Performance of GLASS WOOL FIBERS in ASPHALT CONCRETE Mixtures

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Abstract: Nowadays, in order to improve asphalt pavement performance, durability and reduce environmental pollution caused by asphalt binder, many researchers are studying to modify asphalt concrete (AC) and find alternative paving materials to extend service life of asphalt pavement. One of the successful materials used in a modification of AC are fibers. Different types of fibers have been reinforced in AC mixture and improvements have been observed.

This research studies the performance of glass wool fiber reinforced in a dense-graded asphalt mixture. Generally, glass fibers are known to have excellent mechanical properties such as high tensile modulus, 100% elastic recovery and a very high tolerance to heat. The glass wool fibers are commonly used as a thermal insulation material. In this research to evaluate the performance of glass wool fiber in AC, laboratory tests Marshall mix design test, Indirect tensile strength (IDT), Tensile strength ratio (TSR) and Kim test were conducted to determine a proper mix design, tensile properties, moisture susceptibility, rutting and fatigue behaviors. Results show that addition of glass wool fibers does affect the properties of AC mixture. The use of glass wool fibers showed a positive consistence results, in which it improved the moisture susceptibility and rutting resistance of the AC. Also result showed addition of fiber increased tensile strength and toughness which indicates that fibers have a potential to resist distresses that occur on a surface of the road as a result of heavy traffic loading. The overall results showed that addition of glass wool fiber in AC mixture is beneficial in improving properties of AC pavements.

Keywords: Asphalt concrete, Glass wool fibers, indirect tensile strength, tensile strength ratio, Kim test, Marshall test.

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1. Introduction

Asphalt concrete (AC), also known as hot-mix asphalt (HMA), is a combination of asphalt binder and aggregates mixed together at a high temperature which is then placed and compacted on the road while still hot [1]. Asphalt pavement is the predominant pavement type in the world, it is used for all types of applications from residential streets to expressways, from parking lots to harbor facilities, and from bike path to airport runway [1,2]. AC can be designed to different types of mixtures depending on what the designer wants to achieve in terms of satisfactory performance over traffic and climate conditions of the designated region and durability of a pavement structure throughout the whole designed life expectancy [3,4].

After being applied to a road, AC mixtures tend to have many distresses such as cracking, rutting (permanent deformation), stripping (separation of aggregates from the AC mixture) and pot holes, and these distresses are caused by heavy traffic loading and harsh environment or weather conditions. The occurrence of these distresses on the road may lead to a total failure of pavement structure. Road engineers first and foremost have to ensure that, they are avoiding all distresses at most, and to do so for the past few decades engineers and material scientists have been involved in process of modifying the traditional AC by adding other materials to it so as to improve its performance, durability and reduce costs while also trying to reduce environment pollution caused by asphalt binder [5,6]. Different materials have been mixed together with asphalt binder and aggregates but most common ones are fibers and polymers [7]. Fibers when added in asphalt mixture, it has many purposes but two main purposes are to prevent drain down for gap and open-graded asphalt mixtures and to increase strength and stability (reduce rutting) and improve resistance to cracking for dense graded asphalt mixtures [7,8].

Cellulose (plant-based) and mineral fibers are used in AC to prevent drain down since they have high absorption capabilities. Polypropylene, aramid, polyester and glass fibers have high tensile strength; therefore, they are used to add more strength to the AC [7,9]. The process of adding fibers in either asphalt or cement concretes can be categorized into two categories, direct random inclusion (matrix) of which the outcome in AC is known as fiber reinforced asphalt concrete and Geo-synthetics family [9]. This research studies a glass wool fiber reinforced in AC and its applicability.

Glass wool is an insulating material made from fibers of glass arranged using a binder into a texture similar to wool [10]. Glass wool fiber has good flexibility, easy to install, high thermal resistance with low thermal conductivity (working temperature at about 450℃), fire safe material and environmentally friendly material [11]. In AC mixtures glass wool fibers are not commonly used unlike the widely usage of glass

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fibers, and from literature review glass fibers and glass wool fibers are said to have almost similar mechanical properties. When added to asphalt or cement concretes glass fibers tend to increase tensile strength, compressive strength improve elastic recovery and increase the softening point of asphalt binder [12-15].

2. Materials and Experiment Method

2.1. Materials

The materials used in this research include virgin asphalt binder with PG 64-20 produced by S-OIL company which was used in all AC samples and experiments. The properties of a binder used are given in Table 1 below. The dense-graded AC mixture used is known as Wearing Coarse-2 (WC-2), and it has a maximum aggregate size of 13mm. The WC-2 is commonly used in Korea as a surface asphalt pavement and it is highly water-resistant. Table 2 shows aggregate gradation, the required gradation limits and the aggregates sieves passing percentages used in this study, and as it has shown aggregates used were all within required limits. Figure 1 shows normal appearance and a SEM micrograph of glass wool fibers used in this research. As shown in Figure 1, the glass fiber wool is white color. The thickness of glass wool fiber is about 5~8 μm and is similar to cotton candy. Table 3 shows the composition of glass wool fiber.

Table 1: Properties of Virgin Asphalt

Property	Test value	Standards
Penetration ($25°C$, $100g$, $5s$) 0.1mm	63	ASTM D 5
Ductility ($15°C$, $5cm/min$) (cm)	150	ASTM D 113
Softening (°C)	47.5	ASTM D 36
Flash Point (°C)	354	ASTM D 92
Density ($15°C$) (Kg/m^3)	1.0410	ASTM D 70

Table 2: Gradation of Asphalt mixture

Sieve size (mm)	25	20	13	10	5	2.5	0.6	0.3	0.15	0.08
Limits (%)	100	100	100~95	84~92	55~70	35~50	18~30	10~21	6~16	4~8
Passing (%)	100	100	96	85	56	36	19	12	7	5

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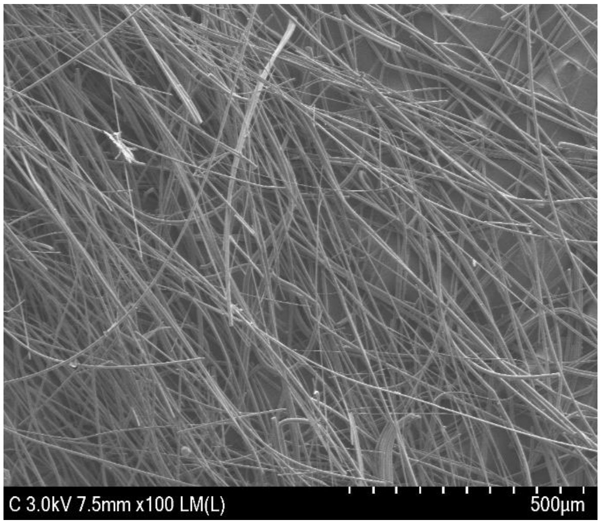
(a)



(b)

Figure 1: Glass wool fiber

Table 3: Properties of glass fiber wool

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	B_2O_3	TiO_2
66.9%	1.2%	0.2%	9.0%	1.9%	15.2%	0.3%	0.06%	5.0%	0.045

2.2. Sample Preparations

To study the effects of glass wool fiber in the AC mixtures, different dosages of fiber measured according to weight of aggregates were mixed together with aggregates and asphalt binder. One control sample which had no fibers, and other samples with 0.2%, 0.3%, 0.4% and 0.5% of fiber content by weight of aggregates were prepared on each experiment conducted. The results obtained from a control samples were compared with samples which has fibers to see if there is any improvement or deterioration observed. Marshall mix design test were used to determine the optimum asphalt content for each dosage of fiber and during mixing, a dry mixing method were employed, where dry aggregates were first mixed with fibers and then asphalt binder was added to fiber and aggregates mixture.

2.3. Experimental methods

2.3.1. Marshall mix design method

Marshall mix design is common method used in Korea for the dense-graded HMA mixes which has two major features namely, density-voids analysis and stability-flow test [16]. In this research Marshall mix design method was used to determine the optimum asphalt content, the percent air voids and Marshall stability of AC mixtures with different dosage of glass wool fibers. The Marshall mix design test was done in accordance to Korean standards KS F 2337.

2.3.2. *Indirect Tensile Strength*

The indirect tensile strength (IDT) test is used to determine the tensile properties of the asphalt mixture, tensile properties include tensile strength, toughness and strain (displacement). Tensile properties play important role in the performance of AC mixture under fatigue, rutting and moisture susceptibility [17]. The resistance of AC to fatigue cracking which is caused by repeated or fluctuated stresses is dependent upon its' tensile strength and extensibility characteristics. The IDT tests were conducted according to the Korean standards KS F 2382, where Marshall specimen is loaded with Compressive load at a constant rate of 51mm/min acting parallel to and along the diametric plane of the specimen. The compressive load indirectly creates a tensile load on the horizontal direction of the sample and tensile failure occurs in a sample rather than a compressive failure [18]. Tensile strength values were obtained using a mathematical equation given bellow and the toughness is given as the dissipated energy during the materials fracture process.

$$S = \frac{2000 * P}{\pi t D}$$

Where,

S = Tensile Strength, kPa

P = Maximum load, N

t = Specimen height before testing, mm

D = Specimen diameter, mm.

2.3.3. *Tensile Strength Ratio (TSR)*

Tensile Strength Ratio (TSR) test is used to determine moisture susceptibility of asphalt mixtures. It measures workability of asphalt pavements in terms of performance and durability in the presence of moisture. For a well-designed AC, it is needed that AC should have a very good resistance to damages caused by moisture. High percentage of TSR results relates with good performance under moisture (wet) conditions. The TSR test was carried out in accordance with Korean standards KS F 2398. TSR results are

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obtained as a ration of indirect tensile strength values of a conditioned samples which are soaked in the water for 24 hours at a temperature of 60℃ to indirect tensile strength values of unconditioned dry samples of the same mixture at air void of 7%.

Figure 2: Tensile Strength Ratio Test

2.3.4. Kim Test for deformation strength.

This is a new test recently developed in Korea and is for determining the rutting properties of AC mixtures. A round edged loading head shown in Figure 3, which simulates almost exactly contact area between the tire and road surface, was applied instead of applying a load to the whole cross-sectional area. The resistance against the formation of a dimple (not flat) on the surface of the specimen is known as deformation strength (S_D). The deformation strength is a combination of compressive stress and shear stress. The Kim test showed good correlations with well-known rutting tests for dense-graded AC mixtures like wheel tracking [17,19]. The Kim test requires normal Marshall specimen to be submerged in water bath for 30 minutes at 60℃, then after a load is applied at a speed of 30mm/min. The S_D value is calculated as;

$$S_D = \frac{0.32P}{\left[10 + \sqrt{20y - y^2}\right]^2}$$

Where,

S_D = Deformation strength

P = Maximum load

y = Deformation

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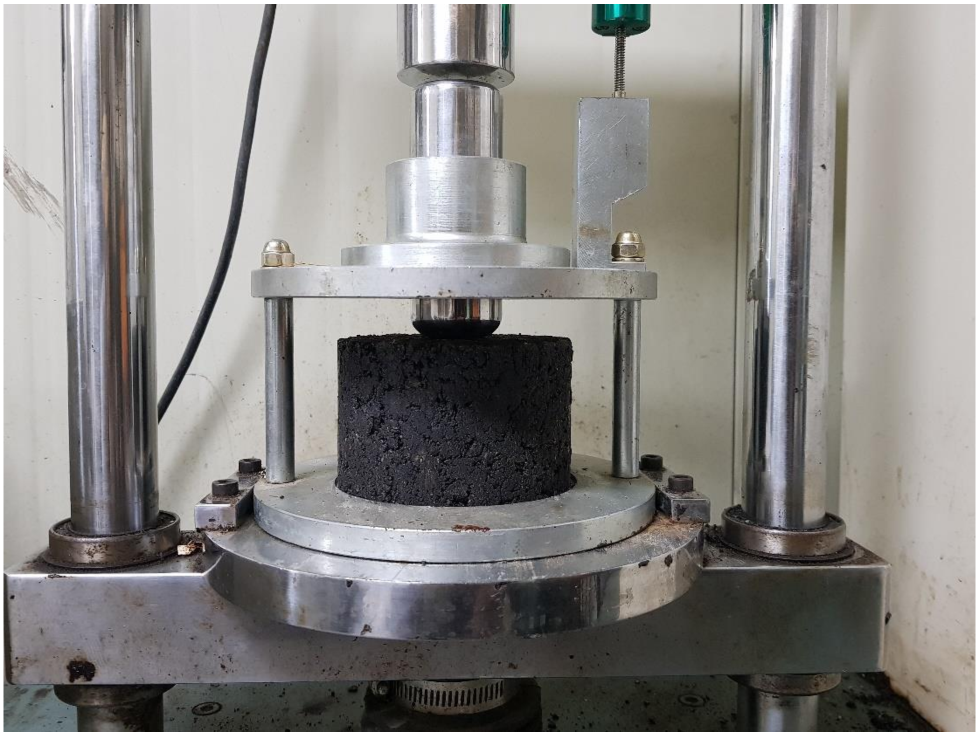

Figure 3: Kim test for deformation strength

2.3.5. *Scanning electronic microscopy (SEM)*

In order to investigate a distribution of glass fiber wool in the asphalt mixture, scanning electronic microscopy (SEM) was adopted in this study. SEM is a method to evaluate the dispersion of added glass fiber wool and to ensure uniformity of dispersion within the matrix of the asphalt mixture. Specimens were cut into small pieces of approximately (10 x 10 x 5) mm for testing, and the samples were then coated with a gold/palladium alloy to increase the stiffness at the surface and to obtain conductivity without affecting observed surface morphology, in order to make them relatively more stable during the testing [21]. For material sciences, it is important to learn about the microstructure of a material so that to understand factors influencing physical properties of a material. The SEM device used was Hitachi, model SU8230.

3. Results and discussion

3.1. Optimum Asphalt Contents Result

The optimum asphalt binder for fiber-reinforced asphalt mixture was determined using the Marshall mix design method. In this research, 4 fiber contents were adopted as shown in Figure 4. The optimum asphalt binder contents of glass fiber wool contents in AC mixtures can be determined according to the procedures described in the Marshall test. Figure 4 shows optimum asphalt content of AC mixtures as function of different usage of glass wool fibers. As shown in Figure 4, the optimum asphalt content increase with the fiber content. Generally, the fiber absorbed the asphalt binder in asphalt mixtures [22]. In this study, the Glass wool fibers used have absorption capabilities and hence absorbs asphalt binder, which leads to the addition of more binder. Figure 5 shows a trend of the asphalt binder content as function of fiber content. The asphalt binder content absorption rapidly increased until 0.4% finer content. It may be considered that the addition of fiber is a complex process, the more reasonable explanation needs to be investigated in the future. In this study, the optimum asphalt content for all mixtures was determined when the air void was 4% in asphalt mixtures.

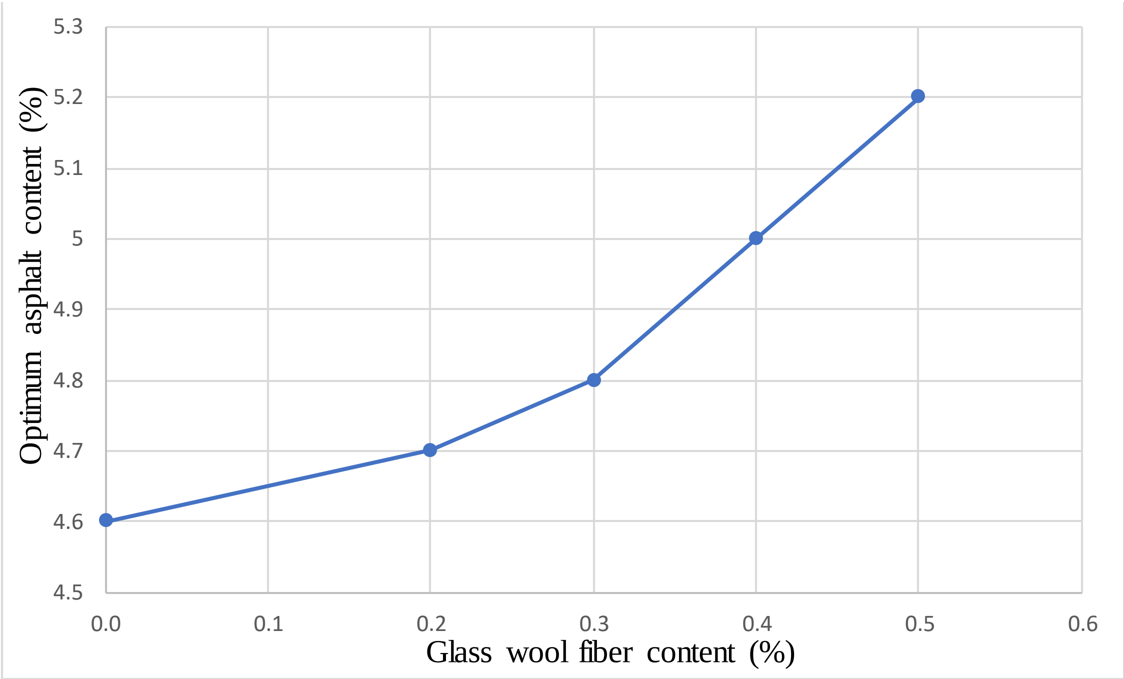

Figure 4: Optimum asphalt content

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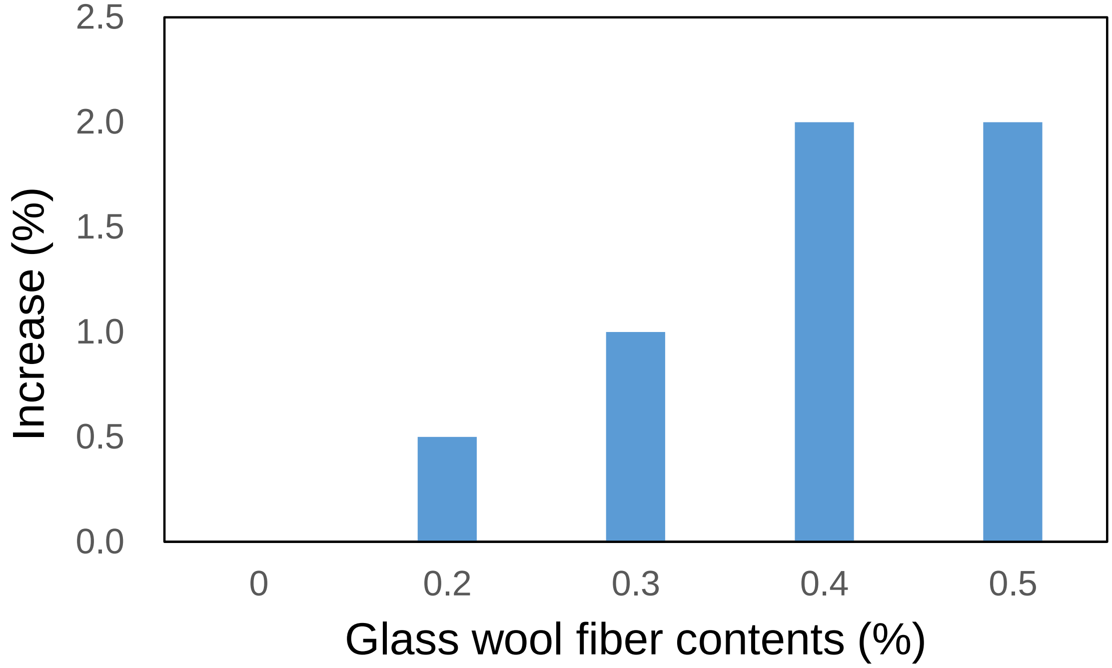

Figure 5 Asphalt absorption ratio as changed finer contents

3.2. Bulk Specific Gravity

In order to determine the effects of Glass wool fiber on the mass and volume of AC mixtures, the bulk specific gravity of each dosage was measured and results are as shown in Figure 6 below. The specific gravity slightly decreases from 2.525 for AC mixture with no fiber to 2.50 for AC mixture with 0.5% of fiber content. The addition of fiber and the increase of optimum asphalt content lead to a decrease of aggregates volume used which has the higher specific gravity, and hence the decrease of bulk specific gravity.

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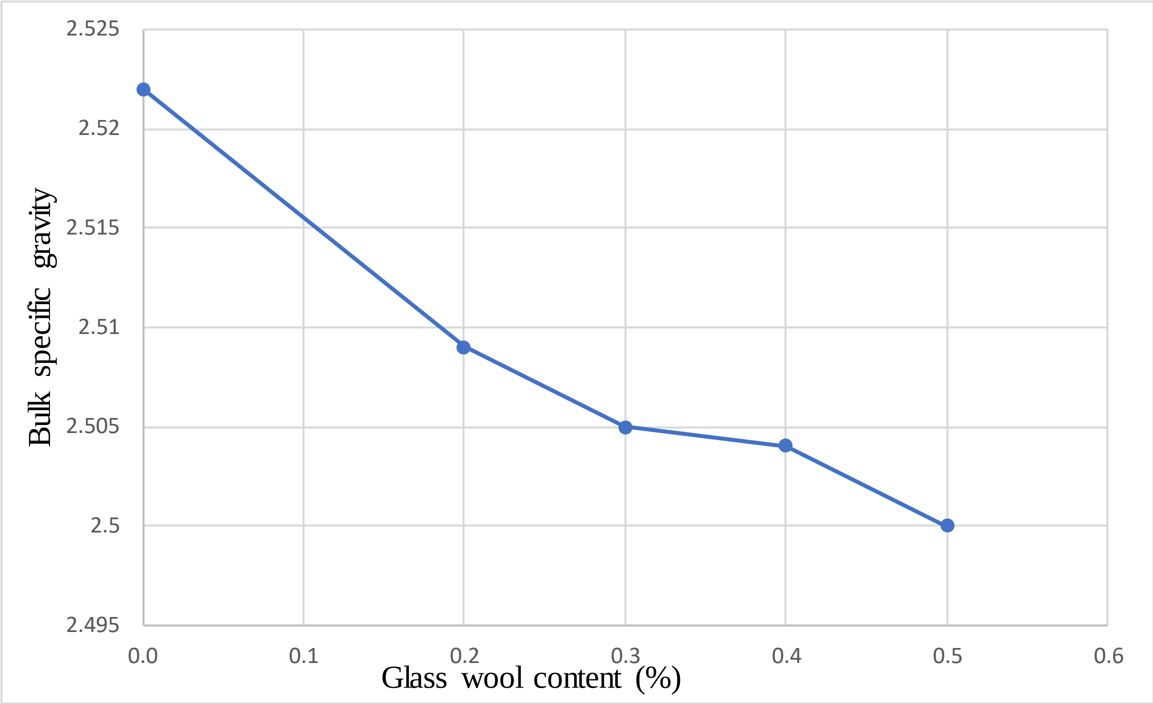

Figure 6: Bulk specific gravity

3.3. Marshall Stability

Figure 7 shows the Marshall stability results, the measured results explains resistance capabilities of a specimen related with distortion, displacement, rutting and shearing stresses under maximum loading. Upon the addition of fibers, the Marshall stability increases and reached a peak when a 0.3% of fiber content was added then starts to decrease. Glass fibers have high tensile strength which is transferred to AC mixture and increase the Marshall stability.

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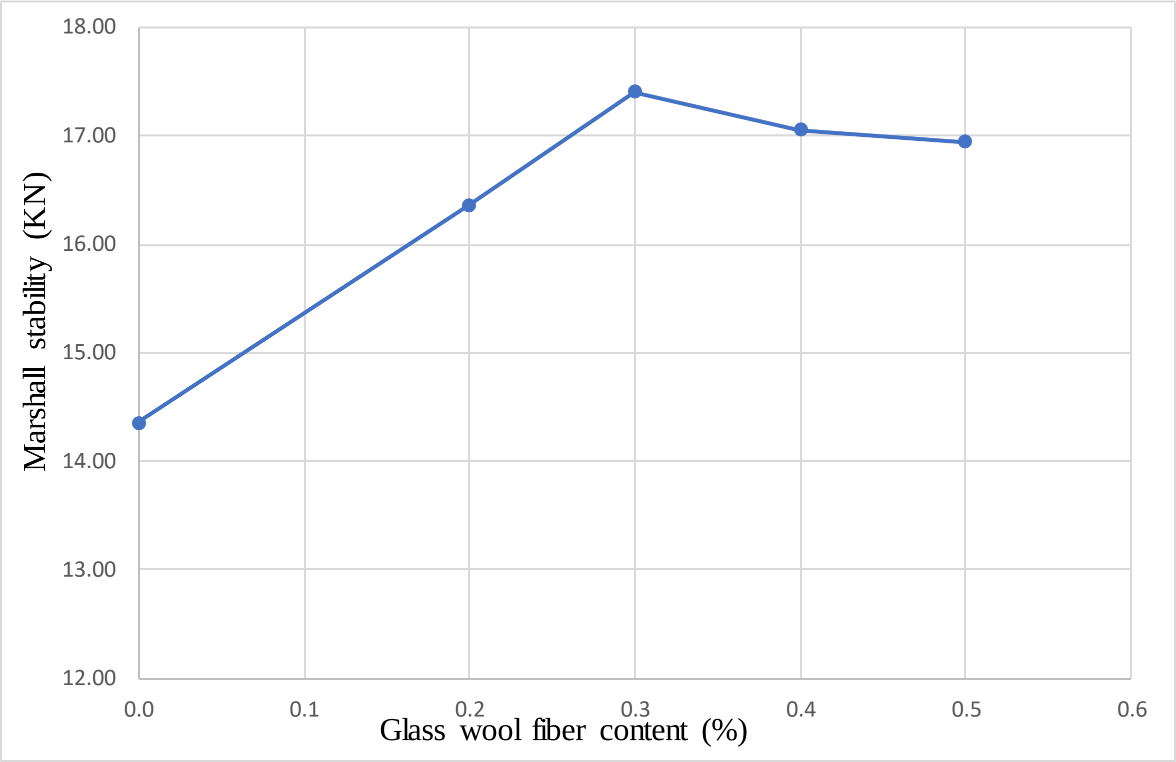

Figure 7: Marshall stability

3.4. Indirect tensile strength

Figure 8 and Figure 9 show Indirect Tensile Strength (IDT) results of asphalt mixtures containing different dosage of glass wool fiber. The results show that when fibers are added into the mixture, both tensile strength and toughness of AC mixture also increase to a maximum point and then starts to decrease. In asphalt pavements, tensile strength (stiffness) relates to cracking properties of a pavement, which is one of the primary asphalt pavements distress types along with rutting and fatigue. A higher tensile strength corresponds to a stronger crack resistance.

For the tensile strength, results show that tensile strength increased from 1.28N/mm^2 for a mixture without fibers to 1.44N/mm^2 for a mixture with 0.3% dosage of glass wool fibers, then for the higher dosage of fiber the values of tensile strength decreased. Toughness results are almost the same as the tensile strength, where the maximum toughness value was observed at a mixture with 0.3% dosage of fibers. The decrease of tensile strength and toughness for higher dosages are caused by the large amount of fibers in a mixture which replace aggregates, while aggregates are stronger than fibers. Glass wool fibers when added in the asphalt mixture, they increase the strength of a bond between asphalt and aggregates by firmly binding aggregate particles inside the matrix and prevent them from movement, which makes the mix stiffer [15].

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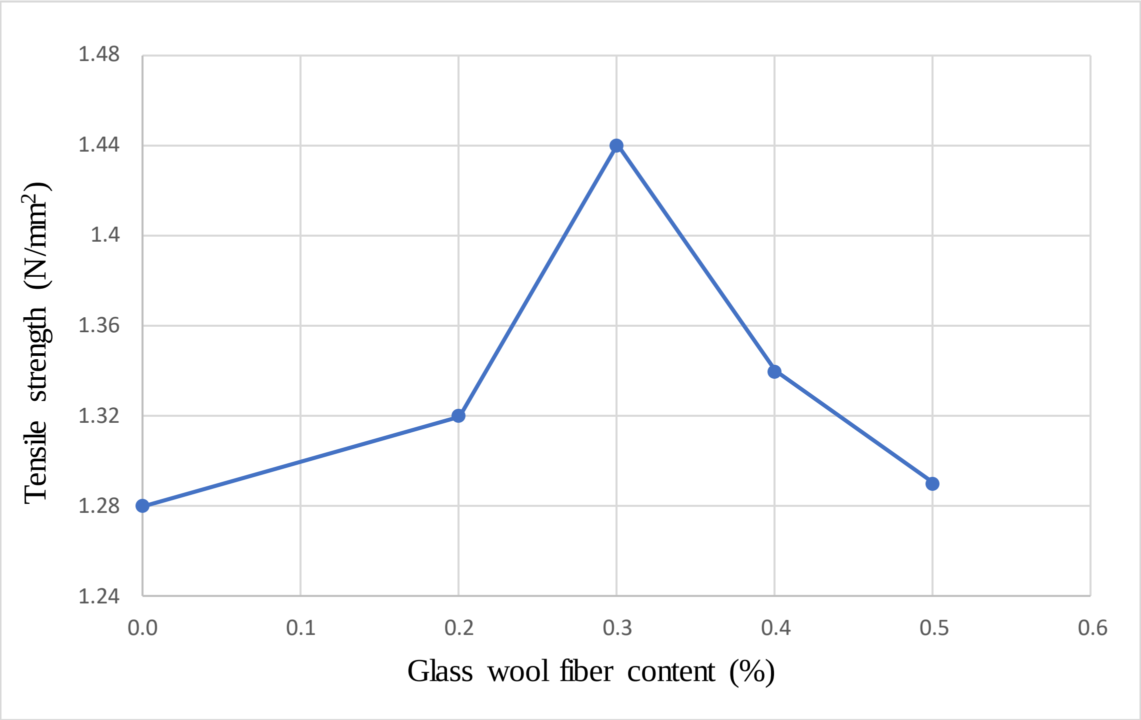

Figure 8: Tensile strength results

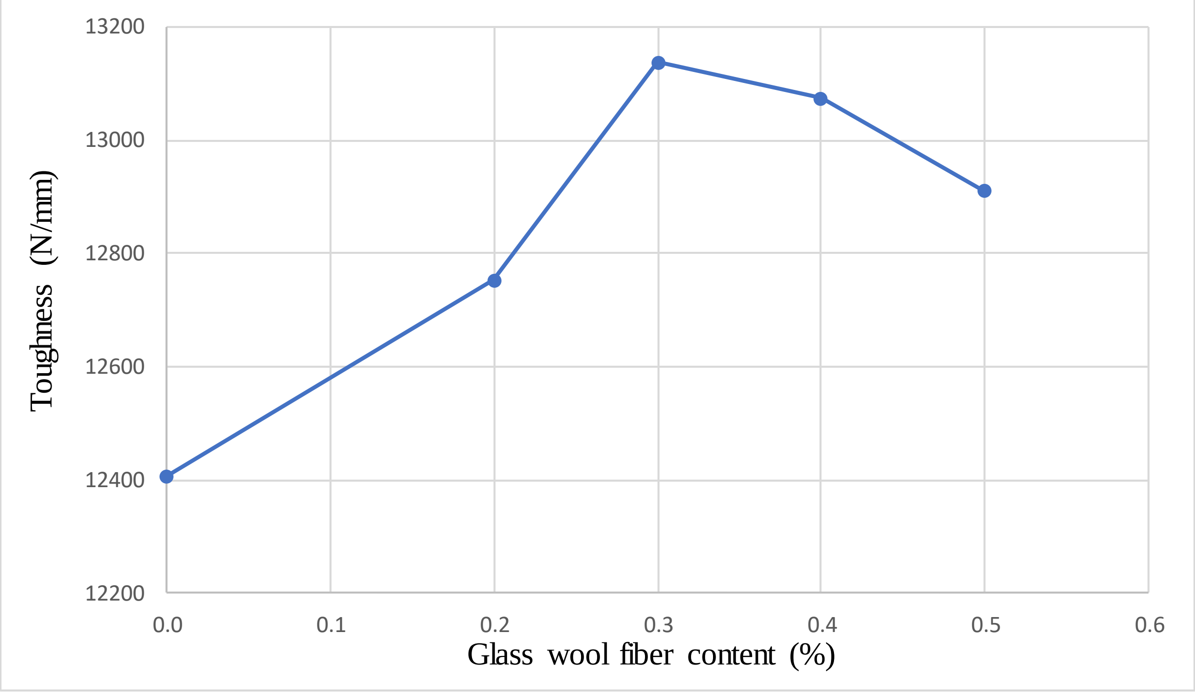

Figure 9: Toughness results

3.5. Indirect Tensile Strength Ratio

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In order to estimate a moisture susceptibility, an indirect tensile strength ratio test was conducted. Figure 10 explains results of Indirect Tensile Strength Ratio (TSR) of asphalt mixtures as function of dosages of fiber contents. As the amount of fiber dosage increases, the percentage of TSR also increases. The TSR increases up to a maximum value at a 0.3% dosage of fiber and then starts to decrease. A higher TSR value indicates that a mixture will have a good resistance to moisture damages. The addition of fiber improves moisture susceptibility of the AC mixture. The main reason behind this phenomenon is when glass wool fiber interacts with asphalt mixture, it not only increases bonding strength but also increases thickness of asphalt film which is beneficial for preventing moisture from entering the interface between asphalt and aggregates.

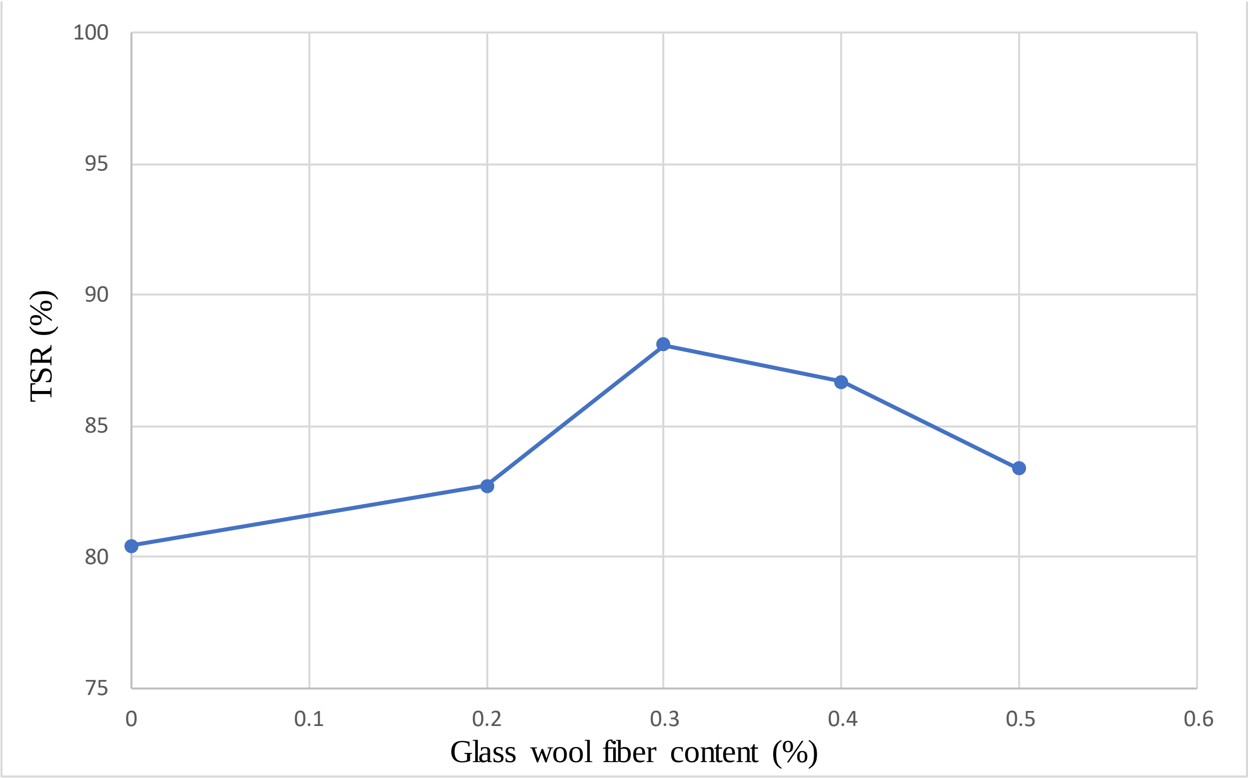

Figure 10: Tensile strength ratio results

3.6. Kim test

Figure 11 shows results of Kim test for deformation strength of AC mixtures with different dosage of glass wool fibers. The results show that addition of fibers improves the high temperature rutting properties of AC. The S_D values increase with the increase dosage of glass wool fibers, and it reached a maximum value at 7.32N/mm^2 when a dosage of 0.4% is added to AC mixture, which is 25% more than AC mixture without fibers. The S_D values increase because glass wool fiber absorbs asphalt binder and increase its

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viscosity, and therefore, due to increased viscosity and bridging effects the bonding strength between the asphalt and aggregates was increased.

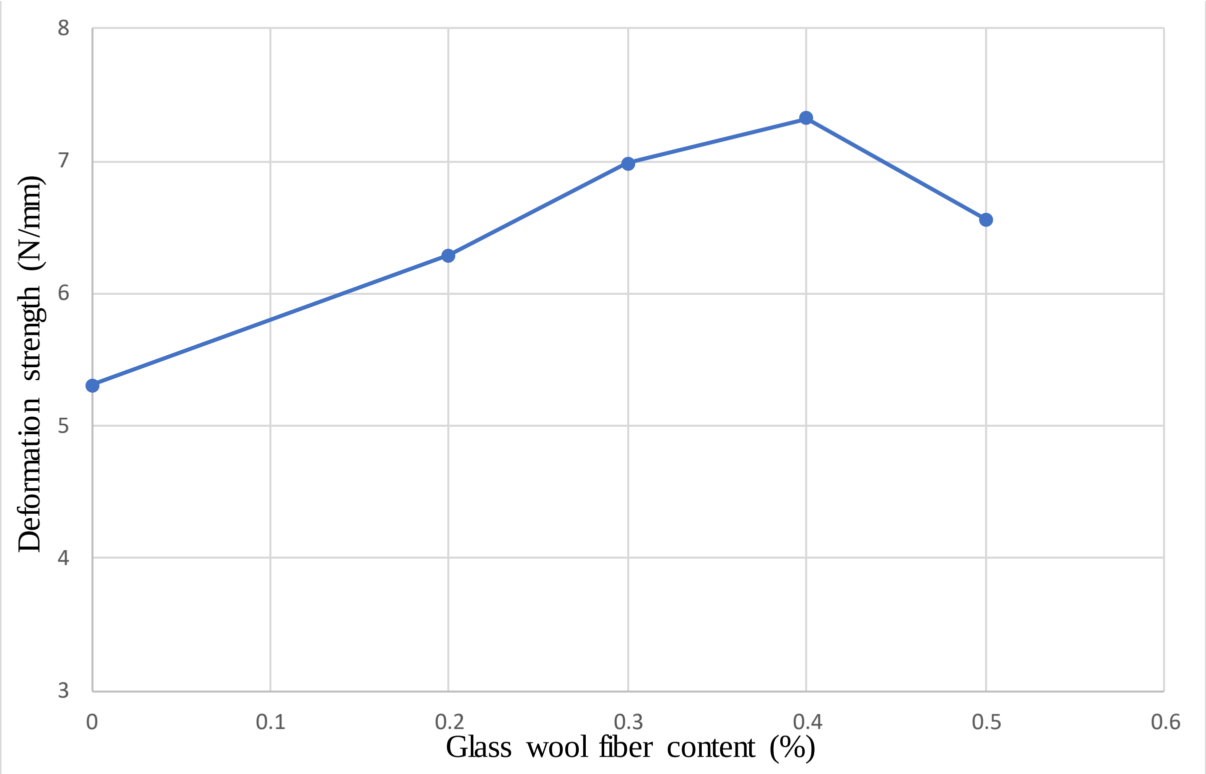

Figure 11: Kim test results

3.7. Scanning Electronic Microscopy (SEM)

The SEM images of the fiber asphalt mixture are commonly useful in recognizing the deviations in the microstructure of the adapted asphalt binder and mixtures, as well as in showing the dispersion of the glass wool fibers. Images obtained by use of the scanning electron microscopic (SEM) are shown in figures below. As shown in Figure 12, the glass wool fibers were well immersed in asphalt binder. The large portion of glass wool fibers was distributed in asphalt mixture and on the edges, there are spikes-looking-like fibers emerged. In AC mixture, glass wool fibers interact with aggregates and binder as it is shown in Figure 12 (b). Figure 13 shows a microstructure with a resolution of 50μm of a destroyed part of IDT sample after the test was conducted. Fibers interacts with aggregates and binder and when tensile strength applied to the AC, fibers add strength to the mixture by bridging together the aggregates and binder and also more tensile strength is needed to break the fibers at it was shown in Figure 13.

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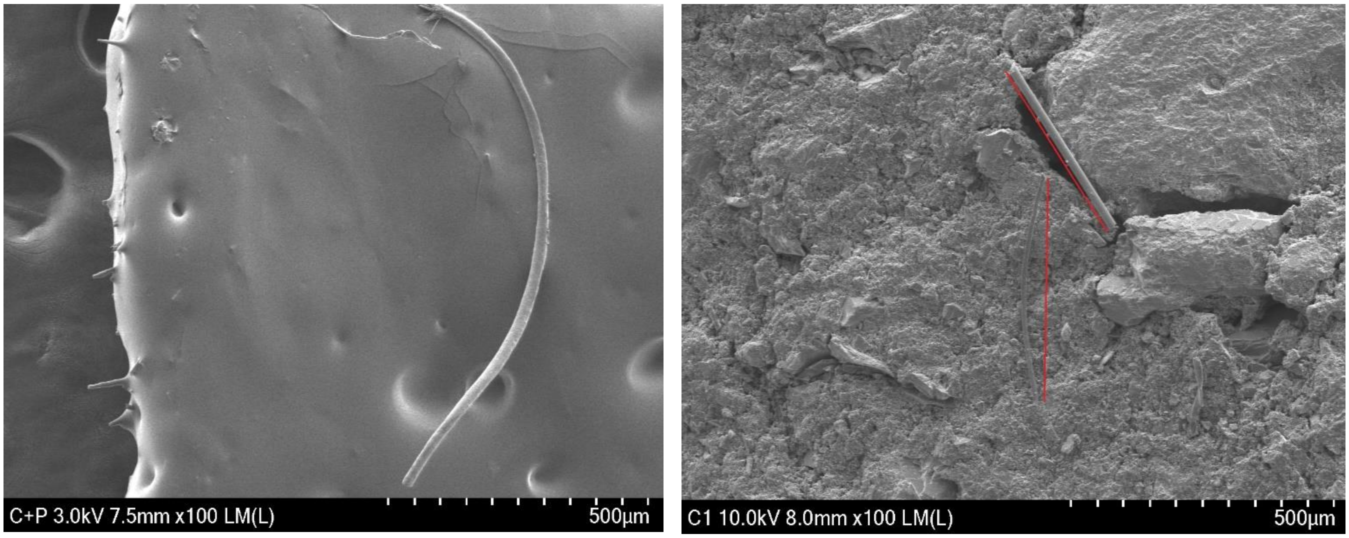

(a) (b)

Figure 12: (a) glass wool fibers mixed with asphalt binder (b) AC mixture with reinforced fibers

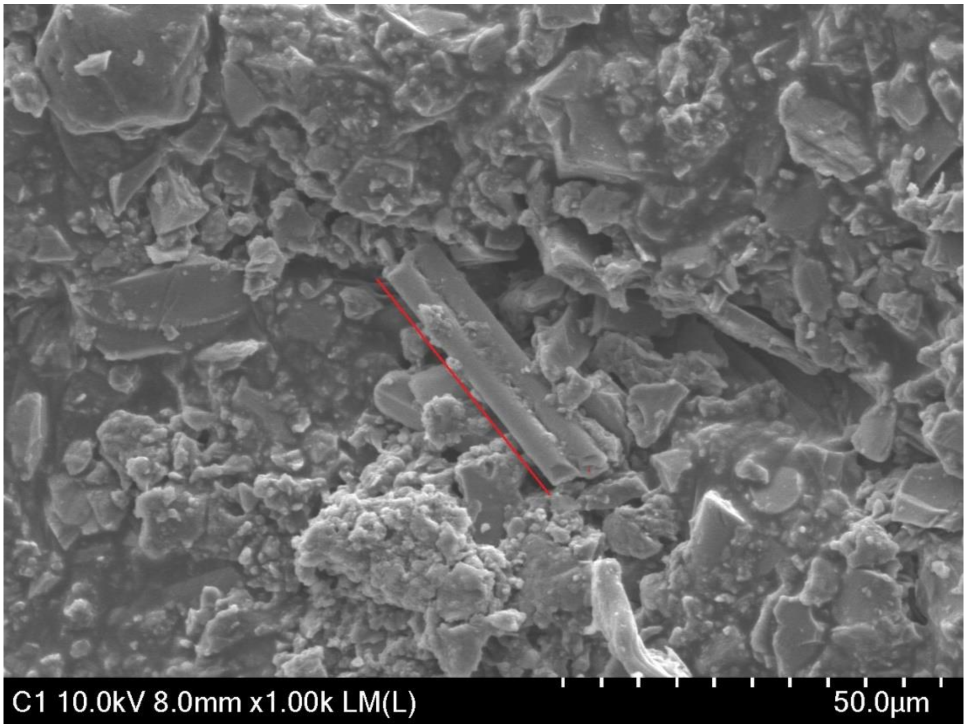

Figure 13: SEM micrograph of AC mixture with fiber after IDT testing

4. Conclusion

The results obtained after laboratory tests were conducted indicate that when glass wool fibers are mixed together with aggregates and asphalt binder in dense-graded the following happens;

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1. The addition of glass wool fiber in AC mixture lead to increase in tensile strength and toughness. When a dosage of 0.3% of glass wool fibers content added, tensile strength and toughness increased to a maximum value.
2. Moisture susceptibility of AC improved upon the addition of fibers. The ratio of a tensile strength of a conditioned samples and unconditioned samples is higher when fiber is reinforced in the AC. Also, introduction of glass wool fibers in the AC improves significantly improves high temperature rutting resistance of a mixture.
3. It was also observed that AC mixture with 0.3% of a fiber content by weight of aggregates showed superior results over the other AC mixtures.
4. The application of glass fiber wool in a dense graded asphalt mixture improves asphalt pavement performance and may extends its service life.

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