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# Improving the Moisture Damage Resistance of HMA by Using Ceramic Fiber and Hydrated Lime

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### ABSTRACT

The Moisture damage is considered as one of the main challenge for the experts in the field of asphalt pavement design. The aims of the present study is to modify moisture resistance of the asphalt concrete by utilizing ceramic fibers as a type of reinforcement incorporated with hydrated lime. For this purpose, a penetration grade of the asphalt cement (40-50) was utilized as a binder with an aggregate of the maximum nominal size of 12.5mm and mineral filler limestone dust. A series of specimens has been fabricated by utilizing 0.50, 1.0, 1.5, and 2.0 percentages from the weight of total mixture of ceramic fibers. For each of these contents, another subsequent group of specimens with hydrated lime with 0.0, 1.0, 1.5, and 2.0 percentages from the total weight of aggregate were molded. For the addition of ceramic fiber and hydrated lime to the mixtures, the dry method for ceramic fiber was adopted. While for the hydrated lime, the saturated surface dry method was adopted. The results of this study have shown that the addition of 1% ceramic fiber from the total weight of the asphalt mixture with 1.5% hydrated lime recorded the highest levels of increase. Furthermore, the outputs of the tests used in this study have shown that the use of ceramic fibers resulted in an increase in the value of tensile strength ratio (TSR) and in the index of retained strength (IRS) compared with the control mixture. Maximum values for TSR were achieved at 1% ceramic fibers with 1.5 % hydrated lime. Maximum values for IRS were achieved at 1% ceramic fibers with 1.5 % hydrated lime.

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## 1. INTRODUCTION

Moisture damage is one of the main reasons for the early failure in the asphalt concrete mixtures. A correct assessment of the moisture susceptibility is necessary to prevent the deterioration of the field mixtures Adriana et al. [1]. The moisture damage as distresses that influence the community in various ways can be considered. Economically, the maintenance and rehabilitation of the damaged pavements that are resulted from the moisture damage cost millions of dollars [2 –3]. Besides,

susceptibility due to moisture is a major concern in asphalt pavements; it can be considered as a deterioration within the mechanical property of the asphalt because of the impact of moisture or water that causes severe distresses. The asphalt mixture's resistance to the moisture damage is highly critical for its long-term performance. If the asphalt mixture is susceptible to the moisture damage, it could, in the end, fail in any of the

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Nomenclature			
AC	asphalt cement, %	SSD	saturated surface dry
ASTM	american Society for testing and material	t	the specimen thickness, mm
D	diameter of specimen, mm	TSR	the tensile strength ratio, %
HMA	hot mix asphalt	IRS	index of retained strength, %
ITS	indirect tensile strength, kPa	P	ultimate load failure, N
SCRB	state commission of roads and bridge		

failure modes, i.e. rutting, fatigue, thermal cracking, or ravelling Sebaaly et al. [4]. Moisture damage in asphalt pavement can lead to several distresses inside asphalt structures such as bleeding, cracking, rutting, ravelling and localized failures which are similar to distress resulting from some other factors such as materials, design, and construction. It is then necessary to differentiate between distresses resulting from moisture or those resulting from the effect of other factors and to consider this as the first step is in selecting the proper solution Hicks et al. [5]. Because of the growing cost of repairing and renewing damaged pavements, extended studies have been carried out to the resistance against damages and to the growing of their service-life Arabani et al. [6].

Many studies have inspected the use of fibre to get better the performance of HMA: some focused on specific performance concerning water effects, environment, and temperature Xu et al. [7]. At the same time, other experiments were conducted to highlight the mechanical performance of HMA, e.g. fatigue, rutting, and stiffness Moreno-Navarro et al. [8]. Different kinds of the modifier fibres like cellulose, polyester, glass, and mineral fibres are widely used into dissimilar types of asphalt mixtures Wan et al. [9]. The influence of reinforcement of the fiber is improved by various means of improving its quantity into a definite value, relying on the kind and length of the fibres Wu et al. [10]. Ceramic fiber has an extensive application value in everyday life and it forms a whole industry as a substance for heat insulation. The main chemical composition of the ceramic fiber is  $Al_2O_3$  and  $SiO_2$ . At the same time, depending on the various purposes, some other chemical substances are added to it to improve its properties. The ceramic fiber diameter ranges from 2 to 5  $\mu m$ , and the length is nearly 20 mm. Its advantages involve being of lightweight, having thermal insulation, no toxicity, resistance to mechanical vibration, and is of low cost compared with other fibers. Ceramic fiber can improve the rendition of the asphalt mixtures because it has a high stability to temperature and chemical changes, appropriate flexibility, and adequate shock resistance. The reinforcing properties of these fibers along with their low deleterious influences and easy-accessibility can make them suitable additives to improve the characteristics of the binder and the asphalt mixture Wan et al. [9]. Anti-stripping agents are categorized into two sets: the first includes those added to the asphalt binder which are usually chemical liquids called "Liquid Anti stripping Agents" while the second set includes those attached directly to the aggregate like fly ash, lime, Portland cement, flue dust, polymers, cement Klein, and numerous others, Epps et al. [11]. The main goal of adding anti-stripping agents is to reduce the moisture sensitivity of the asphalt mixtures by improving the bond between the asphalt binder and the aggregate. Lime has been widely utilized as both a filler and additive to resist moisture in asphalt mixtures Ismael et al. [12]. Three major forms of lime are used with asphalt mixtures according to Hunter et al. [13]; hydrated lime ( $Ca(OH)_2$ ), quicklime ( $CaO$ ), and dolomitic lime ( $CaO.MgO$ ).

The increase in road traffic with inadequate and the repeated with less the maintenance exacerbated the deterioration of asphalt pavements, during the past 20 years in Iraq. The major structural distress that led to a reduction in the serviceability of asphalt pavements are cracking and rutting.

Therefore, different types of additives and modifiers are utilized in asphalt to decrease the distresses effect Hunter et al. [14].

The objective of that research is to study the application of one of the most widely utilized fibres in the insulation manufacture in the asphalt mixtures. The significance of the present study is to use ceramic fibre as suitable and cost-effective additives to excess the service-life of the asphalt pavements, which could promote more types of researches in the future. In this study, hydrated lime was used as anti-stripping with the ceramic fibres as reinforcement fibres for the asphalt mixture.

## 2. EXPERIMENTAL WORK

### 2.1. Materials

The materials utilized in this research are locally obtainable and are now used in road constructions in Iraq. Ceramic fiber and hydrated lime are available in the local market. All materials were obtained from commercial sources without trying to get private products. Therefore, this research investigates the use of the ceramic fibers as reinforcement fibers for improving their resistance to the moisture damage in the asphalt mixtures.

#### 2.1.1. Asphalt Cement (AC)

One kind of AC with a penetration grade of (40-50) and produced by Al-Daurah Refinery was used here. The physical properties of asphalt cement utilized in this study are shown in **Table 1**. The test results were to meet the State Commission of Roads and Bridge (SCRB) [15] specifications.

#### 2.1.2. Coarse Aggregate

The crushed coarse aggregate of about between the sieve size (19mm) and sieve (4.75 mm) has been gained from the Al-Nibae Quarry; it accords to the (SCRB) [15] specifications. The physical property of the coarse aggregate is shown in **Table 2**.

#### 2.1.3. Fine Aggregate

The crushed fine aggregate of about between the sieve size (4.75 mm) and sieve size (0.075 mm) has been gained from the same source of coarse aggregate. It consists of tough, hard, grains, free of the injurious amount of clay, loam, or other harmful substances. The physical property of the fine aggregate is shown in **Table 3**.

#### 2.1.4. Mineral Filler

The substance passage from sieve size (0.075mm) is called the mineral filler. It must be dry and free of the accumulation of accurate particles. The filler material used in making asphalt mixture is the limestone dust because of its availability and comparatively low cost. The physical property of the mineral filler is shown in **Table 4**.

2.2 Combination of Aggregate Gradations

A manual sieving for the coarse and fine aggregate was used to classify it into sets according to size. In this study, one kind of gradation was utilized, (12.5mm) nominal maximum size. Then, the combination percent for Type IIIA wearing coarse was selected to meet the job mix formula specified by the (SCRB) [15]. The aggregate gradation is shown in Table 5 and Fig. 1.

Table 1: Physical Properties of AC (40-50 ).

Tests	Units	Results	SCRB 2003 Specification Limits [15]	ASTM Designation [16]
Penetration (25 °C, 100 gm., 5 sec)	1/10 mm	47	40 – 50	D-5
Ductility (25 ° C, 5 cm/min)	cm	135	≥ 100	D-113
Kinematics Viscosity, @ 135° C	cSt	405	—	D-2170
Softening Point (Ring & Ball)	°C	50	—	D-36
Flash Point (Cleveland Open Cup )	°C	270	232 min.	D-92
Specific gravity at 25 °C	—	1.04	—	D-70
<b>After Thin –Film Oven Test ASTM D 1754</b>				
Retained Penetration of Residue (25°C, 100 gm. , 5 sec )	%	60	55(min)	D 5
Ductility at 25 ° C, 5 cm/min	cm	82	>25	D-113

Table 2 : Physical Properties of Coarse Aggregate.

Property	ASTM Designation [16]	Results	SCRB Specification [15]
Bulk Specific Gravity	C-127	2.579	----
Apparent Specific Gravity	C-127	2.601	----
Percent Water Absorption	C-127	0.54	----
Percent Wear (Los Angeles abrasion)	C-131	15.79	30 Max

Table 3: The Physical Properties for the Fine Aggregate.

Properties	ASTM Designation [16]	Result	SCRB 2003 Specifications [15]
Bulk Specific Gravity	C-128	2.61	---
Apparent Specific Gravity	C-128	2.632	---

Percent Water Absorption	C-128	0.952	---
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Table. 4: Physical Properties of filler (Limestone Dust).

Property	Result
% passing sieve N0.200	95
Specific Gravity	2.71

Table.5 : Gradation of Combined Aggregate for Wearing Course ( Type IIIA ).

Sieve Size	Sieve Size (mm)	Specification Passing Range (%)	Selection Gradation
3/4"	19.0	100	100
1/2"	12.5	90-100	95
3/8"	9.5	76-90	83
No.4	4.75	44-74	59
No. 8	2.36	28-58	43
No.50	0.300	5-21	13
N0.200	0.075	4-10	7

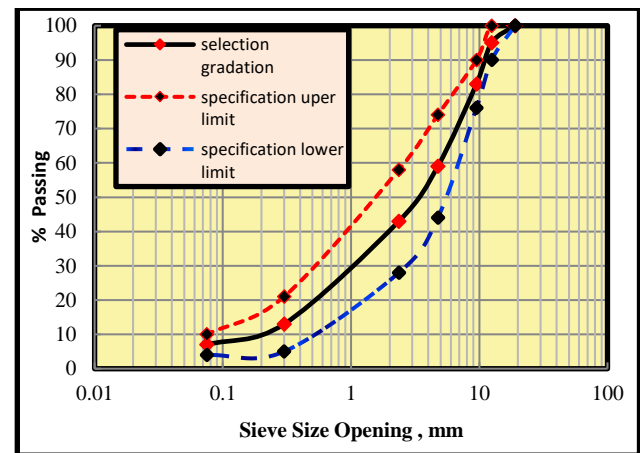


Figure 1: The Specification Limits and Selected Gradation for the Wearing Course SCRBS [15].

2.3. Additives:

To improve the ability of the asphalt mixtures to resist the damaging effect of moisture presence, ceramic fibres and hydrated lime were used in this research, with different percentages for each additive.

2.3.1. Ceramic Fibers

The aluminium silicate fibres are formed by melting and blowing molten kaolin with excessive content of the alumina material, or more popular, the materials to be ceramic fibres Arabani et al. [6]. The use of ceramic fibres as a reinforcement of asphalt concrete is limited in Iraq. Therefore, it is chosen to be used in this study. It was selected due to its high tensile strength property and high melting point. The characteristics of ceramic fibers are listed in **Table 6**.

### 2.3.2. Hydrated Lime

Hydrated lime is well known as an anti-stripping agent. It has been widely utilized as both a filler and additive to resist moisture in the asphalt mixes. Hydrated lime is known to be a promising probable substance for pavements because of its unique chemical, physical, and mechanical characteristics. Hydrated lime was used as an anti-stripping additive for HMA pavements in this study. The physical property and the chemical composition is shown in **Table 7** and **Table 8** respectively.

**Table 6 : The basic properties of the ceramic fibers .**

**Table 7: physical properties .**

Property	Hydrated Lime
Specific gravity	2.44
% Passing N0.200	99

**Table 8: Chemical Composition of Hydrated Lime .**

Chemical composition	Percent %
CaO	56.1
SiO <sub>2</sub>	1.38
MgO	0.13
Fe <sub>2</sub> O <sub>3</sub>	0.12
Al <sub>2</sub> O <sub>3</sub>	0.72
SO <sub>3</sub>	0.21
L.O.I	40.65

### 2.4. The Research Methodology

For this work, the research methodology consists of four phases. The first phase of the experimental part was represented by bringing the substances of asphalt binder, aggregates, the mineral filler, and ceramic fibres and hydrated lime additives and by testing the physical properties of the materials. The second phase include the preparation of asphalt cement mixtures that will be formed to locate the optimum asphalt content of the control mix, without additives. The third phase was to determine the optimum asphalt content of the mixture specimens with ceramic fibre and hydrated lime based on Marshall characteristics. Moreover, in the fourth phase, in addition to the volumetric properties, the Marshall properties flow and stability values are determined to satisfy the requirement of Iraqi specifications.

The optimum asphalt contents specified by these tests were 4.9 for the control mixture, and 5.30 for modified mixtures. Then to produce mixtures for indirect tensile tests to evaluate (TSR) and compressive strength tests for assessing (IRS).

### 2.5. Methods of Incorporating Additives into the Mixture

To add ceramic fibre with hydrated lime to the asphalt cement mixture, the dry method for ceramic fibre and the saturated surface dry process for hydrated lime were used. Using the Saturated Surface Dry method (SSD) for hydrated lime, water was added at 3% of the weight of the combined aggregate without filler. Then, the additives were added and well mixed with; the wet aggregate was left to dry in an oven for two hours at 150 °C. After that, the filler was added to and mixed with asphalt.

### 2.6. Tensile Strength Ratio Test (TSR)

The process for preparing and testing the asphalt concrete samples and of measuring the influence of moisture on the tensile strength for the asphalt mixture is covered by the TSR. This test is utilized to evaluate the

Properties	Ceramic fibers
Type	NC1260
Appearance	White cotton shape
Morphological structure	Glass state
Average length (mm)	2.0
Average diameter ( $\mu\text{m}$ )	3.0
Thermal conductivity	0.03
Density ( $\text{kg/m}^3$ )	128
Melting Point (°C )	1760
Tensile strength ( kPa)	83
The Chemical composition (%)	
Al <sub>2</sub> O <sub>3</sub>	52
Al <sub>2</sub> O <sub>3</sub> +SiO <sub>2</sub>	95
Fe <sub>2</sub> O <sub>3</sub>	<0.2
ZrO <sub>2</sub>	/

impact of the humidity on the asphalt mixture. For more information, ASTM D-4867 [16] provides a full description of this test.

The samples in this test were worked out to have the number of blows that give  $7\pm 1\%$  the air voids appropriate to the job - mix formulation by the trial method by prepared samples free from any additive by made by using the number of blows(45,55,65,75) respectively. The number of blows was 54 to give this percent, as shown in **Fig. 2** below. After identifying the number of blows, groups of Marshall specimens were prepared in six samples where each group is divided into two sets, three samples for every set. The first set was located in a water bath at 25 °C for 30 minutes (specimens unconditioned ), then the ITS has been calculated for every sample and the ITS average for the three samples was determined. The second set was located in a vacuum container full of distilled water at 25 °C to remove the air content. After that, the specimens were put in the freezer for 16 hrs. at  $-18\pm 3$  °C. After the freezing cycle, the samples were put at a water bath for 24 hrs. at 60 °C to complete the thawing cycle. It has been extracted and put in another water bath at 25 °C for 1hr, and the ITS for these specimens conditioned was calculated.

The ITS calculations are made according to the method shown in ASTM D-6931-12 [16]. The sample was located in the loading apparatus, and the loading strips have been put parallel and centered onto the perpendicular diametrical level. The length of the loading strips has exceeded the thickness of the specimen. A diametrical load was applied at 50.8mm/min (2in. /min) until the failure of the sample. The samples and the tests are shown in Fig. 3. The extreme load which causes that breakdown was registered and the ITS were calculated according to the following equation:

$$ITS = \frac{2000Pult}{\pi t D} \tag{1}$$

Where:

ITS = Indirect Tensile Strength , (kPa) .

Pult = Ultimate applied load required to fail specimen,(N).

t = thickness of the sample,(mm).

D = diameter of sample , (mm) .

After calculation of ITS for conditioned and unconditioned samples for each set, the tensile strength ratio was calculated as below:

$$TSR = \frac{con.ITS}{uncon.ITS} \times 100 \tag{2}$$

Where :

TSR = Tensile Strength Ratio, % .

con. ITS = average ITS of the moisture – conditioned samples, kPa.

uncon. ITS= average ITS unconditioned (dry) samples , kPa .

The minimum TSR value is ( 80%) according to the ASTM D-4867-09 [16].

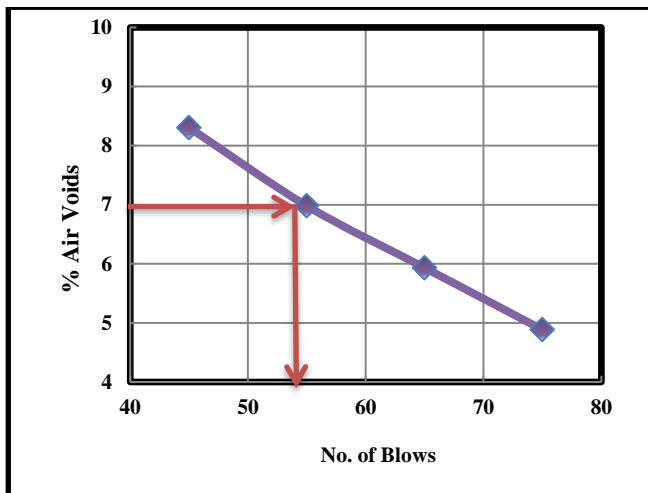


Figure 2 : Relationship between No. of Blows and Air Voids Percent .



(a) Some of the specimens



(b) sample under test .



(c) sample after test ( failure).

Figure 3: Tensile Strength Ratio Test



## 2.7. Compressive Strength Test

A compressive strength of a compacted mixture is usually conducted to determine its suitability for use in the pavement under a given load and environmental condition. This test was conducted according to ASTM D-1074 – 02 [16]. The prepared mixture is compacted by using a compressive device. Samples of 4 in. height (101.6mm) and diameter of 4 in. (101.6mm) were prepared. The specimens were cooled for 24 hours before being tested for compressive strength at a rate of loading of 5.08 mm/min. Then they were placed in a vertical position so that the axial load could be applied to the first surface of the specimen until it fails. Compressive strength specimens and tests are shown in Fig. 4.



(a) Cylinder specimens



(b) Specimen before loading



(c) Specimen after loading and failure

Figure 4: Compressive Strength Test.

## 2.8. Index of Retained Strength Test

This method covers the measurement of the cohesion loss producing from the impact of water on compressed the asphalt mixtures. A group of six samples prepared for that purpose divided into two groups. Three samples for the compressive strength after putting into the air bath with 25 °C for nearly 4 hr. were examined. The three other samples have been put in the water bath with 60 °C for 24 hr. and then transmitted to the water bath, and kept for 2 hours at 25 °C before the compressive strength testing. The IRS is calculated in accordance with the ASTM D-1075-07 [16] specifications, which must be within a minimum of 70% as adopted by SCRB [15].

## 3. RESULTS AND DISCUSSION

### 3.1. Tensile Strength Ratio Results

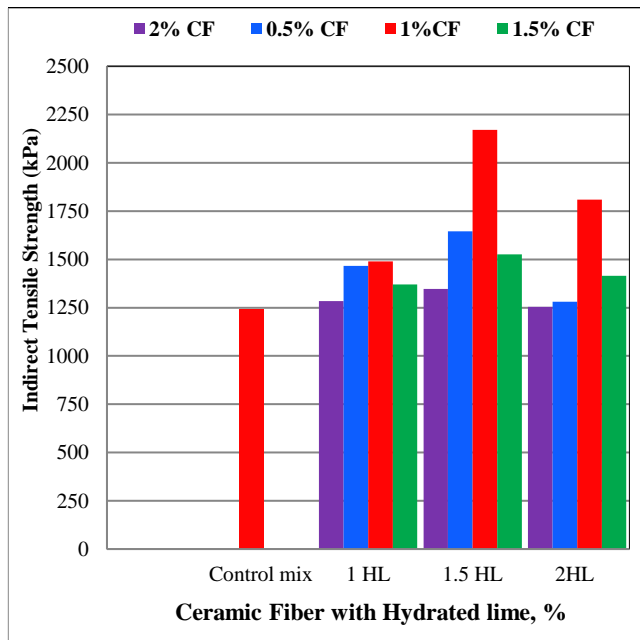
The dry indirect tensile strength, wet indirect tensile strength, and T.S.R values for the asphalt mixtures containing ceramic fibers with hydrated lime for all percentages are greater than the values of the control mixture. The dry ITS with 1% ceramic fiber values have been higher than those with 0.5, 1.5, and 2% ceramic fiber. Samples containing 1, 1.5, and 2% hydrated lime (by weighing the total mixtures) with 1% ceramic fiber have higher dry indirect tensile strength values than the mixtures of control. The effect of the ceramic fiber content increases the dry ITS values because of the increase of tensile modulus of elasticity; this increase is because ceramic fibers with hydrated lime have a much higher strength.

The mixture was stiffer into the specimen because the fibers have a random orientation in various directions, strongly connect particles within the matrix, and eventually stop them from moving. Furthermore, given that the hydrated lime has a high surface area, the aggregate was plated with enough amount of the asphalt, and as a result, the adhesion force became higher between asphalt and aggregate and prevented the stripping beneath the influence of the moisture. As a result, the value of the TSR increased in a way that indicates the increment in the resistance of moisture of asphalt

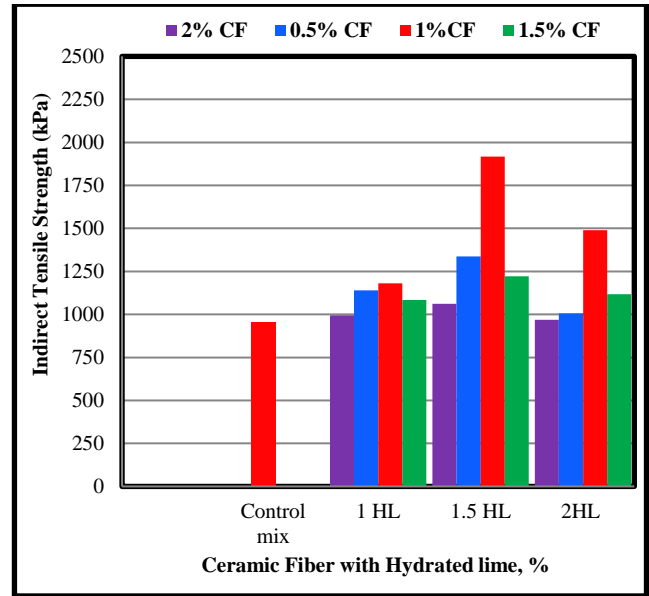
mixture together with the addition of ceramic fiber and hydrated lime. The effect of ceramic fiber with hydrated lime is shown in Table 9 and Fig. 5 through 7 respectively.

**Table 9: Indirect Tensile Strength Test Results.**

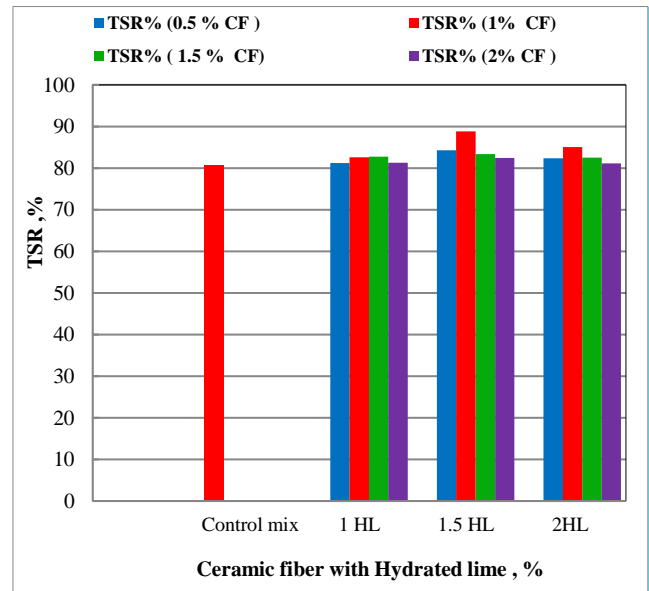
Additives	Additive, %	Dry ITS (kPa)	Wet ITS (kPa)	TSR(%)
Control mix	0	1243	953	76.71
	0.5 CF +1H	1467	1141	77.77
	0.5 CF+1.5H	1645	1336	81.22
	0.5 CF +2 H	1281	1005	78.49
	1 CF +1 H	1489	1180	79.25
Ceramic Fiber with Hydrated Lime	1 CF+1.5 H	2170	1917	88.34
	1 CF +2 H	1809	1489	82.30
	1.5 CF +1 H	1370	1083	79.08
	1.5 CF +1.5 H	1526	1222	80.05
	1.5 CF +2 H	1415	1117	78.95
	2 CF+1 H	1284	994	77.39
	2 CF +1.5 H	1348	1061	78.73
	2 CF +2 H	1255	968	77.15



**Figure 5: Effect the Percentages of Ceramic Fibers Content and Hydrated Lime Content on Dry Indirect Tensile Strength .**



**Figure 6: Effect the Percentages of Ceramic Fibers Content and Hydrated Lime Content on Wet Indirect Tensile Strength.**



**Figure 7: Effect of Fibers Content and Hydrated Lime Content on Tensile Strength Ratio.**

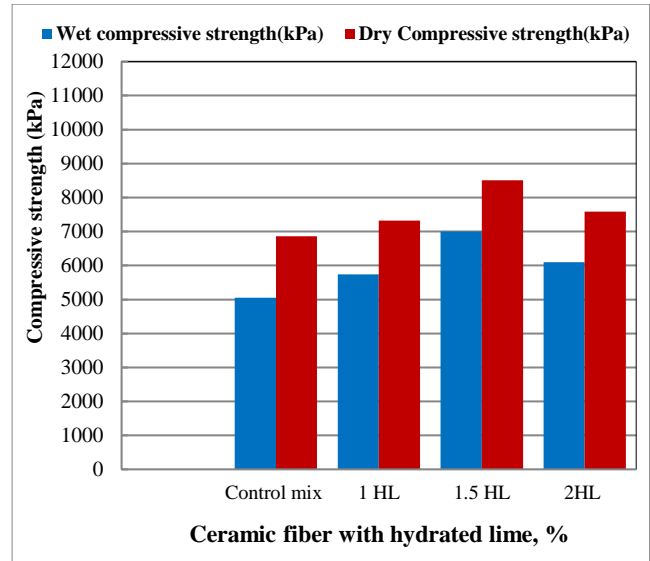
**3.2. Index of Retained Strength results**

The IRS to evaluates the resistance of the asphalt mixture to the susceptibility of moisture has been utilized. In accordance with the SCRB [15], the minimum value of the allowed IRS is 70% which has been considered as a measure if the asphalt mixture is susceptible to moisture. The results of the increase in the value of dry compressive strength, wet compressive strength and IRS percentage in the asphalt mixture modified with ceramic fiber with hydrated lime is listed in Table 10 and Fig. 8 through 12.

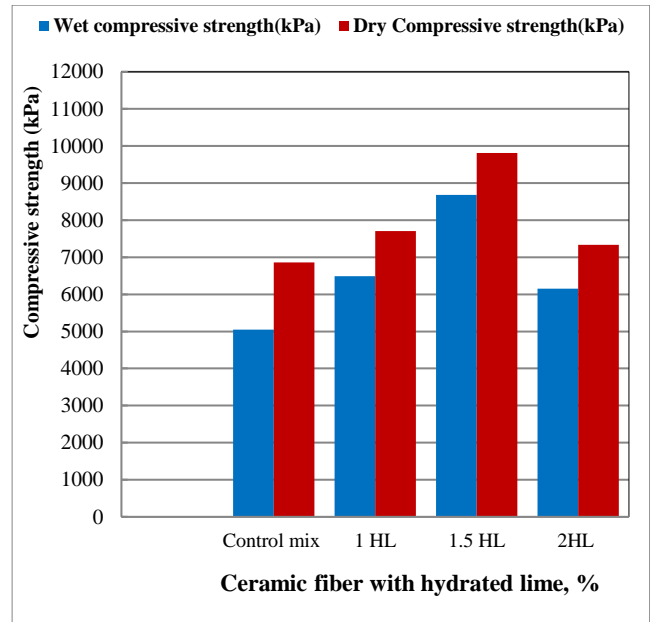
The values for dry compressive strength and wet compressive strength of mixtures that contain ceramic fibers with hydrated lime have been higher than those in the control mixture. The values of the dry and wet compressive strength were higher with 1% ceramic fiber than those with 0.5, 1.5, and 2% ceramic fiber. Samples containing 1, 1.5, and 2% hydrated lime, by weighing the total mixtures, with 1% ceramic fiber have higher values of the dry compressive strength than the mixtures of control. The mixture was stiffer into the specimen because the fibers have a random orientation in various directions, strongly connect particles within the matrix, and eventually stop them from moving. Moreover, given that the hydrated lime has a high surface area, the aggregate was plated with enough amount of the asphalt, and as a result, the adhesion force became higher between asphalt and aggregate and prevented the stripping beneath the influence of the moisture. As a result, the value of the IRS increased in a way that indicates the increment in the resistance of moisture of asphalt mixture together with the addition of ceramic fiber and hydrated lime. Where the addition of ceramic fiber and hydrated lime makes the asphalt mixture of a greater resistance for compression beneath the influence of the moisture. This leads to increasing the IRS which in turn leads to increasing the moisture resistance.

**Table 10: Results of Index of Retained Strength (IRS%) Tests.**

Additives	Additives, %	Dry Compressive Strength (kPa)	Wet Compressive Strength (kPa)	IRS (%)
Control Mix	0	6858	5052	73.67
Ceramic Fiber with Hydrated Lime	0.5 CF +1H	7325	5743	78.40
	0.5 CF +1.5H	8504	7005	82.37
	0.5 CF +2H	7590	6095	80.30
	1 CF +1 H	7704	6493	84.27
	1 CF +1.5 H	9807	8678	88.48
	1 CF +2 H	7338	6150	83.80
	1.5 CF +1 H	7046	5898	83.71
	1.5 CF +1.5 H	7576	6515	86.00
	1.5 CF +2 H	6931	5779	83.38
	2 CF +1 H	7064	5889	83.37
	2 CF +1.5 H	7201	6127	85.08
	2 CF +2 H	6927	5647	81.52



**Figure 8: Effect of Percentages of Fiber on the Dry and Wet Compressive Strength for (0.5% CF).**



**Figure 9: Effect of Percentages of Fiber on the Dry and Wet Compressive Strength for (1% CF).**



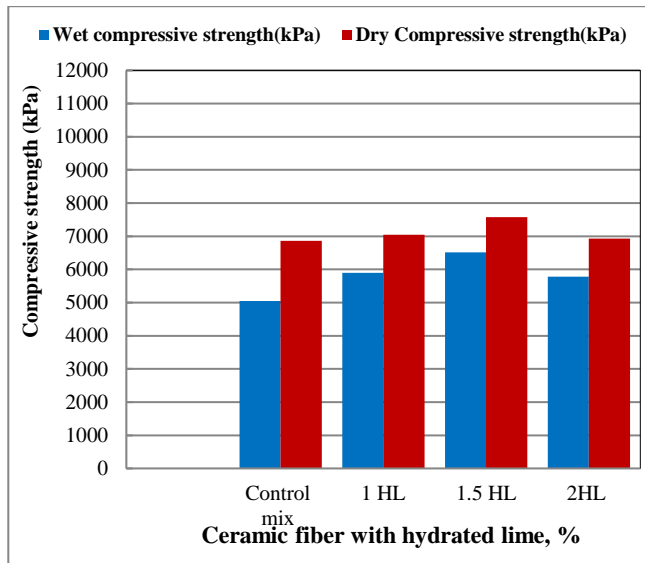


Figure 10: Effect of Percentages of Fiber on the Dry and Wet Compressive Strength for (1.5% CF).

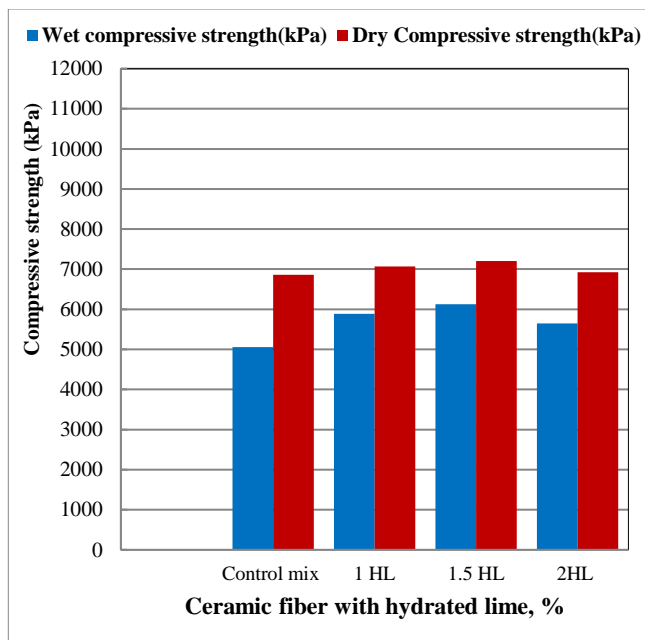


Figure 11: Effect of Percentages of Fiber on the Dry and Wet Compressive Strength for(2%CF).

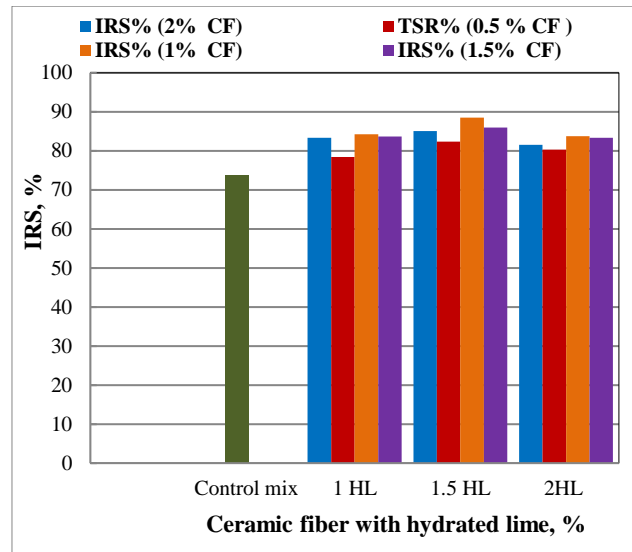


Figure 12: Effect of Fibers Content and Hydrated Lime Content on the IRS.

#### 4. CONCLUSIONS

According to the specification of substances and test result utilized in the present study, the following points have been concluded:

- The addition of ceramic fiber as a reinforcement and the hydrated lime as anti-stripping has led to a reduction in the moisture susceptibility of the asphalt mixture as a result of the excess in TSR values.
- The dry ITS, wet ITS, and TSR values were higher than the control mixtures for the asphalt mixtures containing ceramic fiber with hydrated lime for all percentages.
- The addition of 1% ceramic fiber with 1.5% hydrated lime has given the highest TSR which was 86.55 % compared with the control asphalt mixture that was 76.71 %.
- The results of the dry compressive strength, wet compressive strength, and IRS values were higher than the control mixtures for the asphalt mixtures containing ceramic fiber with hydrated lime for all percentages.
- The addition of 1% of ceramic fiber with 1.5% hydrated lime has also recorded the highest IRS, which was 88.48 % compared with the control asphalt mixture which has been 73.67 %.

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