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EVALUATION OF MOISTURE CHARACTERISTICS OF WARM MIX ASPHALT INVOLVING SYNTHETIC ZEOLITE

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KEYWORDS: Tensile strength ratio (TSR), moisture damage, synthetic zeolite, compressive strength, warm mix asphalt (WMA) and Superpave.

ABSTRACT
Warm mix asphalt (WMA) are mixed at temperatures ranging 20 – 50 °C lower than those in which called hot mix asphalt (HMA).

In this research, the effect of different percentage of synthetic zeolite on performance asphalt mixture in terms of water sensitivity. The best gradation of aggregate was selected and optimum asphalt content was determined according to Superpave design system. Superpave Gyratory Compactor (SGC) was used to compact asphalt samples with (100 and 150) mm in diameter. Five different percentages (3, 4, 5, 6 and 7) of synthetic zeolite were used for preparation warm mixes to compare with hot mixture.

However, there are indications that the use of synthetic zeolites as a warm mix asphalt additive for some percentages increases the moisture sensitivity of pavements except for 5% there is a slightly improve. The results of the study indicated that the selected percentages of synthetic zeolite to the warm asphalt differently effected on the mixture properties. Also the WMA mixture with 5 % of synthetic zeolite increased the punching strength of the mixtures and slightly increased in the tensile strength ratio (TSR), compressive strength and index of retained strength (IRS).

INTRODUCTION
In recent years, there has been increased awareness of environmental problems caused by the asphalt paving industry. Conventional HMA (Hot Mix Asphalt) production and pavements emit large amounts of greenhouse gases such as CO_2, CH_4 and N_2O, [1] as well as aerosols [2]. In order to decrease mixing and compaction temperatures and reduce the emission of harmful compounds, new technologies are used, such as WMAs (Warm Mix Asphalts) which allow temperature reduction of 20-40°C compared to HMA technology.

The mixing and compaction temperatures of WMA can be significantly lowered without affecting the quality of the mix, which means a great reduction in energy requirement and emissions (Kristjansdottir et al. 2007; Prowell et al. 2007).

In addition, under mixing temperatures of 100–140°C (212–280°F), the aggregate may not be completely dried (Prowell 2007; Xiao et al. 2009; Xiao et al. 2010a), and thus the mixture is prone to moisture induced damage.

Water causes loss of adhesion at the bitumen aggregate interface (Thomas, McKay, & Branthaver, 2006). Many variables affect the amount of moisture damage which occurs in an asphalt concrete. Some of these variables are related to the materials forming the asphalt such as aggregate (physical characteristics, composition, dust, and clay coatings) and bitumen (chemical composition, grade, hardness, crude source, and refining process).

Others are related to traffic conditions, type and properties of the additives, asphalt design and construction (temperature during laying and compaction) (Stuart, 1990). Various researches have recently been concentrated on the temperature effect during mixing, laying and compaction processes with the development of a new paving technology named as warm mix asphalt (WMA) (Porter, 2011).

Moisture susceptibility is also significant performance concern for WMA like conventional HMA. It has been thought that, because WMA is not heated to same high temperatures as HMA, the aggregate may not be completely dried before mixing (Dasa, Tasdemir, & Birgissona, 2012; Kvasnak et al., 2009). If the aggregate is not dry prior to mixing, the inherent moisture could prevent the bitumen from bonding with the surface of the aggregate, which could lead to stripping.

AIM OF THE STUDY

In light of the above, various binder properties and warm asphalt additive type affect the performance of the warm mix for example the moisture susceptibility. So a thorough understanding of the properties and performance of the warm mixture technologies is necessary in order to be able to implement WMA safely, especially since WMA is a relatively new topic in Iraq, and no thorough research has been conducted to investigate many aspects of warm asphalt. The current study aims to evaluate the influence of selected Synthetic Zeolite additive on mechanical properties of warm mix asphalt.

EXPERIMENTAL WORK

Materials

In the experimental work, asphalt binder of 40⁄50 penetration grade from Daurah refinery in Baghdad, Iraq was used, with the physical properties as in Table1.

The aggregate used in this work was crushed quartz supplied from Al-Nibaie quarry. Also the gradation for the aggregate is as shown in Figure 1. 12.5 mm used as a nominal aggregate size. The results related with the specification limits set by the SCRB are summarized in Table 2. Test results show that the chosen aggregate met the SCRB specifications.

The filler used in the experimental work is a non- plastic material that passing sieve No.200 (0.075 mm). The first type is the limestone dust which supplied from lime factory in Karbala governorate, south west of Baghdad. The second type is the Portland cement was provided from local market. The physical properties of the fillers are presented in Table 3.

Synthetic Zeolite used in this work was utilized as WMA additive is a hydrothermally crystallized white fine powder of sodium–aluminum–silicate crystal. It contains 21% water by weight into the warm mix causes the release of all the crystalline water and forming a very fine water spray and a volumetric expansion of bitumen. This volume expansion will increase the workability and the compatibility of the mixture at lower temperatures (Hurley et al., 2005). The additive percentages used in this study range from 3 - 7% by weight of the binder which was chosen based on the previous studies. The chemical composition and physical properties of the Synthetic Zeolite were prepared by the manufacturer as illustrated in Table 4.

Sample preparation

The production of the WMA mixtures is by dry process, WMA additive was heated and added to the asphalt then mixed by mechanical mixer for one hour at 179 °C to get required properties for mixing and compaction temperatures. The aggregate and asphalt were mixed in mixing bowl for several minutes until asphalt sufficiently coated the surface of the aggregates. The mixing temperatures corresponding to the asphalt binder. There is no standard specifications available for WMA mixing and compaction temperature in Iraq.

All examined asphalt concrete mixtures were prepared in accordance to the (ASTM Designation: D 6925-03) with the standard 160 number of gyrations for designing hot asphalt concrete mixtures, designated as using superpave gyratory compactor.

Table 1. The result of physical properties and standard limitation

Test	Test Conditions	Standard	Test value (measured)	Standard Limit according to SCRB /R9, 2003
Penetration	100 gm, 25°C, 5 sec., (0.1mm)	ASTM D5	47	40-50

Ductility	25°C, 5cm/min	ASTM D113	+120	+100
Softening Point		ASTM D36-95	53.5	
Specific gravity asphalt	25°C	ASTM D70	1.031	-----
Flash and fire points	…..	ASTM D92	Flash 291°C	> 232 °C
			Fire 305°C	-------
Loss on heating	163 °C, 50gm, 5 hr	ASTM D1754 Penetration	65	>55
		Ductility	55	>25
Rotational Viscosity	Pa.sec	ASTM D4402	0.369 @ 135°C 0.112 @ 165°C	

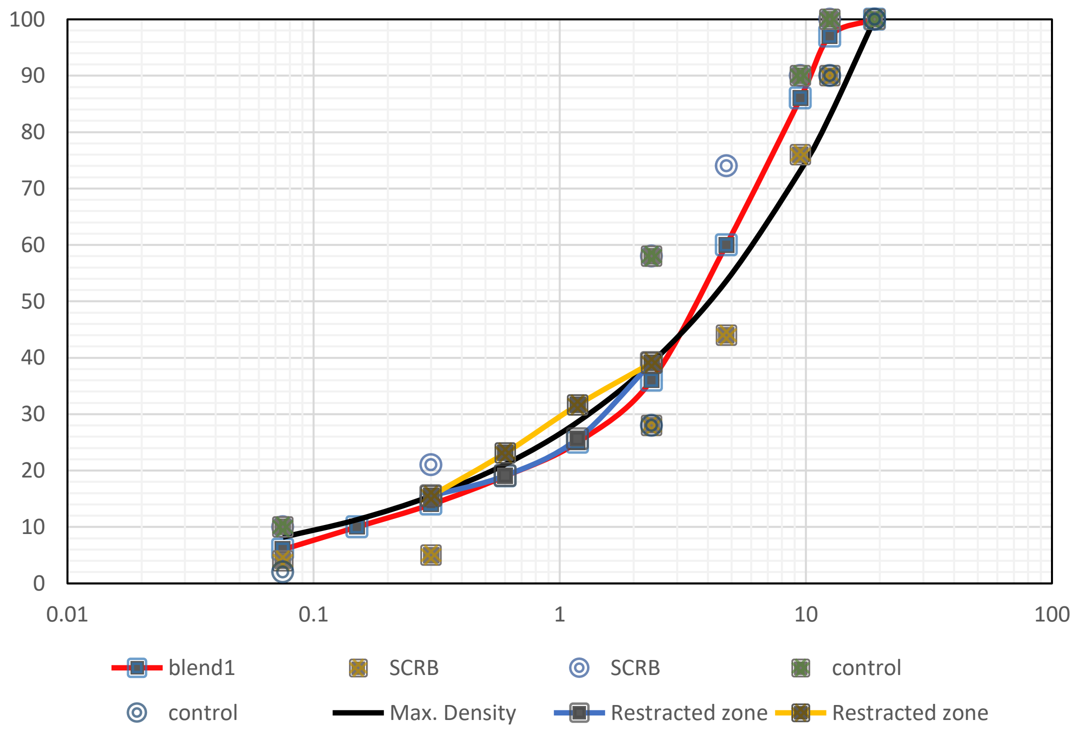

Figure 1. Gradation of the aggregates.

Table 2. Physical properties of aggregates

Property	ASTM Designation	Test results	SCRB specifications
Bulk specific gravity (Coarse agg.)	C 127	2.580	….
Apparent specific gravity		2.591	….
Bulk specific gravity (Fine agg.)	C 128	2.616	….
Apparent specific gravity		2.642	….
Percent wear by Los Angeles abrasion , %	C 131	21.3	30 Max.
Soundness loss by sodium sulfate solution,%	C 88	3.2%	12 Max.
Flat and elongated particles ,%	C 4791	2.5%	10 Max.
Degree of crushing, %	D 5821	97%	90 Min.
Sand equivalent, %	D 2419	89.6	45 Min

Table 3. Physical properties of Filler.

Property	Test Result
Portland Cement Filler	
Specific gravity	3.2
% Passing Sieve No.200 (0.075 mm)	97
Limestone Dust Filler	
Specific gravity	2.92
% Passing Sieve No.200 (0.075 mm)	94

Table 4. Physical properties and chemical structure of Synthetic zeolite.

Property	Test Result
Color	White
Shape	Powder
Diameter	325 Mesh
SiO_2	41.07 %
AL_2O_3	28.25 %
CaO	0.03 %
MgO	0.81 %
K_2O	0.21 %
Na_2O	0.05 %
Ti_2O	12.99 %
Bulk Density	0.5 gm/cm^3
PH	9.3
Water Content	21 %
Static H_2O Adsorption	25.9 %

TESTING PROGRAM

Many mixtures were prepared with limestone dust filler and Portland cement for control mix and warm mixture with different percentages of Synthetic Zeolite. All mixtures were evaluated with some tests:

Marshall and Volumetric Properties

The Marshall test was performed during the mix design according to the (ASTM Designation: D 6927-15). This test was performed at a temperature of 60 ºC and with a deformation rate equal to 51 mm/min (2 inch/min). The properties obtained from this test are the Marshall stability and Marshall Flow. The Marshall stability is define as the peak resistance load obtained during a constant rate of deformation loading sequence. The Marshall flow is the total sample deformation. Marshall Stability and Marshall Flow are reported in (kN) and in (mm) of deformation, respectively. Three specimens were tested and an average is reported and used in the analysis. Table 5. Shows the results of volumetric properties and the specification limits set by the SCRB/ R9.

Type of filler	Dosage of Zeolite (%)	Marshall Stability (kN)	Marshall Flow (mm)	Voids in total mix (%)	Voids in mineral aggregate (%)	Voids fill with binder (%)	Bulk density (gm/cm^3)
Portland Cement	0	14.29	3.1	4.0	15.87	74.80	2.338
	3	13.50	3.9	4.1	15.64	74.42	2.330
	4	14.00	3.7	3.6	15.48	74.16	2.336
	5	15.70	3.1	3.2	15.47	74.14	2.338
	6	13.30	3.5	2.7	15.46	74.13	2.339
	7	11.83	3.6	2.4	15.38	73.99	2.342
	0	12.00	3.4	4.0	15.75	74.60	2.329

Limestone Dust	3	11.10	4.0	4.2	15.38	73.99	2.325
	4	12.20	3.9	3.8	15.26	73.79	2.330
	5	13.40	3.2	3.3	15.20	73.68	2.333
	6	11.90	3.6	2.8	15.18	73.65	2.335
	7	10.60	3.8	2.5	15.17	73.63	2.336
SCRB specifications		**Min. 8 kN**	**(2 –4) mm**	**(3 – 5) %**	**Min. 14**	**(65-85) %**	---

Table 5. Marshall and volumetric properties of different asphalt mixture types

Moisture Damage of Asphalt Mixtures

To evaluate the moisture sensitivity of WMA mixtures, following AASHTO T283 was performed. Six specimens were prepared (three for dry condition and three for wet condition) for each percent of WMA mixture and the control HMA mixture. For dry condition the specimens in a sealed pack were placed in the water bath at 25 ºC for 2 hours and, for wet condition the specimens saturated between 55 % and 80% were placed in a freezer at -18 ºC for 16 hours and in water bath at 60 ºC for 24 hours followed by conditioning in water bath at 25 ºC for 2 hours. The moisture damage in asphalt mixtures is determined as a loss of strength due to the presence of moisture in terms of a tensile strength ratio (TSR) that is defined as a ratio of the indirect tensile strength of a wet specimen over that of a dry specimen.

Immersion–Compression Test:

In this test, two sets of three specimens were prepared for both recycled mixtures by using gyratory compactor, because field compaction can be simulated in a progressive way using this method of compaction. This test was conducted according to ASTM D1075. An air void content of 6 percent was attained. One set of specimens was tested for the compressive strength at 25.0± 1ºC without conditioning and the other set of specimens were conditioned by immersing them in water bath at 60.0 ± 1ºC for 24 hours. After conditioning, the set was transferred to another water bath where temperature was maintained at 25.0 ± 1ºC. After storing the specimens for 2 hours in this bath, the compressive strength of the each conditioned specimen was determined in accordance with ASTM D1074. A numerical index of resistance of bituminous mixtures to the damaging impact of water as the percentage of the main strength that was retained after the immersion period, which should be a minimum of 0.7 (or 70%) as adopted by (SCRB/R9, 2003) for surface course as follows:

$$Index\ of\ Retained\ strength = (S2/S1) * 100 \quad (1)$$

Where:
S1 = compressive strength of dry specimens (Set 1),
S2 = compressive strength of immersed specimens (Set 2).

Double Punch Shear Test:

This test was advanced at the University of Arizona by (Jimenez 1974) for measuring the stripping of the bitumen from the aggregates. Marshall Specimen was used for this test for all mixtures (warm and hot) and at the same manner utilized for mixing and compaction of stability and flow test specimens. A total of 36 specimens were prepared for punch shear test, (30) specimens for WMA and six for HMA mixtures. Specimens were conditioned by placing in water bath at 60 ºC for 30 minutes before testing. The test was conducted by centrally loading the cylindrical specimen which was placed between two cylindrical steel punches (25.4 mm in diameter) on the top and bottom surface of it, skillfully aligned one over the other, and then loaded at a rate of 25.4 mm/minute until failure. The maximum load resistance was recorded.
The punching strength was calculated by the equation (Farouki, O.T. and Rolt, J., 1985):

$$\boldsymbol{\sigma t} = \frac{P}{\pi(1.2bh - a^2)} \quad (2)$$

Where:
σt = Punching shear stress, Pa.

P = Maximum load, N.
a = Radius of punch, mm.
b = Radius of specimen, mm.
h = Height of specimen, mm.

RESULTS AND DISCUSSION

Figure 2 shows the result of tensile strength ratio (TSR) for the both mixes with limestone dust and cement as filler respectively .Result shows that TSR for warn mixture with both limestone dust and cement is gradually increased and decline after warm mix asphalt with 5% synthetic Zeolite, which is similar to control mix.

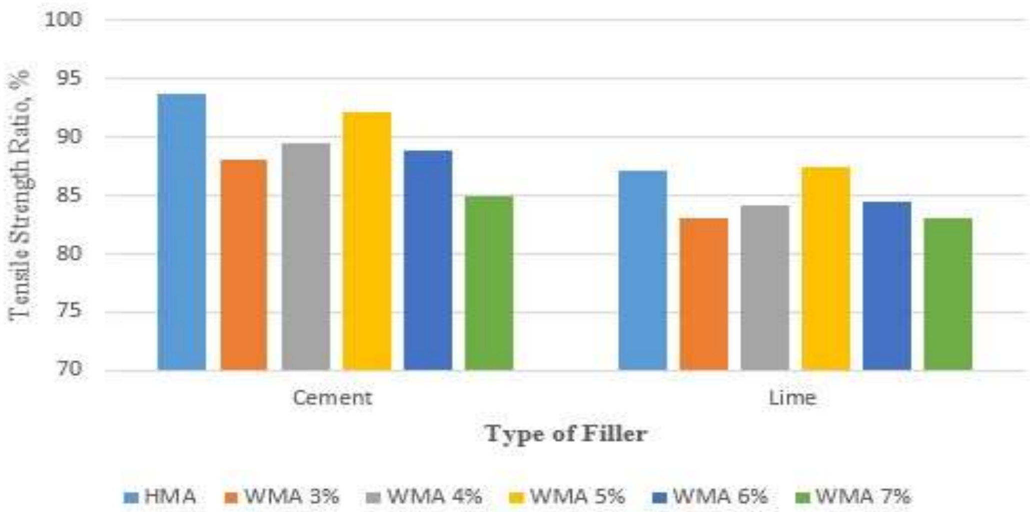

Figure 2 Tensile strength Ratio

Fig.3 showed the result of Punching Shear for both mixes, it is observed that the value of punching shear of warm mixture is higher than control mix and it is increase as increase in Zeolite percent up to 5%.

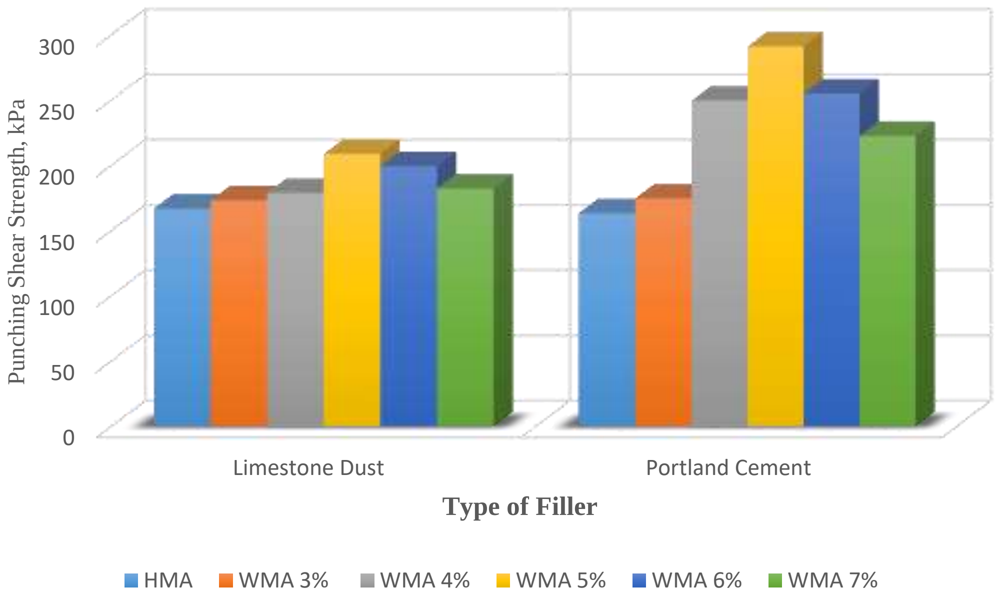

Figure 3 Punching shear

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It could be noticed from Figure 4 that the highest compressive strength at 5 % Synthetic Zeolite with (4550.8 kPa) and the lowest value at 7 % Synthetic Zeolite with (4290.8 kPa) for dry condition. While in wet condition the highest value (4212.0 kPa) for 5 % Synthetic Zeolite and the lowest value (3304.5 kPa) for 7 % Synthetic Zeolite.

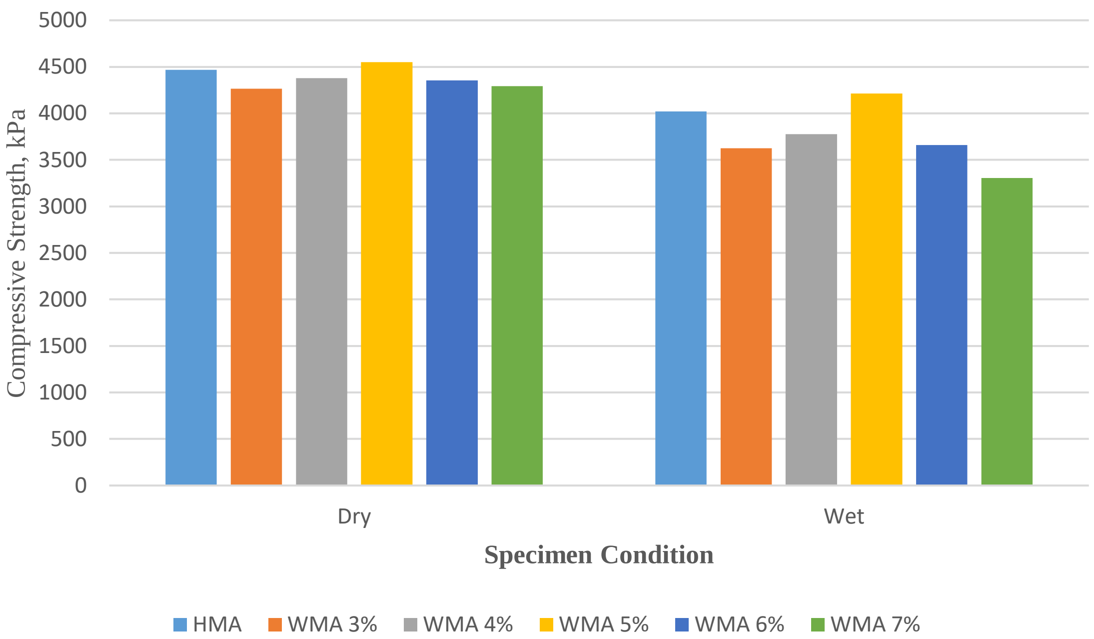

Figure 4 Compressive strength for mixtures with cement filler

Figure 5 shows that 5% of Synthetic Zeolite improved Compressive strength by increasing to 9.4% and 5% for dry and wet condition respectively.

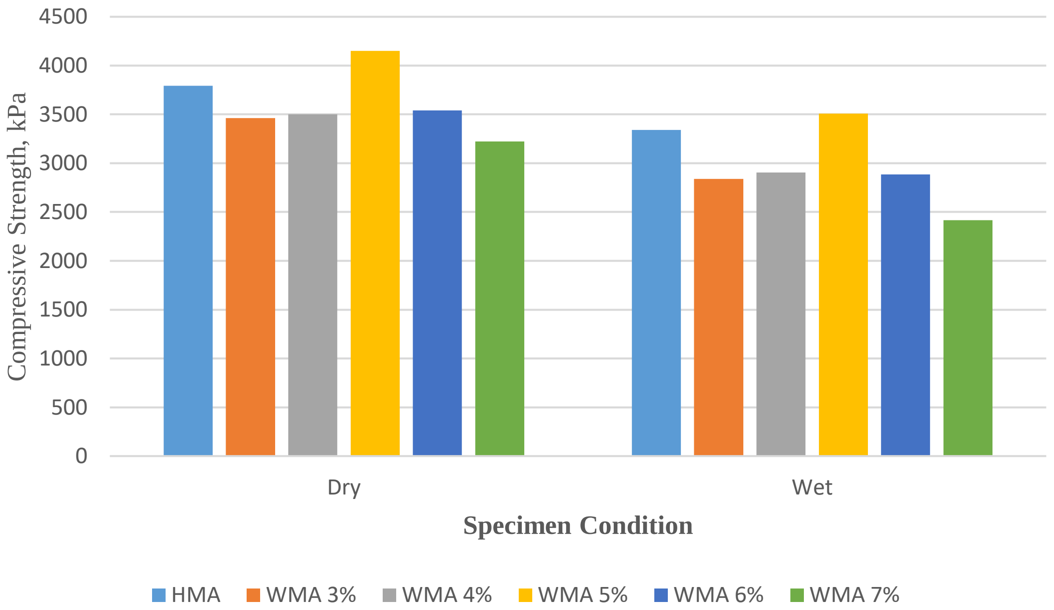

Figure 5 Compressive strength for mixtures with limestone dust filler

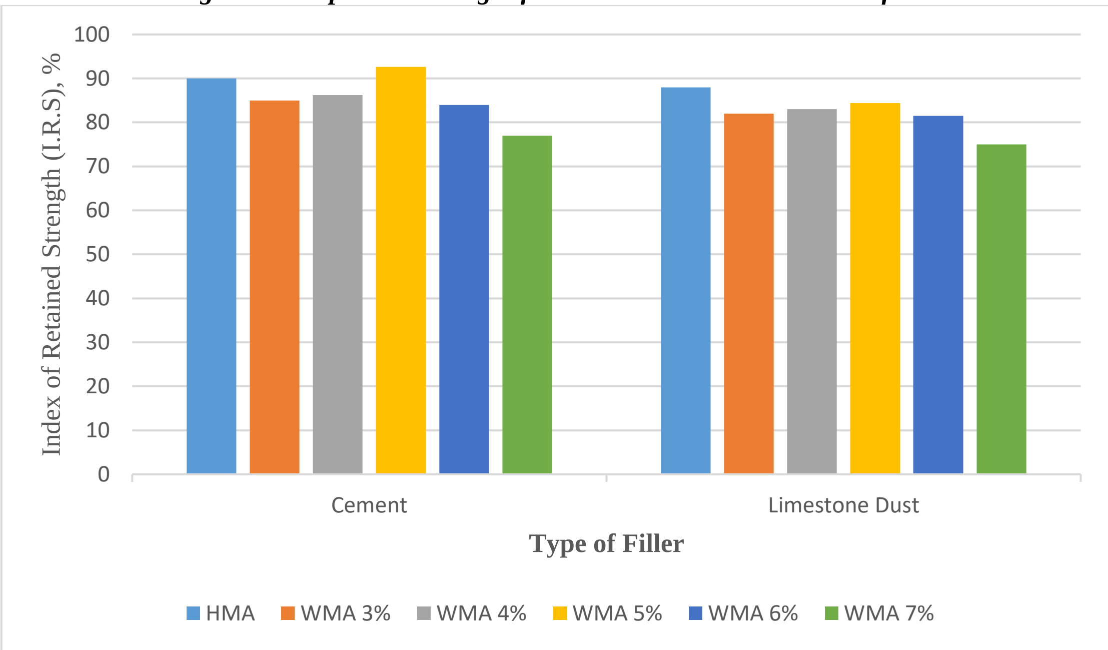

Figure 6 Index of Retained Strength Results for Mixtures

Index of Retained Strength (I.R.S) is a reference for mixture impedance to water damage. It is obtained as the ratio of average compressive strength of conditioned specimens (wet) to that of unconditioned (dry) specimens in each category.

Figure 6 shows that I.R.S for WMA was slightly higher than HMA by 2.9%, which indicates that these mixtures were less susceptible to water damage as compared to HMA.

All of (I.R.S) values for both mixtures exceeded the target of (SCRB /R9, 2003) for binder course which was 70%.

CONCLUSION

Based on laboratory for test for Hot and Warm mixtures the following conclusion can be drawn:

1. Compressive strength for condition and unconditional samples increase with increase Synthetic Zeolite percentages up to 5%.
2. For all of the mixtures (hot and warm) with different percentages of Synthetic Zeolite, the mixture with 5% Synthetic Zeolite is better.
3. Tensile Strength Ratio (TSR) for warm mix asphalt mixtures with 5% of Synthetic Zeolite are similar to control mix.
4. The warm mix asphalt mixtures with cement filler has the highest strength than these with limestone dust filler.

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