characteristics that meet the required parameters and specifications, where as the percentage of asphalt content increased from 5.6% to 6%, the stability value increased and the percentage the cavities in the mixture decreased. This showed that the fibers in the mixture are capable of increasing the adherence and binding capacity of the mixture so that the density and the density level of the mixture are increased to the optimum level of asphalt content. However, the increase in percentage of asphalt content 6.5% to 7% led the value of stability to decrease (Table 1). This was due to an increase in the percentage of cavities filled by asphalt and the value of VMA and VIM decreased.

The results of Electron Microscopy Scanning (SEM) showed the morphological shape of the fibers surface without immersion having a smaller roughness (Fig 6 a), while fibers treated with sea water immersions were more coarse (Fig 6 b, c and d). The effect of marine water immersion results in the removal of lignin and cellulose elements that cause the surface to become rougher and improve the flexibility.

Based on the measurement of surface roughness of fiber in previous research, it showed that the model of fibers with immersion was able to increase the roughness of the surface with the smallest surface roughness value of fibers without immersion with a roughness value of 0.692 m[14]. The highest value occurred at 2 weeks immersion as 1.366 m, while for 1 week immersion value as 0.990 m, for 3 weeks as 0.946 m and 4 weeks as 1,400 m.

The influence of morphological shape of the fibers surface with the coarser surface contributes in increasing the tensile strength and elastic modulus as in Table 2 and Table 3 where the fibers with the immersion model show the mixture of asphalt concrete by immersion of the fibers of the tensile and elastic modulus values increases and is higher than mixture of asphalt concrete with fibers without immersion. While in Table 4 and Table 5 the fiber with immersion has a maximum strain of 0.01486 and 0.01317 without immersion at a 0.6% percentage with a fiber length of 0.8 mm.

This indicates that the immersion treatment to the fibers provided higher adhesion strength and higher bonding by interlaying between aggregates and asphalt as a better bonding material, thus the risk of shear strength between the larger surface areas due to the loading could be minimized.

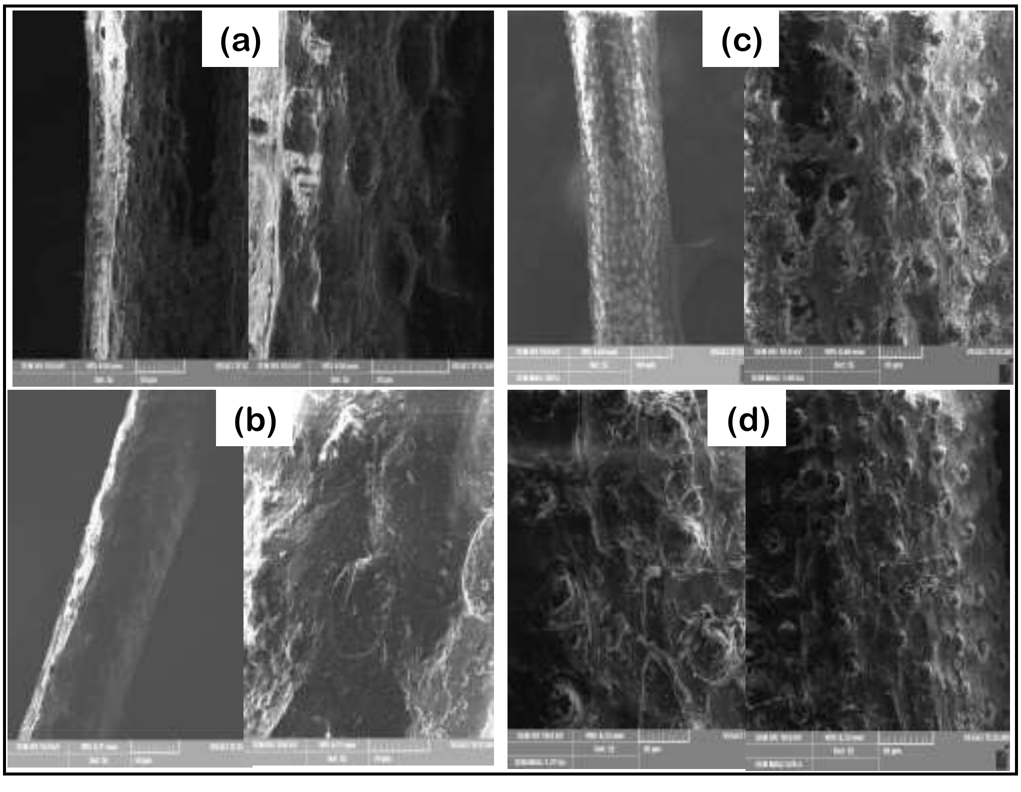


Figure 6. The morphological structure of the fiber surface for after 3 weeks immersion: (a) control without immersion with diameter of 0.3 mm, (b) treatment with the diameter of 0.2 mm, (c) application with the diameter of 0.3 mm, and (d) with diameter of 0.4 mm

From the above results, the fiber in the asphalt concrete was used to improve the properties of the mixture, for instance increasing material strength and fatigue characteristic while increasing ductility[15,16], changing the visco-elastic properties of polymer modified by asphalt binder[17], having the potential to improve the dynamic modulus[5], waterproof[9], flexible, resistant to rutting[18]. In addition, it was known that fiber could contribute to avoid the formation and crack propagation[19]. Particularly, when the fiber has a relatively high tensile strength to the asphalt mixture, the fibers could increase the cohesive and tensile strength of the asphalt mixtures[20]. In addition, fiber-reinforced concrete asphalt might have good resistance to aging, damp damage and crack reflections[21]. Finally, the fiber could also prevent the decrease of adhesive capacity of the binder in the asphalt mixture[22]. As finely dispersed, the fiber provided a high surface area for per unit of weight and acts like filler.

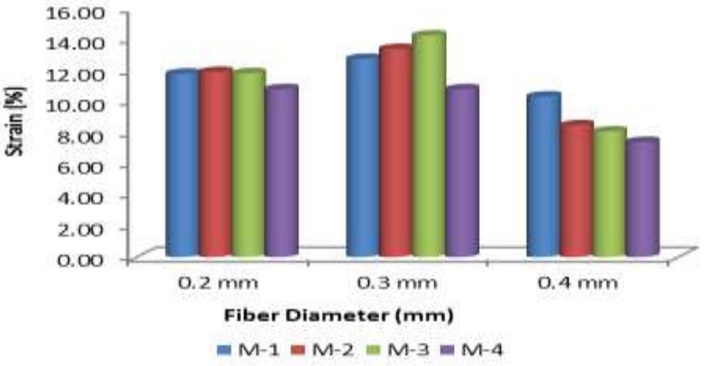


Fig. 7. Relationship of strain and fiber diameter

Table 1. Marshall Composite test results II (fiber + aggregate) + asphalt

Marshall Parameters	**Unit**	**Asphalt level**					
		5	**5,5**	**6**	**6,5**	**7**	**Spec.**
Density	gr/cm^3	2.207	2.253	2.293	2.328	2.351	-
Stability	Kg/cm^2	1298.94	1358.40	1390.65	1366.46	1330.18	> 800 kg
Flow	mm	3.53	3.57	3.60	3.68	3.80	2 - 4
VIM	%	8.88	6.88	5.91	4.73	4.07	3 – 5.
VMA	%	18.99	17.21	16.35	15.30	14.71	Min. 15
VFB	%	53.23	60.04	63.87	69.11	72.62	Min. 65
MQ	kg/mm	365.18	377.43	369.2	381.6	367.3	Min. 250

Table 2. Test results of ITS and fiber modulus without immersion

Composition	**Test**	**Fiber Length**	**Fiber percentage (%)**					
			SI-TP- 0.2	**SI-TP- 0.4**	**SI -TP- 0.6**	**SI-TP-0.8**	**SI-TP0.8**	**SI-TP-1.2**
		5 mm	17214.519	18797.851	20684.374	14351.048	13542.538	12632.964
		6 mm	16810.265	18932.603	20785.437	13812.041	12936.156	11757.079
		8 mm	15462.748	17046.08	18966.291	13037.219	11824.455	10712.754
		10 mm	13273.035	14788.99	17113.456	11689.703	10140.059	9129.4223
	ITS	12 mm	11622.327	12632.964	15260.621	9567.365	8590.4158	6906.0205
	(Kpa)	14 mm	10274.811	11588.639	13273.035	8354.6004	6703.8931	4817.3704
		5 mm	1538300.75	1679788.29	1848369.19	1282419.02	1210170.06	1128889.98
		6 mm	1502176.27	1691829.78	1857400.31	1234253.05	1155983.34	1050620.28
		8 mm	1381761.34	1523248.88	1694840.16	1165014.46	1056641.02	957298.70
Without	Elastic	10 mm	1186087.07	1321553.87	1529269.63	1044599.53	906122.36	815811.16
Immersion	Modulus	12 mm	1038578.78	1128889.98	1363699.10	854946.01	767645.19	617126.52
	(Kpa)	14 mm	918163.85	1035568.41	1186087.07	746572.57	599064.28	430483.38

Table 3. Test results of ITS and fiber elastic modulus by immersion

Composition	Test	Fiber Length	Fiber percentage (%)					
			SI-DP- 0.2	SI-DP- 0.4	SI -DP- 0.6	SI-DP-0.8	SI-DP0.8	SI-DP-1.2
Treatment (with Immersion)	ITS (Kpa)	5 mm	19290.372	22417.651	24326.937	25314.499	15636.394	12739.546
		6 mm	21166.739	24524.449	25775.361	26894.597	17282.33	14780.507
		8 mm	19915.828	24261.099	26795.841	27289.622	17183.574	14582.995
		10 mm	18599.079	21923.87	23668.562	24326.937	16031.418	12706.627
		12 mm	16196.012	18730.754	19487.884	20804.633	13266.246	10369.398
		14 mm	11850.741	13694.189	14253.807	15833.906	10138.967	7670.0626
	Elastic Modulus (Kpa)	5 mm	1669076.5	1939660.55	2104859.25	2190306.9	1352920.4	1102274.1
		6 mm	1831426.9	2121948.77	2230182.40	2327023	1495333	1278865.8
		8 mm	1723193.3	2099162.74	2318478.25	2361202.1	1486788.3	1261776.2
		10 mm	1609263.2	1896936.75	2047894.18	2104859.2	1387099.4	1099425.8
		12 mm	1401340.7	1620656.17	1686166.00	1800096.1	1147846.1	897199.82
		14 mm	1025371.2	1184873.41	1233293.71	1370009.9	877262.04	663643.04

Table 4. Results of the strain test and Poisson Number of fiber with immersion

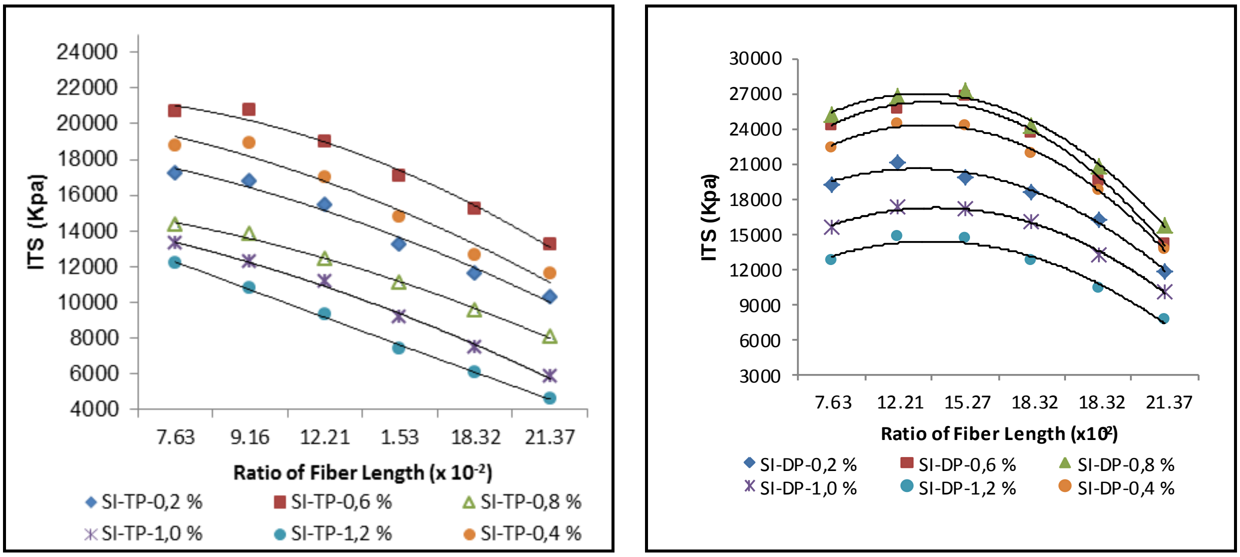
Composition	Test	Fiber Length	Fiber percentage (%)					
			SI-TP- 0.2	SI-TP- 0.4	SI -TP- 0.6	SI-TP-0.8	SI-TP0.8	SI-TP-1.2
Without Immersion	Strain	5 mm	0.01119	0.01200	0.01229	0.01174	0.01064	0.01009
		6 mm	0.01145	0.01255	0.01310	0.01200	0.01101	0.01024
		8 mm	0.01137	0.01244	0.01317	0.01192	0.01064	0.00972
		10 mm	0.01064	0.01178	0.01229	0.01137	0.01009	0.00881
		12 mm	0.00972	0.01101	0.01167	0.01046	0.00881	0.00771
		14 mm	0.00862	0.01024	0.01046	0.00936	0.00752	0.00642
	Possiom value	5 mm	0.33	0.34	0.36	0.32	0.32	0.31
		6 mm	0.35	0.36	0.37	0.35	0.33	0.30
		8 mm	0.32	0.34	0.36	0.31	0.31	0.28
		10 mm	0.32	0.33	0.35	0.30	0.28	0.27
		12 mm	0.31	0.32	0.33	0.29	0.28	0.25
		14 mm	0.29	0.30	0.32	0.27	0.25	0.23

Table 5. Results of strain test and Poisson Number of fiber without immersion

Composition	Test	Fiber Length	Fiber percentage (%)					
			SI-DP- 0.2	SI-DP- 0.4	SI -DP- 0.6	SI-DP-0.8	SI-DP0.8	SI-DP-1.2
Treatment (with Immersion)	Strain	5 mm	0.01156	0.01211	0.01303	0.01262	0.01119	0.01082
		6 mm	0.01211	0.01266	0.01376	0.01343	0.01134	0.01057
		8 mm	0.01247	0.01303	0.01486	0.01449	0.01156	0.01009
		10 mm	0.01174	0.01266	0.01457	0.01413	0.01064	0.00862
		12 mm	0.01082	0.01156	0.01339	0.01303	0.00991	0.00789
		14 mm	0.01009	0.01046	0.01101	0.01082	0.00844	0.00679
	Possiom value	5 mm	0.33	0.35	0.36	0.36	0.32	0.31
		6 mm	0.34	0.36	0.40	0.39	0.33	0.30
		8 mm	0.36	0.38	0.44	0.41	0.32	0.29
		10 mm	0.34	0.37	0.41	0.39	0.30	0.28
		12 mm	0.31	0.33	0.37	0.34	0.28	0.26
		14 mm	0.29	0.30	0.33	0.31	0.25	0.22

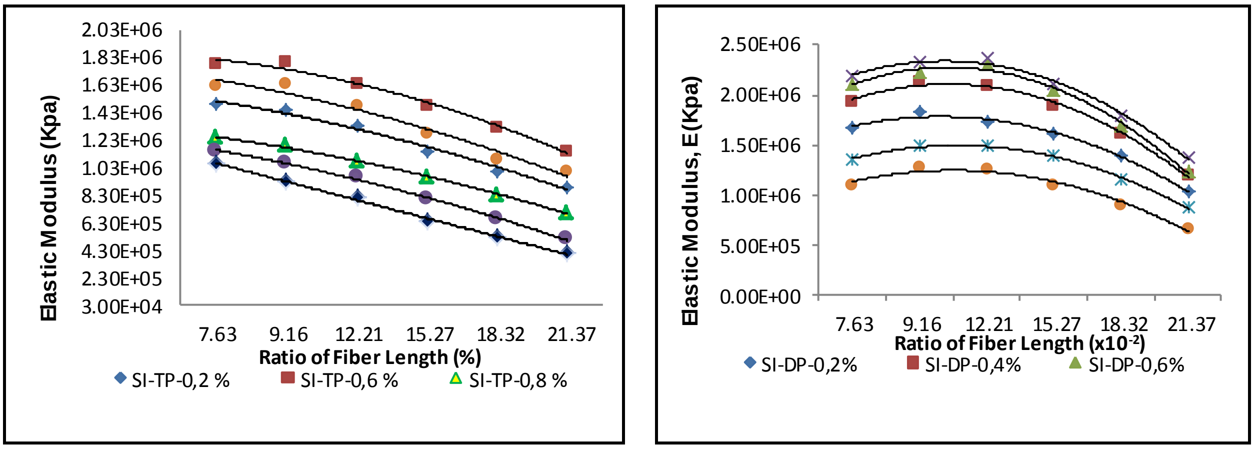
Figure 8 shows that there was a difference in the value of ITS to the mixture in the percentage of 0.6% and 0.8% of the fiber weight with the same diameter (0.3 mm), but they were different in lengths; the use of longer fibers provides lower density values of the mixture that indicates the cavities increase in the mixture with longer fibers compared to the fibers with a shorter size. The increase of this cavity was caused by the length of the fiber, also the damage and the changes in length caused by the compaction load; there was a reduction in length and the increase in the percentage of fiber. Therefore, the percentage and the length of fibers that exceed the effective limits usage have less profit effect to the characteristics of the resulting mixture[6] [36].

Figure 9 shows the relationship of elastic modulus value with the ratio of fiber length. The elastic modulus value of the fiber without immersion decreases with the ratio of fiber length. Fibers treated with immersion increased in the ratio of 9.16 to 12.21 ($x10^{-2}$) and the highest at 1% percentage.



(a) (b)

Figure 8. The relation of ITS value and the ratio of fiber length: (a) Control; (b) application with immersion



(a) (b)

Figure 9. The relation of elastic modulus value and the ratio of fiber length (a) control, (b) application with immersion

The length factor and the percentage of fiber optimal usage in the mixture showed a random distribution pattern and forms of a strong structure on the asphalt mixture, which limits the displacement and deformation of the mixture and provided the tensile stress of the mixture to the excess load. The existence of fibers in the mixture caused greater tensile pressure with Asphalt Pavement, JTG / F40-2004[3]. To ensure a good distribution of the mixture, the fiber must have an optimal length[6]. The structure of the porous network in one bond attached to the fiber surface, which significantly increased the cohesive strength between the fibers and the mixture, and limited the slip of the fibers in the mixture[6].

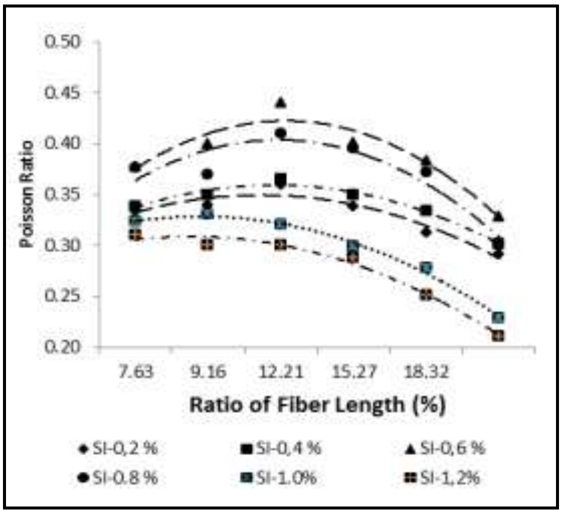


Figure 10. The relation of Poisson number with the ratio of fiber length

One of the indicators in determining the level of flexibility of an asphalt concrete mixture is the Poisson number. Passion score is the ratio between horizontal strain (lateral strain) and vertical strain (axial strain) caused by parallel load and axial strains[24]. Figures 10 and Table 4 indicate the increase of the Poisson number was as the percentage of fiber increases to the optimum limit of 0.6% with the fiber length of 8 mm and the maximum Poissom value of 0.44 in treatment and of 0.37 at control, this composition indicates the characteristics of the mixture having properties with high flexibility, in which the correlation of the balance between fiber length and percentage gives a more flexible stiffness to maximum tensile stress and further it would decrease as the percentage and the fiber length on asphalt concrete mixture increase. This indicates that the increase of the percentage and fiber length would minimize the horizontal strain and vertical strain caused by the increase of cavity in the mixture so that the mixture becomes inflexible and rigid. The decrease of Poisson number on fibers that were greater than 8 mm had no significant effect on increasing flexibility and tensile stress on the mixture.

4. Conclusions

From the research results of fiber treatment model in improving the performance of asphalt concrete mixture, we can conclude that:

a. The treatment of sea water immersion on the fiber made a higher morphological change of roughness on the surface layer than without sea water immersion.

b. The fibers without an immersion had a higher stiffness modulus than the immersed fibers.

c. The use of fiber on asphalt concrete mixture improved the performance of tensile strength and elastic modulus

d. The optimum percentage of 0.6% fibers usage with 0.8 mm length provides a high ductility mixture in the maximum strain of 0.01486 and indirect tensile strength.

e. It is necessary to adjust the temperatures of the mixing process in order to reduce the risk of damage to fiber during the compaction process.

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