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Assessment of Moisture Susceptibility for Asphalt Mixtures Modified by Carbon Fibers

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Abstract

Moisture induced damage in asphaltic pavement might be considered as a serious defect that contributed to growth other distresses such as permanent deformation and fatigue cracking. This paper work aimed through an experimental effort to assess the behaviour of asphaltic mixtures that fabricated by incorporating several dosages of carbon fiber in regard to the resistance potential of harmful effect of moisture in pavement. Laboratory tests were performed on specimens containing fiber with different lengths and contents. These tests are: Marshall Test, the indirect tensile test and the index of retained strength. The optimum asphalt contents were determined based on the Marshall method. The preparation of asphaltic mixtures involved three contents of carbon fiber namely (0.10%, 0.20%, and 0.30%) by weight of asphalt mixture and three lengths including (1.0, 2.0 and 3.0) cm. The results of this work lead to several conclusions that mainly refer to the benefits of the contribution of carbon fibers to improving the performance of asphalt mixtures, such as an increase in its stability and a decrease in the flow value as well as an increase in voids in the mixture. The addition of 2.0 cm length carbon fibers with 0.30 percent increased indirect tensile strength ratio by 11.23 percent and the index of retained strength by 12.52 percent. It is also found that 0.30 % by weight of the mixture is the optimum fiber content for the three lengths.

Keywords: Asphalt; Moisture Damage; Carbon Fiber; Compressive Strength; Indirect Tensile Strength.

1. Introduction

Asphalt pavements deteriorate over time because of the combined effect of traffic loading and the environment. The service life of asphalt pavements can even be cut short if quality materials are not used in the hot mix asphalt (HMA) design and manufacturing [1]. In recent years, researchers have used different types of additives to improve the performance of the asphalt mixture. Scientists and engineers are permanently trying to improve properties of asphalt mixtures, such as their stability and durability, by incorporating new additives either in the bitumen or in the asphalt mixture [2, 3]. The addition of polymers is a common method applied to modify the binder, although different types of fibers have been evaluated [4]. However, it has been claimed that among various modifiers for asphalt, fibers have gotten much attention due to their improving effects [5]. In asphalt concrete (AC), fibers have been added to prevent draindown or raveling of porous asphalt and stone matrix asphalt, and to improve resistance to cracking and rutting [6]. Adding fibers to the binder or the bituminous mixtures ensures their stability and mechanical strength [7].

The types of fibers that have been investigated to date are polymeric fibers (polyester, polypropylene, polyacrylonitrile), organic fibers (cellulose, lignin, date-palm, oil-palm), mineral fibers (asbestos, rock wool), waste

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fibers (nylon, scrap tire, textile), and other fibers (glass, carbon, steel) [8]. Fibers provided this material with a higher modulus, resistance, durability, and deformation, and thus with more ductile behavior [9].

Artificial fibers are usually preferred, as natural ones are highly water absorbent [10]. Fiber's effects on improving the engineering properties of the asphalt mixture have been recognized by previous research. Some researchers have reported that fiber increases the optimum asphalt content in the mixture design and prevents asphalt leakage due to its absorption of asphalts [11], improves moisture susceptibility and reduces the reflective cracking of AC mixtures and pavements [12]. As a reinforcing material, the primary function of fibers is to provide an additional tensile strength in the resulting composite. As a kind of modification, carbon fiber was added to the asphalt material to investigate the performance of many researchers.

Jahromi and Khodaii (2008) studied the characteristics and properties of carbon fiber reinforced asphalt mixtures. It found that the addition of carbon fibers increases the mix's stability and voids in the mix while decreases flow value. They also found that the addition of fibers can improve the fatigue life and permanent deformation of the mixtures [4].

Liu and Wu (2011) found the carbon fiber could increase the Marshall stability, residual stability, and rutting dynamic stability. .Also, measuring the mechanical and electrical properties of graphite and carbon fiber modified asphalt concrete [13]. Khattak et al. (2012) believed that the carbon nanofibers modified asphalt binder could increase the complex shear modulus of asphalt binder and fatigue life of asphalt mixture [14].

Cleven (2000) investigated the behavior of carbon fiber modified asphalt mixtures. Carbon fibers were found to create improvements in high temperature and low temperature behavior. HMA samples containing 0.5% to 0.8% and fiber length taken from 2.54 cm to between 0.2mm and 0.65mm. Resilient modulus, creep compliance, beam fatigue, and indirect tensile tests were used to evaluate the effect of carbon fiber on HMA. The results showed that carbon fiber modified HMA was stiffer and performed better against permanent deformation. The modified HMA also showed improved tensile strength; however, no significant difference was observed in fatigue resistance [15].

Moghadas et al. (2014) an approach was developed to mix carbon fibers and bitumen which guarantees uniform fiber distribution. Subsequently, to find out the best set of fiber lengths and a dose of usage aimed at fortifying asphalt concrete, Marshall's stability and fatigue property of carbon fiber-reinforced asphalt concrete were investigated. Then, indirect tensile stiffness modulus and fatigue properties under different stresses and permanent deformation of modified and unmodified samples at two different temperatures (35°C and 60°C) were studied. Comparing the obtained results indicated that the addition of carbon fibers to the asphalt concrete considerably increases the mechanical performance, which benefits all the corresponding fields involved such as repair and maintenance [16].

Doo-Yeol et al. (2019**)** investigated the effect of carbon-based materials, i.e., carbon fibers (CFs), carbon nanotubes (CNTs), and graphite nanofibers (GNFs), on the mechanical properties of asphalt concrete. For this, 0.5% CF, CNT, and GNF, and 1.0% CF were incorporated, and plain asphalt concrete was also considered for comparison. Test results indicated that adding the carbon nanomaterials, i.e., CNTs and GNFs, was more effective in improving the Marshall stability, indirect tensile strength, and dynamic stability, and reducing the porosity, compared to adding macro CFS. However, the flexural performance of asphalt concrete was more efficiently enhanced by adding the CFs relative to CNTs and GNFs [17].

Khabiri and Alidadi (2017) studied the properties of reinforced asphalt mixtures with carbon and glass fibers. To evaluate the effect of carbon fiber and glass on asphalt mixtures. Physical performance, Marshal stability, and indirect tensile tests were performed by international standards for samples with fiber and without fiber by dry method. Three contents of carbon fiber (0.1, 0.2 and 0.3) % by weight of asphalt mixture were used. The results of the study indicated that the behavior of fracture for fibrous samples was somewhat different from the fracture of non-fibrous samples [18].

Abtahi et al. (2010) investigated the advantages of using random-inclusion fibers in flexible pavements as fiber-reinforced asphalt-concrete. They found that fibers change the viscoelasticity of mixture; moisture susceptibility and reduce the reflective cracking of asphalt mixtures and pavements. These properties were separately discussed for different kinds of fibers including Polypropylene, Polyester, Asbestos, Cellulose, Carbon, Glass and Nylon. Polyester was chosen over polypropylene because of its higher melting point. In addition, methods of sample preparation and executive problems conversed. Therefore, it was found that there are two potential methods for the introduction of the fibers: the wet process (addition of fibers to the asphalt) and the dry process (addition of fibers to the dry aggregate). They found that the dry one is preferred over the other [19].

Liu and Wu (2011) studied the mechanical and electrical properties of modified graphite and modified carbon fiber were measured by indirect tensile test. Experimental results suggest that mechanical properties of the asphalt mixture are affected by the addition of a conductive component such as Graphite and carbon fiber, when graphite content increased from 0 to 22% volume, and Marshall stability decreased from 12.8 kN to 9.43 kN and when the carbon fiber Content increased from 0 to 2% Marshall stability increased from 12.8 kN to 13.5 kN [13].

Yang et al. (2006) studied the rutting resistance for cellulose and polyester fiber-reinforced asphalt by using both the Circular Road Track and Hamburg Wheel Tracking Device tests. The obtained results from two tests showed that the rut depth can be significantly improved by adding fibers, but polyester fibers are better and improve the rutting resistance than that of cellulose fibers [20].

Liu et al. (2010) used steel fibers as the conductive filler to enhance the electrical conductivity of porous asphalt and it is found that long fibers with a small diameter are better than short fibers with a bigger diameter to make higher electrical conductivity in porous asphalt [21].

Ismael and Al-Taher (2015) studied the role of polyester fibers as reinforcement in the process of paving materials improvements. Marshall Stability, Indirect Tensile Strength (ITS) and compressive strength are studied. The indication of moisture damage resistance represented by the "Indirect Tensile Strength Ratio" and "Index of Retained Strength" has been calculated. Also, the flexural bending test of beam specimens has been carried out. They are used three percentages (0.25, 0.50 and 0.75 by weight of mixture with the two lengths (6.35 and 12.70 mm). It was found that (0.5) % by weight of the mixture is the optimum fiber content for the two lengths [22].

Chen et al. (2009) founded the volumetric and mechanical characteristics obtained by the fiber-reinforced asphalt mixture design method. The obtained results indicated that optimum bitumen content, air void, volume of mineral aggregate and Marshall Stability value increased, while unit weight decreased with the addition of fiber [23].

Mehrez and Karim (2010) explained that reinforcing generally includes the addition of materials with certain required properties to other materials that do not contain these properties. Fiber reinforcement was used to carry tensile loads, improve pavement resistance to some distress as well as to prevent the formation and spread of cracks [24].

The primary objective of this work is to evaluate the effect of the addition of different length and content of carbon fibers on Marshall properties and moisture susceptibility of asphalt mixtures considering the values of the Index of Retained Strength and the Tensile Strength ratio to show the reinforcement effect to control the harmful effect of moisture.

2. Research Methodology

The first phase of the laboratory work is represented by asphalt binder conventional test for a virgin asphalt. The second phase includes the design of the asphalt mixture with and without carbon fiber by using Marshall method and obtaining the optimum asphalt content. Furthermore, the stability and flow value in addition to the volumetric properties were determined to satisfy the requirement of Iraqi specification. Following this phase, the compressive strength and the indirect tensile strength value were determined to find the Index of retained strength (IRS) and tensile strength ratio (TSR) to find out the best content and length of carbon fiber was added to resist moisture damage as shown in Figure 1.

2.1. Materials and Methods

Asphalt Cement

Asphalt binder (40-50) penetration grade was used in this study which was obtained from Al-Durrah Refinery. All test results of asphalt binder satisfied the requirement of the State Commission of Roads and Bridges (SCRB R/9, 2003) specification [25]. Table 1, exhibits the physical properties of asphalt cement which was used in this research.

Table 1. Physical properties of asphalt cement

Test	Result	SCRB Specification Limits [32]	ASTM Designation No. [33]
Penetration (25^{0}C, 100 gm, and 5sec)	44 (0.1mm)	40 - 50	D-5
Ductility, (25 ^{0}C and 5cm/minute),	151 (cm)	≥ 100	D-113
Softening point, (Ring and Ball)	50 (^{0}C)	-------	D-36
Flash point ,(Cleveland open Cup)	280 (^{0}C)	>232	D-92
Specific Gravity @ 25^{0}C	1.03	-------	D-70
		After Thin-Film Oven Test	
Retained penetration, of original, (%)	61(0.1mm)	>55	D-5
Ductility (25^{0}C and 5cm/minute)	89 (cm)	>25	D-11

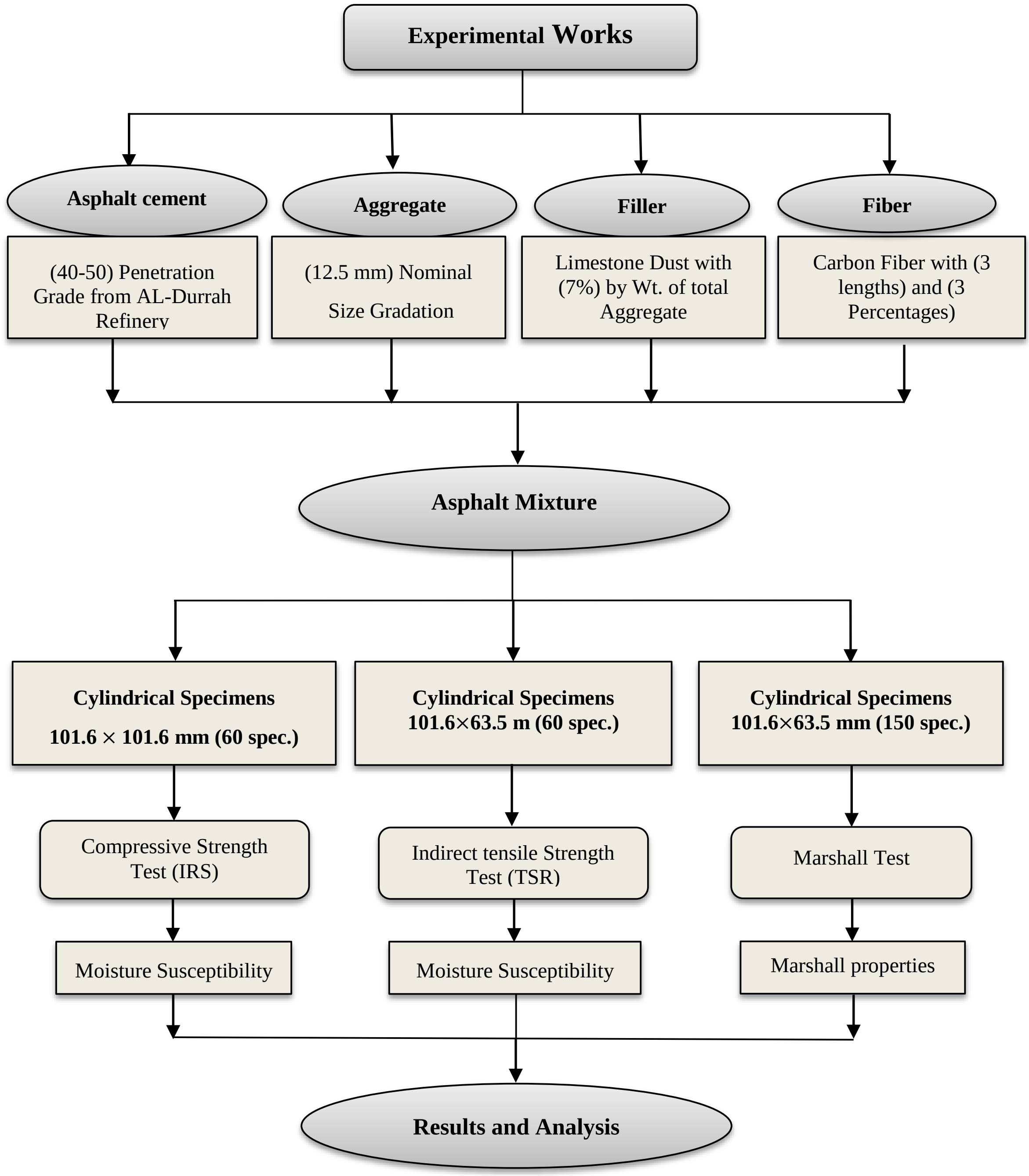

Figure 1. Experimental Work Flow Chart

Coarse and Fine Aggregates

The coarse 12.5 mm nominal aggregate maximum size brought from Al-Nibaee quarry was used in preparation asphalt mixture. The gradation of fine aggregate is between No.4 sieve size (4.75 mm) and No.200 sieve size (0.075 mm). The aggregates were tested for physical properties and Table 2 presents the test results.

Table 2. Physical properties of coarse and fine aggregates

Property	ASTM Designation No.	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 & C-128	2.618	2.576
Percent Water Absorption	C-127 & C-128	0.435	0.562
(Los Angeles Abrasion) %	C-131	18	-------

Mineral Filler

The filler is a material passing sieve No.200 (0.075 mm). It was decided to use limestone dust as filler in preparing the asphalt mixture due to its accessibility and relatively lower cost. It was brought from a lime factory in Karbala governorate. The physical properties of the mineral filler are listed in Table 3.

Table 3. Physical properties of limestone dust

Property	limestone
% Passing No.200	98
Bulk Specific Gravity	2.68

Carbon Fiber (CF)

Carbon fiber was brought from a sika company with the cost of the roller (20) $ per meter width 50 cm. It was chosen because of its higher tensile strength property and higher melting point. Three lengths (1.0, 2.0 and 3.0) cm and three percentages (0.10, 0.20 and 0.30) % by weight of asphalt mixture were selected. The physical characteristics of carbon fibers are shown in Table 4.

Table 4. Physical properties of CF

Test Properties	Typical Value
Nominal thickness (mm)	0.167
Fiber Length (mm)	Can be produced by any length
Color	Black
Density gm/cm^3	1.82
Tensile Strength (N/mm^2)	40000
Elongation-at-Break, %	1.7
Tensile Modulus of elasticity(kN/mm^2)	225
Base	Polyacrylonitrile
Temperature of Carbonization	1400 °C

2.2. Selection of Aggregates Gradation

The selection of the aggregates in this work is the following (SCRB R/9, 2003), [32] for wearing course with a nominal maximum size of aggregate of 12.5 mm. Figure 2 presents the gradation of the selected aggregates for the wearing course.

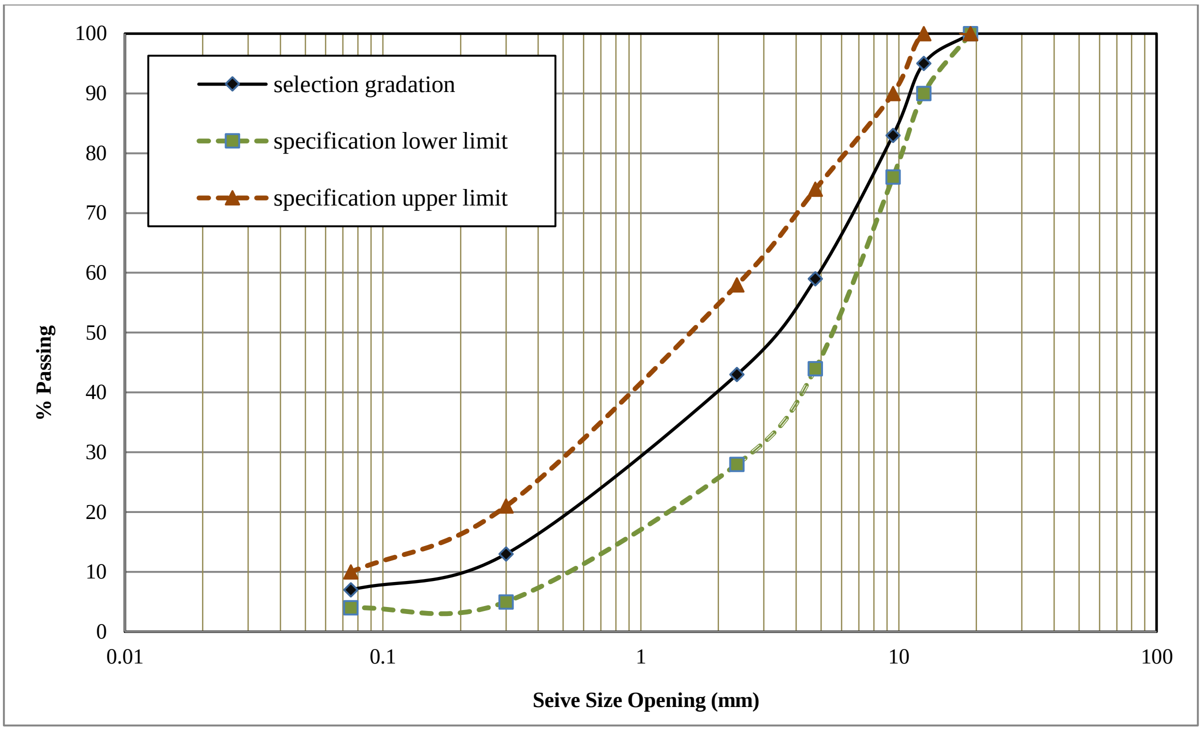

Figure 2. Gradation of the aggregates for wearing course according to SCRB [32]

3. Preparation of Marshall Mixtures

The aggregates are separated into the desired size and recombined with the mineral filler to meet the required gradation according to the (SCRB, 2003) for wearing course. The dry mixing method was implemented, and by visual comparison, it was realized that the dry mixing process was more practical in dispersing fibers and employing fibers through the mixture. As a result, the dry procedure was chosen for use. The carbon fiber is blended with aggregates for 40-60 seconds. The aggregates are then heated to a temperature (155-165 ° C) before mixing with asphalt cement which has already been heated to a temperature that produces a kinematic viscosity of (170 ± 20) centistokes (up to 163 °C as an upper limit). The asphalt cement was then added to the preheated aggregate to reach the required amount of asphalt content. Mix asphalt and aggregate in a mixing bowl by hand on the hot plate for (3-4) minutes until the asphalt adequately covers the surface of the aggregate and fiber as shown in Figure 3.

Figure 3. preparation of asphalt mixtures

4. Indirect Tensile Strength Test (ITS)

This test was performed according to the method described in ASTM D-6931 and explained in [26]. The same Marshall mold dimensions have been utilized with the total number equal to 21 specimens. They left to cool at room temperature for 24 hours and then placed in an air bath at 25 °C for 4 hours to bring them to test temperature. The loading strips were placed and the load was applied at a strain rate of 50 mm/min as shown in Figure 4. Three specimens for each mix combination were tested and the average results were reported. The indirect tensile strength in kPa was then calculated as follows.

$$I.T.S = \frac{2P}{\pi.t.D} \quad (1)$$

$$TSR = \frac{I.T.Ss}{I.T.Sd} \quad (2)$$

Where; P: Ultimate applied load required to fail specimen (N); t: Thickness of the specimen (mm) D: Diameter of specimen (mm); I.T.Ss: indirect tensile strength for soaked specimens (kPa); I.T.Sd = indirect tensile strength for dry specimens (kPa).

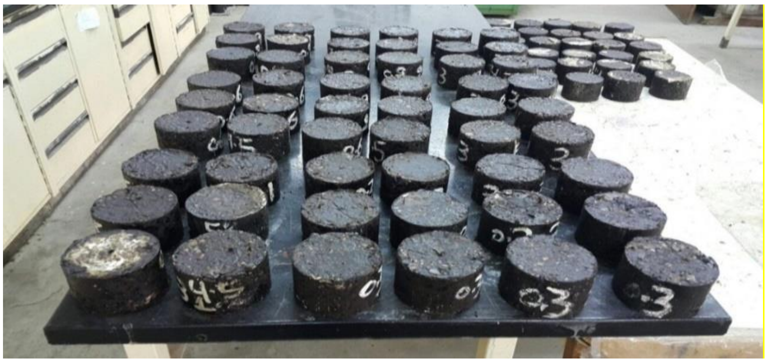

Figure 4. Indirect Tensile Strength Specimen

5. Compressive Strength Test

This method covers the measurement of the loss of cohesion resulting from the action of water on compacted bituminous mixtures. Specimens 4.0 in (101.6 mm) in diameter and 4 in. (101.6 mm) in height were prepared. A set of six specimens prepared for this purpose. Three specimens were tested for compressive strength after storing in an air bath at 25 °C for about 4 hours. The other three specimens were placed in a water bath for 24 hours at 60 °C, then transferred to a water bath, and maintained at 25 °C for 2 hours before testing for compressive strength as shown in Figure 5. The index of retained strength is calculated as follows in accordance with ASTM D-1075-07 [27], which should be a minimum of 0.7 (or 70%) as adopted by (SCRB/R9, 2003) [25].

$$IRS = (S2/S1) \times 100 \quad (3)$$

Where: $S1$: Compressive strength of a dry specimen; $S2$: Compressive strength of an immersed specimen.

Figure 5. Compressive Strength Specimen

6. Results and Discussion

6.1. Marshall Test

The Marshall test was performed to determine the optimum asphalt content for different mixtures groups. The control mix contains (0%) CF achieved 4.90% of the asphalt content (depending on the weight of the total mixture). This percentage increases slightly when the carbon fiber added to the asphalt mixture, three percentages of carbon fiber contents (0.10, 0.20 and 0.30) % (by weight of asphalt mixture) with three fiber lengths (1.0, 2.0 and 3.0) cm spread during mixing. The optimum asphalt content for mixture with fiber percentages of (0.1, 0.2 and 0.3) are obtained as 5.0, 5.15 and 5.3 respectively for a length of 1.0cm. The optimum asphalt content for mixture with fiber percentages of (0.10, 0.20 and 0.30) are also obtained as 5.1, 5.25 and 5.4 % respectively for a length of 2.0 cm. The optimum asphalt content for mixture with fiber percentages of (0.10, 0.20 and 0.30) are also obtained as 5.23, 5.3 and 5.5 % respectively for a length of 3.0 cm. Table 5 shows the results of Marshall test. The optimum content of asphalt for all of the fiber mixtures had a higher optimum percentage of asphalt content than the control mixture, for length 1.0 cm OAC was higher than control mix by (2.0 , 5.1and 8.16) % for fiber content (0.1, 0.2 and 0.3) % respectively, for 2.0 cm OAC was higher than control mix by (4.08, 6.12 and 10.2) % for fiber content (0.10, 0.20 and 0.30) % respectively and for length 3.0 cm OAC was higher than control mix by(6.7, 8.16 and 12.24) % for fiber content (0.10, 0.20 and 0.30) % respectively. This increase dependent on the absorption and surface area of the fibers and thus not only affected by different concentrations of fibers but also by the length of different fibers. Adding fiber requires more asphalt to wrap on its surface because of it's relatively define by surface area and absorption light asphalt components.

Marshall test showed that the stability of mixtures containing fibers was higher than the stability of control mixtures. Specimens containing fiber length (1.0 cm and 2.0 cm) had higher stability values than the control mixtures by (19.28, 27.18 and 31.5) % and (26.7, 38.9 and 51) % for (0.10, 0.20 and 0.30) % CF respectively, while specimens containing (0.10, 0.20 and 0.30) % by weight of asphalt mixture with fiber length 3.0 cm had higher stability values than the control mixtures by (21.2, 17.36 and 10.17) % respectively. The increase in the stability values as the fiber increase in content and length to a certain percentage, then begin to decrease. These results could be attributed to fibers adhesion and networking effects. A large amount of fiber in the mixture produces low contact points between the aggregates, leading to less stability .The decrease shows that the fiber length has little effect on the stability of the mixture. Fibers also form spatial networking to stabilize and strength mixture. Therefore, excessive fiber may do not disperse uniformly, while coagulating together to form a weak Point inside the mixture. As a result, Marshall stability is decreasing in high fiber content.

The flow values were lower than the control mix for fiber length (1.0cm and 2.0 cm) for mixes containing (0.10, 0.20 and 0.30) % by weight of asphalt mixture. Flow value decrease by (3.12, 9.37 and 9.37) % for fiber length (1.0 cm), while decrease by (6.25, 12.5 and 15.62) for fiber length 2.0 cm and specimens containing (0.10, 0.20 and 0.30) % of CF with 3.0 cm shows an increase in flow about (6.25, 15.62 and 31.25) % over the control mix. This increase in flow values can be due to excessive asphalt content of induced fiber mixtures. The presence of further bitumen makes the aggregates "float" within the mix leading to higher flow value. The effect of fiber length on the flow is clearer of stability.

The bulk density of the asphalt mixture decreases with the increase in fiber content and length. The mixtures with (1.0, 2.0 and 3.0 cm) long have a lower density than the control mixtures. Specimens containing (0.10, 0.20 and 0.30) % CF by weight of asphalt mixture with fiber length 1.0cm had lower bulk density than the control mixture by (0.3, 0.47 and 1.96) % respectively, while specimens containing (0.10, 0.20 and 0.30) % of CF with 2.0 cm long had lower bulk density than the control mixture by (1.28, 1.75 and 2.52) % respectively and specimens containing (0.10, 0.20 and 0.30)

% of CF with 3.0 cm long had lower bulk density than the control mixture by (2.22, 2.85 and 3.5) % respectively. This is related to the higher optimum asphalt contents and fibers at high percentage are distributed less homogeneously when mixed, which increase the formation of fiber blends. The increase of OAC requires more compaction effort to achieve the same density due to the relatively lower specific gravity of asphalt than that of mineral aggregate or reduces the density of asphalt mixture at the same compaction effort. As a result, at the same compaction effort (75 blows on both sides of the Marshall sample), adding fiber reduces the bulk density of asphalt mixture. Therefore if it needs to improve bulk density in the field construction more compaction efforts than the ordinary mixture will be essential.

The specimens containing no fibers had lower air void contents than the mixtures containing carbon fibers. It was also observed that the specimens made with 0.30% fiber contents had higher air void contents than the specimen containing (0.10 and 0.20)% fiber contents. Specimens containing (0.10, 0.20 and 0.30)% by weight of total mixture with fiber length 1.0 cm had higher air voids than the control mixture by (4.63, 8.7 and 16)% respectively while specimens containing (0.10, 0.20 and 0.30) % of fiber with 2.0 cm long had higher air voids than the control mixture by (8.11, 18.8 and 21.73)% respectively and specimens containing (0.10, 0.20 and 0.30) % of fiber with 3.0cm long had higher air voids than the control mixture by (21.73, 30.43 and 42)% respectively. This is due to the larger surface areas (aggregate and fibers) that need to be wetted by binder failing which would lead to an increase in the voids in the mixture. Extreme air voids would result in cracking due to insufficient asphalt binders to coating onto aggregates, while too low air void may induce more plastic flow (rutting) and asphalt bleeding.

An increase in fiber content and length in the mixture followed an increase in the (V.M.A) due to the decrease of bulk density (lower bulk density results in higher VMA). This property is significant in so far as the pavements of hot regions are concerned because asphalt may be prone to bleeding and increasing void ratio could prevent bleeding by providing more spaces for the binder to move into.

Table 5. Marshall Test Results

Fiber length cm	CF (%) by wt. of Asphalt mixture	O.A.C., (%) by wt. of mix.	Stability (kN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)	V.M.A (%)	V.F.A (%)
control	0	4.9	8.35	3.2	2.344	3.45	15.18	78
1.0	0.10	5.0	9.96	3.1	2.337	3.61	15.5	76.69
	0.20	5.15	10.62	2.9	2.333	3.75	15.7	76.1
	0.30	5.3	10.98	2.9	2.298	4	17.2	75.4
2.0	0.10	5.1	10.58	3	2.314	3.73	16.45	76
	0.20	5.2	11.6	2.8	2.303	4.1	16.8	75
	0.30	5.4	12.62	2.7	2.285	4.2	17.72	74.8
3.0	0.10	5.23	10.12	3.4	2.292	4.2	17.4	74.7
	0.20	5.3	9.8	3.7	2.277	4.5	18	72.5
	0.30	5.5	9.2	4.2	2.262	4.9	18.6	72.3

6.2. Indirect Tensile Strength Test Results

The tensile strength ratio (TSR) was used to predict the moisture sensitivity of the mixtures. The recommended TSR limit of 0.8 is used to distinguish between moisture sensitive mixtures and moisture resistance mixtures as adopted by (ASTM D-4867). High TSR values indicate that the mixture will work best to resist moisture damage. The dry I.T.S. values of the mixtures containing fibers were higher than the control mixtures. The values of dry I.T.S. were higher for 2.0 cm than (1.0 and 3.0 cm) long. Specimens containing (0.10, 0.20, and 0.30) % CF with 1.0 cm long have higher dry I.T.S. values than the control mixtures by about (7.57, 12.5 and 21.9) % respectively, also specimens containing (0.10, 0.20, and 0.30)% CF with 2.0 cm long have higher dry I.T.S. values than the control mixtures by about (13.64 , 16.55, and 24)% respectively and specimens containing (0.10, 0.20, and 0.30)% CF with 3.0 cm long have higher dry I.T.S. values than the control mixtures by about (11.35, 10.56, and 3.52)% respectively as shown in Figure 6. Results showed that the mean wet I.T.S. values of all the fiber mixtures were greater than the control mixtures. The mixtures with (0.10, 0.20, and 0.30) % fiber content (by weight of asphalt mixture) with 1.0 cm length were higher than control mixture by (10.76, 18.35, and 32.19) % respectively, also the mixtures with (0.10, 0.20, and 0.30) % fiber content (by weight of asphalt mixture) with 2.0 cm length were higher than control mixture by (17.8, 26.26 and 37.91) % respectively and the mixtures with (0.10, 0.20, and 0.30) % fiber content (by weight of asphalt mixture) with 3.0 cm length were higher than control mixture by (17.9, 15.16 and 5.6) % respectively as shown in Figure 7. It is observed that as the fiber content increases, the tensile strength increases slightly. This observation exhibits that the effect of fiber length on strength is significantly large so that the combined effect of fiber content and fiber length leads to only a slight increase in the strength.

It should be noted that the increase in dry I.T.S may be due to the high tensile modulus of elasticity and lower ability of extension of carbon fibers. In the proposed sample, the fibers have a random orientation in a different direction which strongly binds particles inside the matrix and prevents them from moving, thus making the mixture stiffer. Fiber carries some tensile loads when bitumen fiber mastics are tested under tension, the stress is transmitted from the matrix to the fiber. Fiber carries some tensile loads part of the tensile stress can be achieved by fiber, so the wet tensile strength increases with increased fiber concentration and length to a certain extent then begin to decrease. This increase associated with the fact that the presence of fibers increases the strength of the mixture due to the interlocking phenomenon. The networking between fibers and bitumen seems to prevent the penetration of water into the mixture. This plays an important role in increasing wet tensile strength making the mixture more resistant to moisture damage. The use of an appropriate fiber type and content has an important effect on the tensile strength of the asphalt mixture.

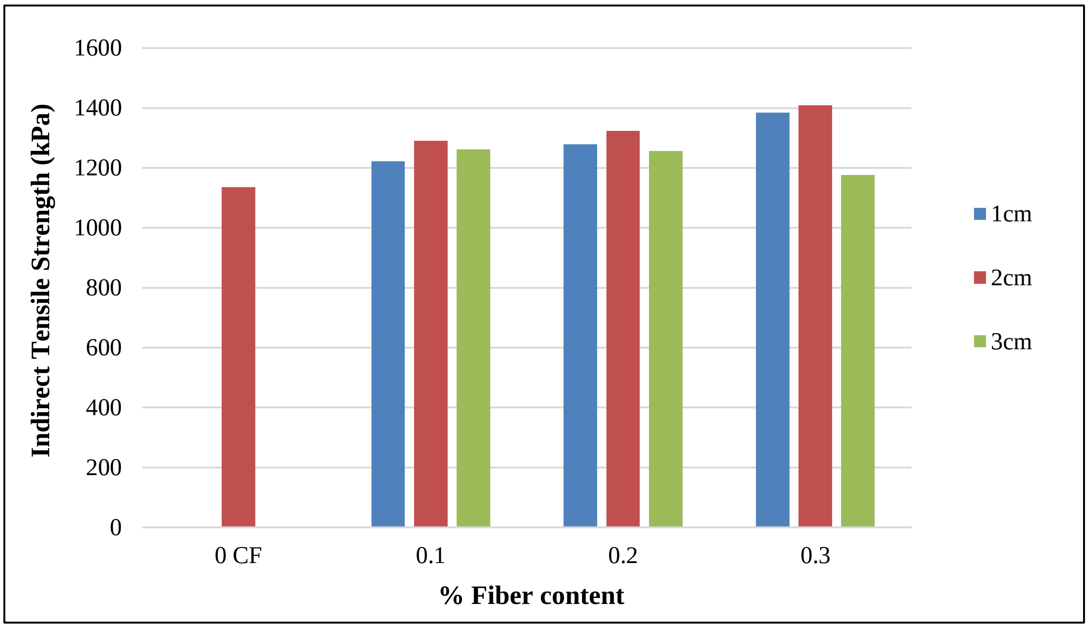

Figure 6. Effect of CF and length on I.T.S of dry specimens

T.S.R values of control mixtures were significantly lower than that of fiber mixtures. T.S.R values of 1.0 cm length is increased by about (2.99, 5.11 and 8.48) for (0.10, 0.20 and 0.30)% fiber content respectively than the control mixture while T.S.R values of 2.0 cm length is increased by about (3.62, 8.36 and 11.23) % for (0.10, 0.20 and 0.30)% fiber content respectively than the control mixture and T.S.R values of 3.0 cm length is increased by about (6.24, 4.74 and 1.87) % for (0.10, 0.20 and 0.30) % fiber content respectively than the control mixture as shown in Figure 8.

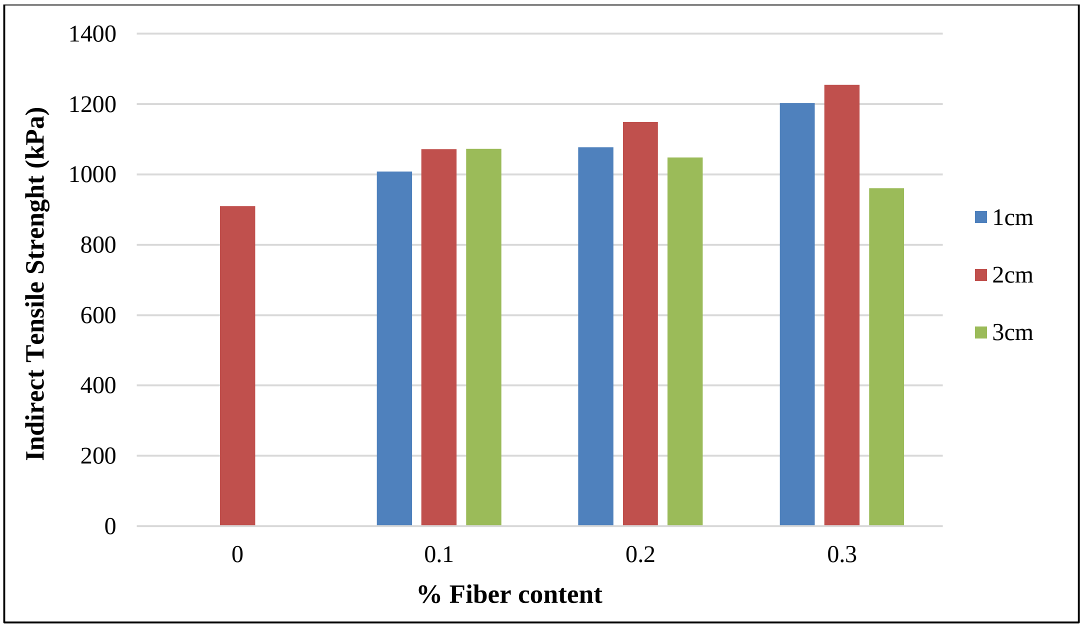

Figure 7. Effect of CF and length on I.T.S of wet specimens

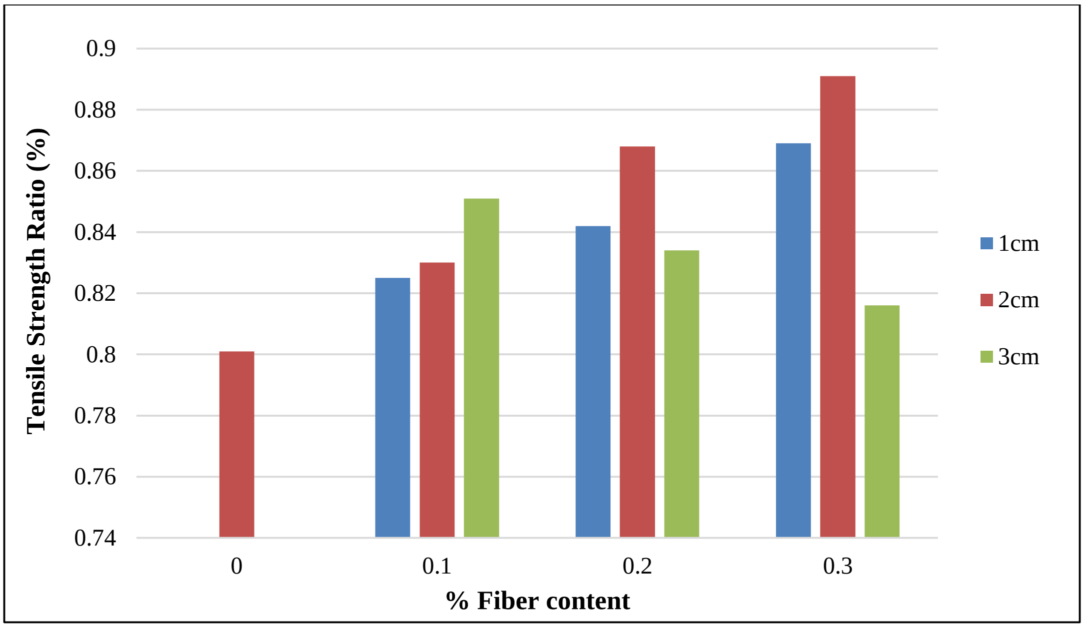

Figure 8. Tensile strength ratio results

6.3. Compressive Strength Test Results

According to ASTM D-1074 and D-1075, (SCRB, 2003) indicated that the acceptable value of the index of retained strength is (70%) or higher, so any mixture has an I.R.S. below this value is considered susceptible to water damage. The dry compressive strength values of the mixtures containing fibers were higher than the control mixtures. Specimens containing (0.10, 0.20 and 0.30) % carbon fibers (by weight of asphalt mixture) have higher compressive strength values than the control mixtures by about (2.4, 4.32 and 7.18) % for length 1.0 cm, (2.84, 8.83 and 10.43) % for length 2.0 cm and specimens with a length of 3.0 cm containing 0.10% CF were higher control mixture by (0.14) %, while the other percentage (0.20 and 0.30) % of CF (by weight of asphalt mixture) have lower compressive strength values than the control mixtures by (1.14 and 2.97) % respectively as shown in Figures 9 to 11.

The mean wet compressive strength values of all the fiber mixtures were greater than the control mixtures. The wet compressive strength values for mixtures with (2.0 cm) fiber length found to be higher than the mixtures with (1.0 and 3.0 cm) fiber length. The wet compressive strength value of (1.0 cm) fiber length increased by about (6.21, 11.3 and 16) %, for 2.0 cm fiber length is increased by about (9.4, 19 and 24) %. Specimens with (3.0 cm) fiber length content (0.1 and 0.2) % carbon fiber increased by about (5 and 1.77) % than the control mixture and the specimens containing (0.3) % fiber content (by weight of asphalt mixture) decrease by about (4.72) % than the control mixture as shown in Figures 9 to 11.

Dry and wet compressive strength values for 0.30% fiber content were higher than (0.10 and 0.20) % fiber content for length (2.0 cm). Higher wet compressive strength of fiber mixtures could be associated to the fact that presence of fibers with the bitumen producing network bonding which prevent the penetration of water to the mixture and this increases the strength of the mixture and make the mixture more resistant to moisture damage indicating that the use of carbon fibers decrease the moisture susceptibility of mixtures.

The values of the index of retained strength (I.R.S.) of control mixtures were significantly lower than that of fiber mixtures. The percentage and size of fibers had significant effects on I.R.S values. The mixtures with 2.0 cm long have higher I.R.S. values than mixtures with (1.0 and 3.0 cm) long. I.R.S values of 1.0 cm length is increased by about (3.8, 6.6 and 8.3) %, for 2.0 cm length is increased by about (6.51, 10 and 12.5) % for (0.10, 0.20 and 0.30) % carbon fiber and I.R.S values of 3.0 cm length is increased by about (5 and 2.9) % for (0.10 and 0.20) % fiber content respectively than the control value and decrease by about (1.76) % for 0.3% fiber content as shown in Figure 12. Higher I.R.S. refers to lower moisture susceptibility and good resistance to moisture damage. This indicates that 0.30% is the optimum fiber content and the increase in fiber length may not blend well with the mixture. Higher I.R.S. refers to lower moisture susceptibility and good resistance to moisture damage.

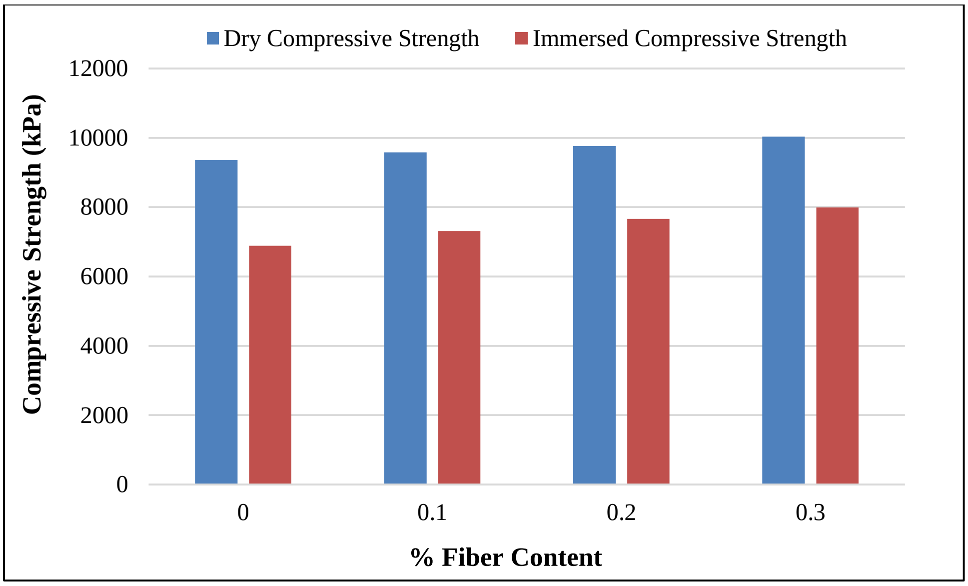

Figure 9. Effect of Fiber Percentages on Dry and Wet Compressive Strength for (1 cm Fiber Length)

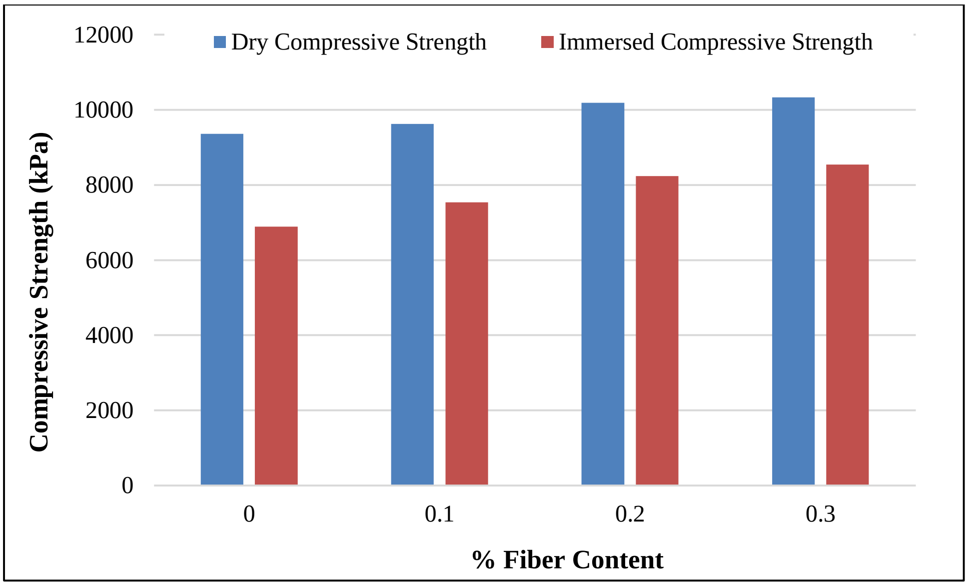

Figure 10. Effect of Fiber Percentages on Dry and Wet Compressive Strength for (2 cm Fiber Length)

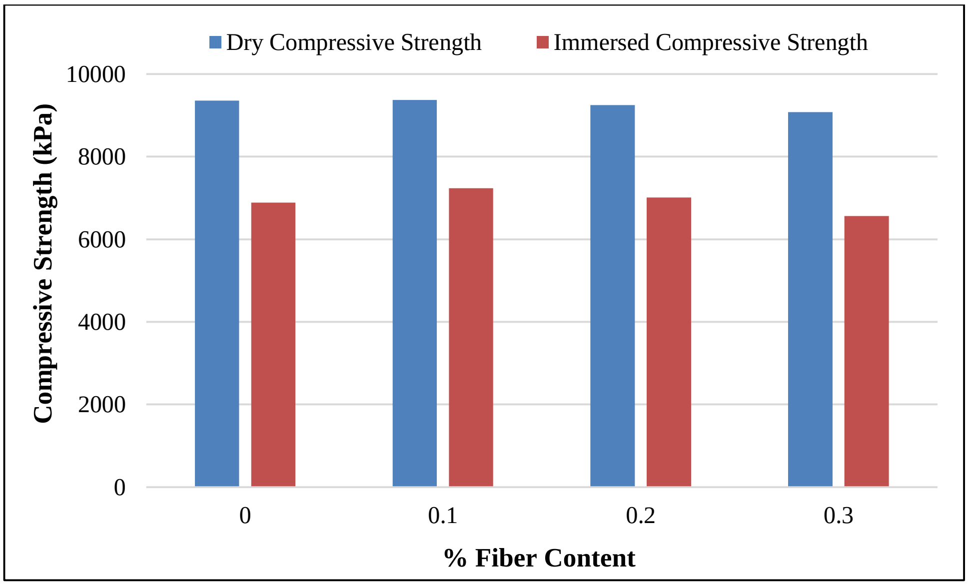

Figure 11. Effect of Fiber Percentages on Dry and Wet Compressive Strength for (3 cm Fiber Length)

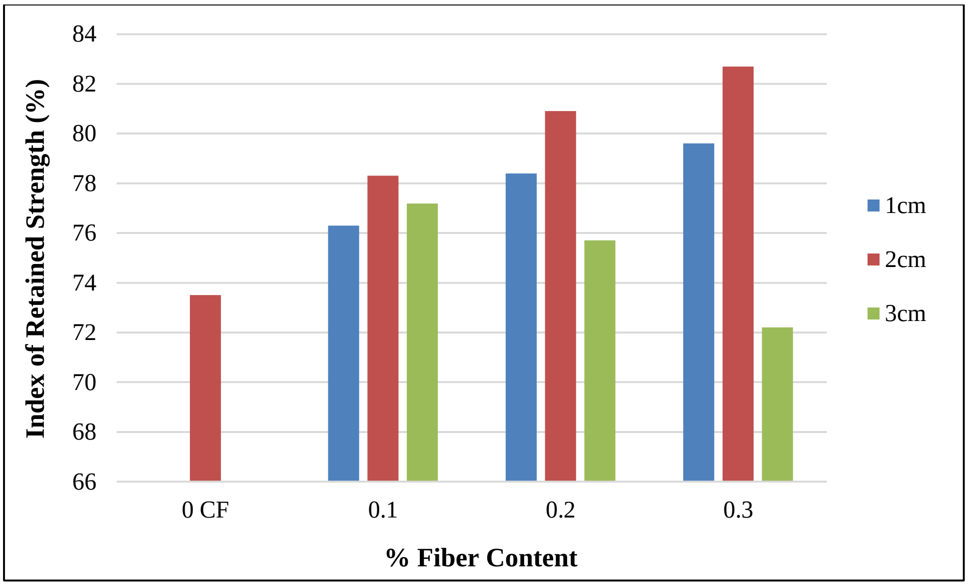

Figure 12. Effect of Fiber Contents and Lengths on Index of Retained Strength

7. Conclusions

- The addition of carbon fibers to the asphalt mixtures showed an improve in Marshall properties, Stability values increased when CF increased by length and content to a certain limit and then decreased. Specimens containing 2.0 cm long fiber mixtures had higher stability values than the 1.0 cm and 3.0 cm long fiber. Flow value decreases when CF adding to the mixture. Air void and VMA increase, while bulk specific gravity decreases after adding carbon fibers or increasing fiber content in asphalt mixture.
- The tensile strength ratios for all mixtures containing carbon fiber were higher than those without fibers mixtures. This indicates that the use of carbon fibers decreased moisture susceptibility of asphaltic mixtures. The 0.30 % fiber content gives the highest value of the Tensile Strength Ratio for lengths 1.0 and 2.0 cm. T.S.R value increased by 8.48 % for the 1.0 cm fiber length and 11.23 % for the 2.0 cm fiber length while 3.0 cm fiber length recorded the highest increment in T.S.R with 0.10 % CF by about 6.24%.
- The Index of Retained Strength values increases for all mixtures containing fibers. This indicates that the use of carbon fibers decreased moisture susceptibility of asphaltic mixtures. The 0.30 % fiber content gives the highest value of Index of Retained Strength. For this content, the I.R.S. value increased by 8.3 percent for the 1.0 cm fibers length, 12.52 percent for the 2.0 cm fibers length. Excluding 0.30% with 3.0 cm fiber length reduced by about 1.76% of the control value.
- The 0.30 % carbon fiber with 2.0 cm fiber length leads to the best values of indirect tensile strength ratio and index of retained strength and exhibited better mechanical behavior than longer fibers, which may lead to the phenomenon of "balling" in the mix which lead to lose its positive effects.

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9. Conflicts of Interest

The authors declare no conflict of interest.

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