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EFFECTS OF COMPACTION EFFORTS ON TENSILE STRENGTH CHARACTERISTICS AND DURABILITY OF WARM-ASPHALT MIXTURE CONTAINING NATURAL AND SYNTHETIC ZEOLITE

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ABSTRACT

Many studies have been conducted to evaluate the mechanical properties of warm-mix asphalt (WMA) mixtures using Natural Zeolite (NZ) and Synthetic Zeolite (SZ) without considering the impact of compaction efforts. In this study, the influence of compaction cycles on the mechanical characteristics of WMA mixtures including NZ & SZ additives, is studied and compared with hot mix asphalt (HMA) mixtures. The amount of NZ and SZ used to make the WMA mixes was 5% of the whole asphalt mass. For the research, six WMA mixtures with a penetration grade of 40-50 were designed and compared to HMA traditional mixture. HMA &WMA mixtures were designed with 35, 50 and 75 compaction efforts. Mechanical and durability experiments were performed on HMA and WMA mixtures, involving Marshall stability, Marshall quotient, static indirect tensile strength at 25 and 60°C, and tensile stiffness modulus at 25 and 60°C. Calculating the tensile strength ratio (TSR) to study the moisture susceptibility of the mixes was used to assess their durability. The study indicates that compaction efforts had a considerable impact on the performance of the mixtures. The Natural Zeolite of WMA & Synthetic Zeolite of WMA mixtures display lower Marshall stability and Marshall quotient with greater tensile strength and tensile strength ratio than HMA mixture for 35, 50 and 75 compaction efforts. Increased compaction efforts result in a greater reduction in mechanical and durability characteristics of WMA. The flow values of NZWMA and SZWMA mixtures are larger than HMA mixtures indicating higher strain capacities to achieve failure. All NZWMA and SZWMA mixtures achieve the SCRB standard specifications of 8kN stability, 2-4mm flow, 14 percent VMA, and 85 percent TSR when using the same optimum binder content. Furthermore, the NZAC mixtures show higher performance than SZAC mixtures in terms of stability and strength.

KEYWORDS: Warm mix asphalt; Natural Zeolite; Synthetic Zeolite; Compaction Efforts; Tensile strength; Tensile stiffness modulus; Durability.

1. INTRODUCTION

Warm-mix asphalt (WMA) technologies for the manufacturing of asphalt pavement have lately achieved widespread favor globally, especially in USA. This is owing to the numerous advantages of using WMA. When compared to conventional hot-mix asphalt (HMA) pavements, WMA pavements create asphalt at a lower temperature. Various approaches, such as the use of chemical additives, organic additives, and water-based foaming processes, can be used to achieve this process [1]. The temperature of asphalt mixtures manufacturing can be reduced by 16.7–55.6°C depending on the technology utilized [2], resulting in a range of economic, environmental, and construction benefits. In addition, when compared to HMA, the lower production temperature in WMA pavements can contribute to lower aging levels [2]. In one hand, this may cause rutting, but on the other hand, it may increase cracking resistance during the pavement's service life [3].

Number of researches have been undertaken in recent years to evaluate the influence of natural zeolite & synthetic zeolite and petroleum wax on asphalt mix characteristics with taking no aging into account [4-9]. The impacts of WMA additives (such as Sasobit®, Zeolite®, PAWMA®, and Kaowax®) and recovered asphalt pavement (RAP) materials on the mechanical and durability performance of HMA were investigated by Yousefi et al. [5]. As

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control mixtures, the characteristics of WMA & HMA containing 50% RAP were evaluated. Following that, the impact of WMA additions on the characteristics of each kinds of mixes with or without RAP were studied. At 25 °C, indirect tensile stress was applied, resilient modulus was measured at many temperatures of 5 °C, 25 °C, and 40 °C, dynamic creep was measured at 54.4 °C, and semi-circular bending fracture was measured at 25 °C. These experiments were carried out to assess the asphalt mixtures' mechanical properties, while the tensile strength ratio (TSR) was employed to assess the durability of WMA additions enhance asphalt mixture fracture energy, allowing up to 50% of RAP to be included in asphalt mixtures without affecting their mechanical performance, as indicated by the results. In the study, it was found that the fracture energy value of asphalt mixtures may be increased by up to 50% by adding WMA additives, without affecting the mechanical properties of the asphalt. In semi-circular bending experiment for each type of mixtures, with or without RAP. Zeolite-containing mixtures had the greatest strain energy values in both types of mixtures. In addition, the reduction in TSR values was observed in mixtures with Zeolite [5].

Valdes et al. [6] WMA mixtures including Chilean Natural Zeolite (clinoptilolite-modernite kind), also WMA mixtures having natural Zeolite and various quantities of RAP, were investigated for mechanical performance and practicality. The study used all five WMA mixtures as well as one HMA traditional mixture. 0.3 and 0.6 percent natural zeolite were used in two WMA mixes, which were tested. It was decided to use 0.6 percent natural Zeolite in the rest three WMA combinations with 10 percent, 20 percent, and 30 percent RAP in each, respectively. Stiffness modulus, resistance to cracking, moisture sensitivity, rutting resistance, and fatigue performance were among the mechanical characteristics studied. According to the findings, WMA mixtures including natural zeolite can be produced at a low temperature than conventional HMA by as much as 20°C. WMA mixtures with just natural Zeolites, on the other hand, have the same cracking resistance to the HMA mixture with same bending values. Similarly, recycled asphalt mixtures made with natural Zeolite and produced at a lower temperature displayed good performance characteristics for producing a long-lasting pavement.

De Visscher et al. [7] researchers had studied the influence of adding zeolite on asphalt mixtures properties by making tests of permanent deformation and moisture damage on field work and lab samples. They discovered that zeolite material has the capability to decrease the temperature of asphalt mixture at 30°C, in which at the same time there is no problem concerning permanent deformation and moisture Susceptibility for the performance of asphalt mixture on the short term.

Sengöz et al. [8,] In comparing to conventional HMA a zeolite-modified asphalt mixture made at 140°C had greater fatigue life and a similar permanent deformation as the conventional HMA. Wax-modified mixtures, on the other hand, performed badly relating to rutting and fatigue than Zeolite-modified mixtures. Sengöz et al. Warm modified mixes containing natural and synthetic Zeolite were also evaluated for moisture damage. Warm asphalt mixtures using synthetic zeolite couldn't increase moisture sensitive resistance when compared to mixtures having natural zeolite, according to the findings.

Al-Araji [9] looked at how warm asphalt mixtures' moisture damage and permanent deformation performance changed when synthetic Zeolite was added. Zeolite was shown to enhance the density and reduce air voids in asphalt mixtures when used in synthetic Zeolite. On the other hand , it has been stated that WMA can be used to pave in lower temperature because the resulting temperature was reduced by 25° C compared to HMA.

Droge [10] and Hurley and Prowell [11] Using gyratory and vibratory techniques, researchers investigated the influence of zeolite on the volumetric characteristics of asphalt mixtures and the needed compaction. In terms of air voids, the zeolite-modified mixture was lower than the traditional HMA, indicating that Zeolite has the potential to enhance the volumetric characteristics of asphalt mixtures.

Vaitkus et al. [12] Depending on stability, flow, and moisture sensitive to the foam, chemical, and organic technology dosages were evaluated in a study conducted. Dosages of (NZ) & Asph-min were utilized as agents for foaming (0.1 percent to 0.4 percent). Cecabase and Iterlene, on the other hand, were used as chemical additions in concentrations ranging from 0.1% to 0.4% of the binder weight. A dosage of 1 percent to 2.5 percent of binder weight of Sasobit and Rediset WMX was also utilized as an organic additive. All WMAs were made at 120°C, whereas the control HMA was made at 150°C. The optimal foamy, chemical, and organic dosages were found to be (0.3 percent, 0.3 percent, and 2 percent, respectively). In comparison to HMA, these techniques produced better results in terms of minimizing gas emissions, decreasing the energy needed to make asphalt mixture, and enhances the employees safeness in this field.

Marinkovic et al. [13] natural and synthetic Zeolite were both examined in depth in the study. The authors employed varying concentrations of both natural and manufactured Zeolite in the studies (0.3 percent, 0.4 percent, 0.5 percent ,0.6 percent and 0.7 percent). The optimal dosage was determined by the use of softening point , penetration, and Rolling Thin-Film Oven testing. Overall, Zeolite demonstrated the ability to lower production and compaction temperatures. Natural and synthetic Zeolite were determined to have the best production and compaction temperatures. Synthetic Zeolite outperforms natural Zeolite, as well, according to the report's results.

In view of the previous considerations, most research on natural Zeolite (NZ) & synthetic Zeolite (SZ) additives used in WMA mixtures, to the author's knowledge, concentrate on the fulfillment requirements of NZ and SZ mixtures regardless to the effects of compaction efforts. As just a result, it may be beneficial to explore the impact of compaction efforts on the characteristics of NZWMA and SZWMA mixtures, as well as to compare them to HMA mixtures.

2. Methodology and Research Objectives

Although studies on the topic of using NZ and SZ on asphalt paving mixtures has been reported in several studies [4-6], more studies are still required. The current research purposes to study the influence of compaction efforts on the performance of NZ and SZ warm- asphalt mixtures such as Marshall test (ASTM D 6927) [14], indirect tensile strength at 25 °C and 60 °C (ASTM D7369) [15], tensile stiffness modulus at 25 °C and 60 °C, and moisture sensitivity (ASTM D7369), and the results were compared with the HMA reference mixture. Fig. 1 illustrates the methods used to accomplish the study's research objectives.

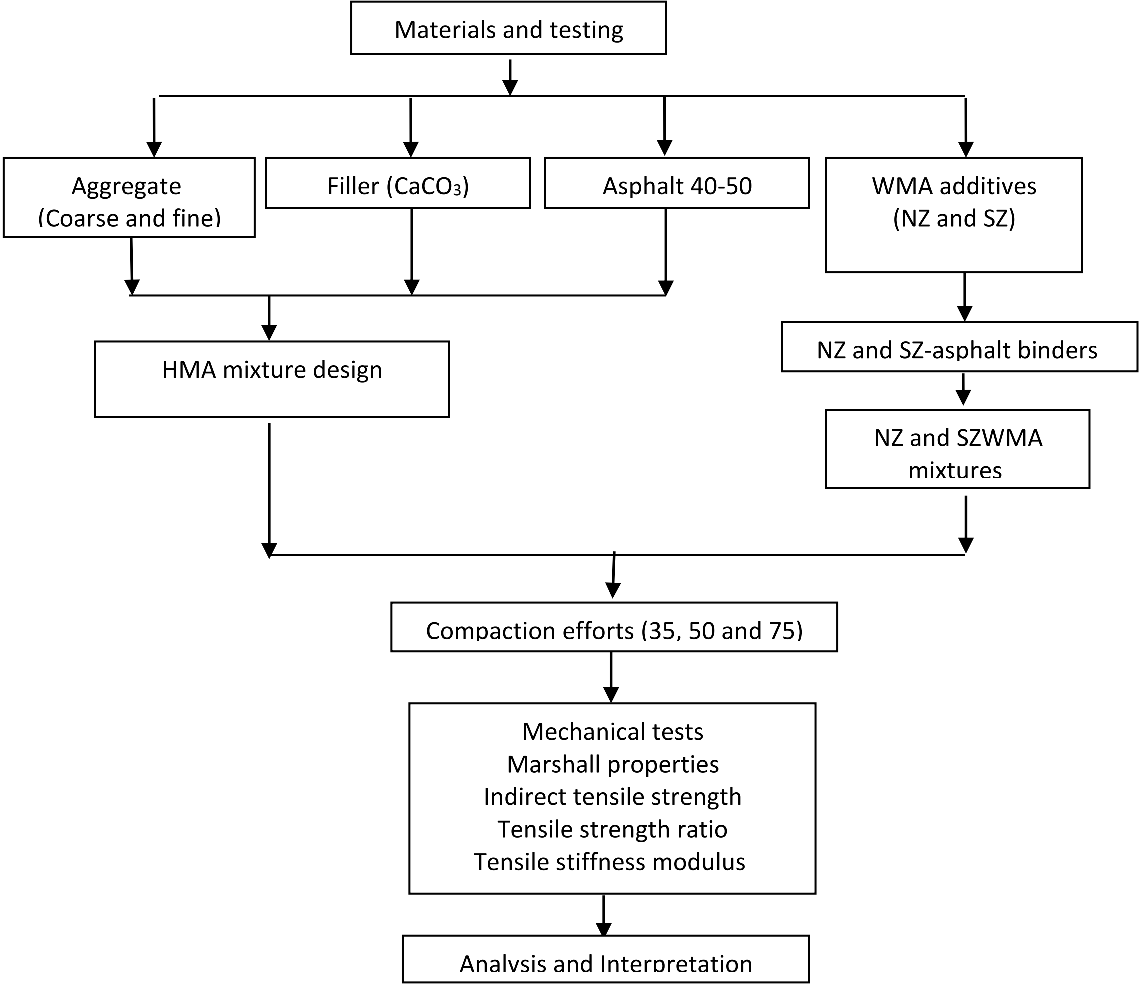

Fig. (1): Flow chart of experimental work of the study

3. MATERIALS

3.1. Aggregates

For the aggregate, employees in Dohuk city carried river sand and crushed gravel from the Kashe hot mix plant (located nearby). There is a significant concentration of silica in the sedimentary rock that makes up this gravel. In Iraq's northern highway development projects, this kind of aggregate is readily available and commonly employed. The aggregates' tested qualities, including as toughness, angularity, water absorption, soundness, and specific gravities, are listed in Table 1. As a reference filler material, calcium carbonate ($CaCO3$) from the Kashe hot mix facility (located in the Duhok-Iraq) was used. Calcium carbonate had a specific gravity of 2.75 after passing through sieve number (200).

Table (1): Source and consensus properties of aggregate

Property	ASTM No.	Coarse Agg	Fine Agg	ASTM limits [17]
Toughness (%)	D-131	19.8	-	40 max.
Angularity (%)	D5821& C-1252	95.7	43.0	55 min. (Coarse agg.) 40 min. (Fine agg.)
Soundness, Na_2SO_4 (%)	C-88	0.91	0.68	10 max.
Water absorption (%)	D127 & D-128	0.987	1.40	4.0 max.
Bulk sp .gr.	D127 & D-128	2.666	2.646	-
Apparent sp .gr.	D127 & D-128	2.739	2.748	-

3.2. Asphalt cement, Natural zeolite and Synthetic zeolite

The asphalt cement utilized in this study came from the Kwashi oil refinery (located in Erbil-Kurdistan region of Iraq). The asphalt cement had a penetration grade of 40-50. This asphalt grade is mainly used in the pavement design of roadways around the United States. The physicochemical parameters of 40-50 penetration grade asphalt are summarized in Table 2. The experiment employed NZ and SZ warm asphalt additives to create NZ and SZ warm mix asphalt (NZWMA) and (SZWMA) binders. The physicochemical parameters of NZ and SZ are summarized in Tables 3 and 4, respectively. The additive concentration for NZ and SZ-WMA (in powder form) was set at 5% wt. of asphalt. The providers' recommendations are used to determine how to use this content.

Table (2): Rheological properties of asphalt cement

Property	Results	NCCL limits [21]
Penetration (25 deg. C,100gm,5 s,0.1mm)	42	40-50
Softening point (ºC)	52.4	51-62
Ductility (25 °C, 50 mm/min, cm)	>150	-
Specific gravity (25 ºC/25ºC)	1.03	-
Flash point (ºC)	300	232 min.
Fire point (ºC)	315	-
Loss on heat (5hrs, l63 deg. C, %)	0.113	0.75 max.
Retained Penetration % of original (25 deg. C,100gm,5 s,0.1mm)	62	55 min.
Residue Ductility (25°C, 50 mm/min, cm)	53	25 min.
Rotational viscosity at 135°C, cP	578	3000 max.
Asphaltenes (%)	27.6	--

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Table (3): Physicochemical characteristics of NZ

Characteristics	NZ*
Ingredients	Na2O.Al2O3.2SiO2.XH2O
SiO2 (%)	39.46
Al2O3 (%)	28.35
Na2O (%)	13.16
CaO (%)	0.26
MgO (%)	0.26
Fe2O3	0.84
K2O	0.29
Loss of ignition (%)	15.13
Surface area (m2/g)	7.7
Apparent density (g/cc)	0.730
Water absorption (%)	18.5
Porosity size	0.32

*****As provided from Areej Al-Furat supplier.

Table (4): Physicochemical characteristics of SZ

Characteristics	SZ*
Model name	Y zeolite
Density, g/cc	0.45-0.55
PH	3-5
Color	White
Purity, %	100

*****As provided from supplier

This WMA additive mixture (NZ and SZ) was mixed for 15 minutes at a 1500 rpm-speed stirrer at 130°C to achieve the Saybolt-Furol viscosities [5, 16]. No separation occurs between asphalt binder NZ and SZ when it is warmed to 130°C [16]. NZ &SZ asphalt binders were then removed from the container, separated into small cans, warmed to lab temperature, roofed with aluminum foil, and stored for Furol viscosity testing in accordance to ASTM D88 [17]. The mixing and compaction temperatures of natural zeolite & synthetic zeolite asphalt binders were determined by measuring the furol viscosity of natural zeolite and synthetic zeolite asphalt binders with a Saybolt-Furol viscometer at various temperatures. According to the Asphalt Institute guidebook [18], these temperatures result in Saybolt-Furol viscosities of 85 and 140 seconds, respectively. Saybolt-Furol viscosities indicate that NZ and SZ asphalt binders decreased hot-mix asphalt mixing temperatures by 24 & 26 degrees Celsius, respectively, while compaction temperatures were decreased by 20 and 22 degrees Celsius. These findings are consistent with those studied by Ali Topal et al. [19], who found that mixing and compaction temperatures can be kept to a minimum between 20 and 30°C. Table 5 summarizes the physical characteristics of natural zeolite and synthetic zeolite asphalt binders.

Table (5): Physical properties of NZ and SZ-asphalt binders

Property	Results	
	NZ	SZ
Penetration (25 deg. C,100gm,5 s,0.1mm)	39	44
Softening point (ºC)	50.2	54
Ductility (25 °C, 50 mm/min, cm)	145	>150

4. EXPERIMENTAL METHODS

4.1. Mixture design

The study employed a dense asphalt mixture type D5 that met ASTM D3515 specifications [20]. With the addition of CaCO3 filler, aggregate was sieved into various sizes to approximate the mid-range of the ASTM D3515 gradation limitations for surface courses [20]. The gradation of the combined aggregate with filler is shown in Fig. 2. The Marshall Method [14] was used to design the asphalt mixture. To meet the NCCL [21] and ASTM specifications [20], an analysis of air voids (percent), flow (mm), stability (kN), and voids in mineral aggregates (percent) was carried out, yielding an optimum bitumen content (OBC) of 5.08 percent on aggregates weight for an HMA (control) traditional mixture containing 5% CaCO3 filler. The mixing and compaction temperatures for NZWMA and SZWMA mixtures were determined to be 130+5 and 128+5ºC and 118+5 and 116+5ºC, respectively. The viscosity-temperature relationship was tested to determine these values.

This OBC was utilized in the fabrication of all NZ and SZ asphalt mixtures investigated in this work to preserve consistency throughout the study. Three HMA, three NZWMA, and three SZWMA mixtures at three distinct compaction efforts (i.e. 35, 50, and 75 Marshall blows) were selected after a mixture design procedure in which the variables of NZWMA, SZWMA binders, and compaction efforts were examined.

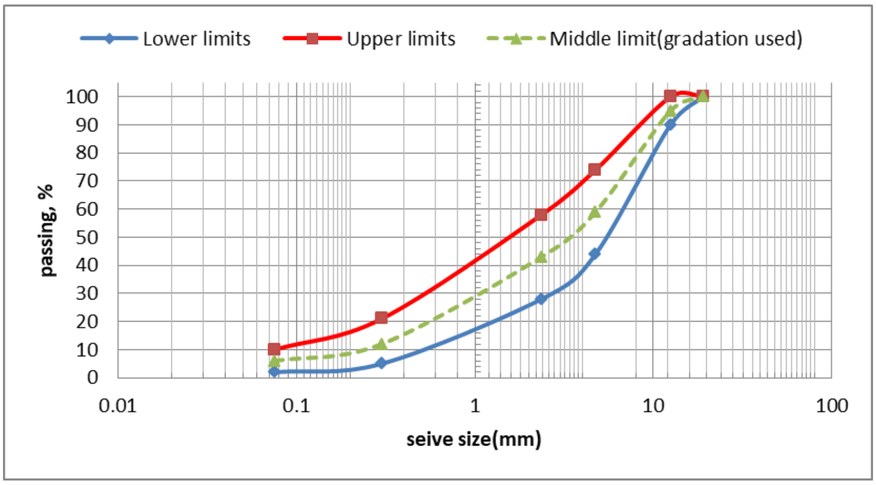


Fig. (2:) Aggregate gradation

4.2. Marshall stability and flow tests

Marshall stability and flow experiments for HMA (control), NZWMA, and SZWMA mixtures were performed on compacted specimens according to ASTM D6927 [14]. The Marshall test is an experimental examination in which cylindrical compacted specimens with a diameter of 100 mm and a height of rounding 63.5 mm are submerged in water at 60°C for 30-40 minutes before being loaded to failure with curved steel loading plates along a diameter at a stable rate of compression of 51 mm/min. The greatest force measured during compression is the Marshall stability value in (kN), whereas the deformation measured at maximum force is the flow in (mm).

The Marshall quotient (MQ) (kN/mm) is the ratio of stability (kN) to flow (mm) and indicates the stiffness of the mix. In Draft BSEN 12697-34: Bituminous mixtures examination procedures for hot mix, the MQ has been restored. Part 34 of the Asphalt series is the Marshall exam. BS 598-Part 107 [22] will be superseded by the aforementioned BS.

4.3. Tensile characteristics and moisture susceptibility tests

Bitumen stripping (separation of bitumen from aggregate) is linked to mixes that are sensitive to long-term moisture degradation. In dense Asphalts or Macadams with little void content, stripping is unlikely. There is a risk of stripping in water-permeable materials, even if they are reasonably dense, causing a reduction of internal cohesiveness and probably disintegration of the flattening. The linking between the aggregate and the bitumen, as well as the aggregate's capability to combat the displacing action of water, determines the possibility for stripping.

Immersion mechanical testing entail determining how a compacted bituminous mix changes mechanically after being submerged in water. As a result, an indirect measure of stripping is the proportion of the property after immersion split by the original property. The indirect tensile strength (ITS) is perhaps the most common; the tensile strength ratio (TSR) is the ratio of the ITS of bituminous samples after wet conditioning to identical samples not exposed to the conditioning procedure and is usually expressed as a percentage.

According to ASTM D6931 [15], indirect tensile strength (ITS) was utilized to analyze the tensile properties and moisture damage of the HMA, NZWMA, and SZWMA mixture. The mixes were compressed to a 7.0 percent average air void content. The HMA, NZWMA, &

SZWMA samples were separated into two subsets for the ITS test: unconditioned (U) and conditioned (C). The unconditioned specimens were kept in a water bath at 25°C for 2 hours, while the conditioned specimens were held in a water bath at 60°C for 24 hours before being returned to 25°C for 2 hours. The samples were then tested at a rate of 51 mm/min on Marshall equipment until they failed. The maximum load at which the sample will fail has been determined, and ITS has been calculated by equation (1).

indirect tensile strength (ITS) = $2P / \pi dt$ ……………... (1)

Where indirect tensile strength (ITS) in (N/mm^2), maximum load (P) in (N), specimen thickness (t) in (mm), and specimen diameter (d) in (mm).

Tensile strength ratio (TSR) of conditional (C) to unconditional (U) group was calculated from ITS test at 25ºC as given in Equation. (2).

Tensile strength ratio (%) = ITSC / ITSU × 100 ………….(2)

Where ITSC and ITSU are the conditional and unconditional indirect tensile strengths (N/mm2), respectively. The stiffness modulus of the road base and base course layers is regarded as a critical performance feature. It is a measurement of the bituminous wearing load-spreading ability and regulates the degree of traffic-generated tensile strains at the underside of the road foundation, which cause fatigue cracking, as well as the compressive strains induced in the subgrade, which can cause permanent deformation. The stiffness modulus is known as the ratio of the maximum stress to the maximum strain under uniaxial loading. The TSM in (N/mm2) was estimated at 25°C and 60°C using the maximum values of the applying vertical load and the average value of the horizontal deformation Equation (3).

TSM= [P (μ+0.27)]/Dt]……………………...(3)

Where the maximum applied vertical load (P) in (N), the average horizontal deformation (D) in (mm), the average test specimen thickness (t) in (mm), and the Poisson's ratio (μ) is (a value of 0.35 is normally utilized).

5. TEST RESULTS AND DISCUSSIONS

The above characterization tests were carried out at the optimum binder content value for each mix type and each result is from an average of three test specimens.

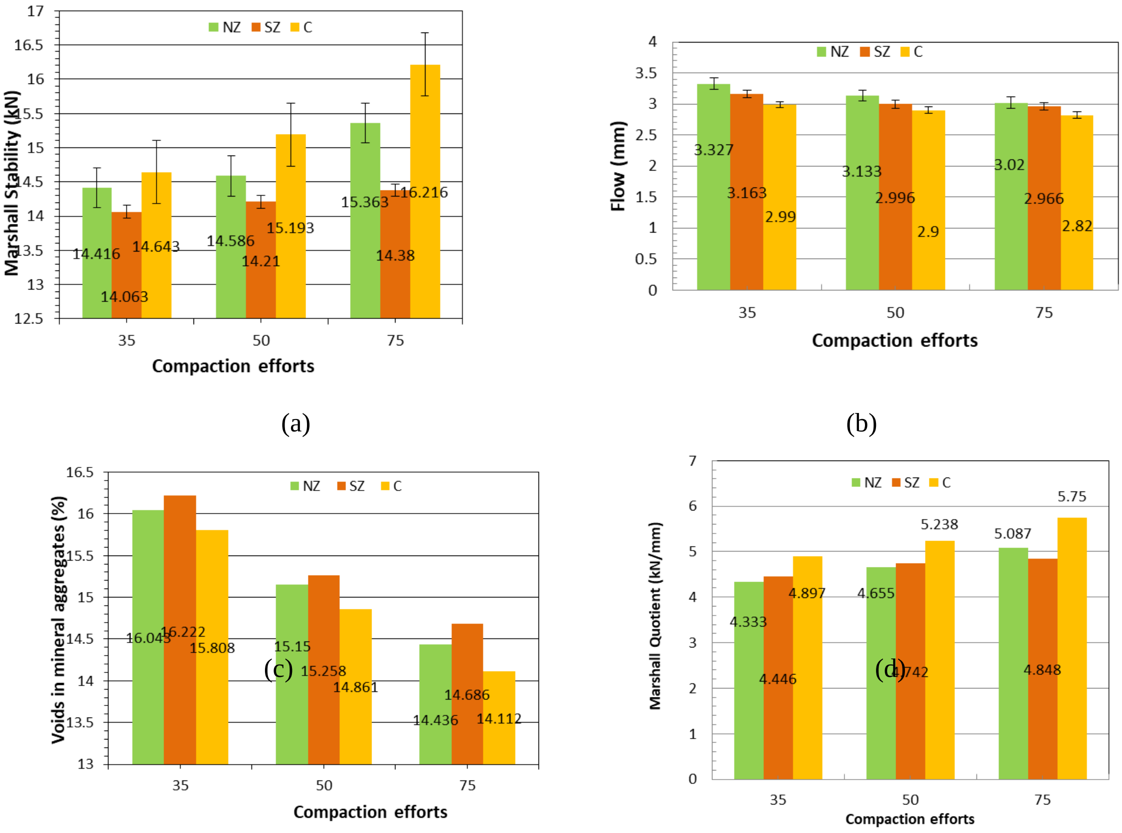
5.1. Marshall stability, flow and Marshall quotient

Marshall stability, flow and Marshall quotient of hot mix asphalt (control), natural zeolite of WMA & synthetic zeolite of WMA mixtures for 35, 50 and 75 compaction efforts are displayed in Fig. 3. From Fig 3, it able be seen that the natural zeolite (WMA) & synthetic zeolite (ZWMA) mixtures display decrease in Marshall stability (Fig. 3a) and Marshall quotient (Fig. 3d) values compared to the hot mix asphalt mixtures. The natural zeolite(WMA) & synthetic zeolite (ZWMA) mixtures display a reduction 1.5% and 4%, 4% and 6.5%, and 5.3% and 11.3% in stability values for 35, 50 and 75 compaction efforts, respectively. In addition, these mixtures display slightly greater flow values (Fig. 3b) for all compaction efforts when compared with AC mixtures.

Conventional dense graded mixtures normally show high Marshall quotient (MQ) values indicate a high stiffness mixture with a greater capability to spread the supplied load and combat creep deformation. concern must be exercised with very high stiffness mixtures a result of their lesser tensile strain capacity to failure i.e. such mixtures are more probable to fail by cracking specially when laid over basis which be unsuccessful to provide suitable support. Though the Marshall stability of NZWMA and SZWMA mixtures is lower than the AC control mixtures, the flow values of NZWMA and SZWMA mixtures are also larger indicating higher strain capacities to obtain failed. The value of MQ of NZWMA and SZWMA mixtures is lower than AC control mixtures. It is well recognized that the MQ (a form of pseudo stiffness) is a measure of the material's resistance to shear stresses, permanent deformation and hence rutting [23].

In comparison to HMA mixture, results obtained from NZWMA and SZWMA mixtures show a decrease by about 13% and 9.2%, 11.2% and 9.5%, 11.6% and 15.7% in MQ values for 35, 50 and 75 compaction efforts, respectively. The reduction in MQ is related to the lower stability and higher flow values of NZWMA and SZWMA mixtures. Overall, NZWMA and SZWMA mixtures for all compaction efforts accept the lower ASTM requests of 8kN stability, 2-4mm flow, and 14% VMA (Fig. 3c).

With regard to the WMA mixtures, NZ mixtures show higher stability than SZ mixtures for all compaction efforts. NZ mixtures show 2.5%, 2.6% and 6.4% increase in stability value, for 35, 50 and 75 compaction efforts, respectively. Furthermore, these mixtures depict lower Marshall quotient than SZ mixtures for 35 and 50 compaction efforts, whilst ZN shows slightly higher Marshall quotient for 75 compaction effort. The flow value (Fig. 3b) of NZ mixes is slightly higher than SZ mixtures, indicating that NZ specimens are low brittleness comparing with the SZ mixes. Consequence in reducing the chances of premature cracking. Generally, NZ mixtures are relatively better than SZ mixtures. At optimum binder content, NZ and SZ mixtures display slightly higher void in mineral aggregates (VMA) when compared to hot mix asphalt.



(a) (b)

(c) (d)

Fig. (3): Marshall properties of mixtures
(a- Stability, b-Flow, c- Voids in mineral aggregates, & d- Marshall quotient)

5.2. Indirect tensile strength

The effect of moisture and temperature on the tensile strength of hot mix asphalt, natural zeolite (WMA) & synthetic zeolite (WMA) mixtures for 35, 50 and 75 compaction efforts evaluated by implementation the ITS test. The findings for unconditioned and conditioned tensile strength of these mixtures are graphically clarify in Figure 4a. The figure displays that the values of ITS for each conditioned and unconditioned NZWMA and SZWMA samples are lesser than those gained from the control HMA mixtures. The decreasing in the indirect tensile strength values of unconditioned samples is as a result of the utilize natural and synthetic zeolite in asphalt mixtures.

In comparison to HMA mixture, consequence obtained from natural zeolite(WMA) & synthetic zeolite(WMA) mixtures display a reduction 2.7% and 6.3%, 2.9% and 9.2%, and 6.8% and 12.7% the ITS values of unconditioned samples for 35, 50 and 75 compaction efforts, respectively. Likewise, the mean ITS values of conditioned samples of NZWMA and SZWMA mixtures decrease by 1.7% and 4.2%, 9.9% and 6.4%, and 5.9% and 10.4% the ITS values of unconditioned specimens for 35, 50 and 75 compaction efforts, respectively. The decrease in ITS can be as a result of the decrease in stiffness of the NZWMA and SZWMA mixtures.

With regard to the WMA mixtures, NZ mixtures show higher conditioned and unconditioned than SZ mixtures for all compaction efforts. NZ mixtures show a decrease 3.7%, 13.7% and 6.3% the ITS values of unconditioned specimens for 35, 50 and 75 compaction efforts, respectively. Likewise, the average ITS values of conditioned samples of NZ and SZ mixtures decrease by 2.5%, 4.5% and 6.1% the ITS values of unconditioned specimens for 35, 50 and 75 compaction efforts, respectively. From this, it is evident that using of NZ/asphalt as WMA binder has more influence on the tensile strength characteristic of the AC mixtures due to the higher stiffness of NZ/asphalt binder.

Moreover, the moisture damage of HMA, NZWMA and SZWMA mixtures was assessed utilize tensile strength ratio (TSR) of conditioned to unconditioned category as displayed in Figure. 4b. Compared to the hot mix asphalt mixture, NZ and SZ mixtures display slightly greater TSR, which indicate increased resistance to moisture damage. NZ mixtures show 1.0%, 1.0% and 1.0% increases in TSR values, for 35, 50 and 75 compaction efforts, respectively with respect to HMA mixtures, whereas SZ mixtures display increase of TSR values by 2.3%, 3.2% and 2.7%, respectively. The increase in TSR of NZ and SZ mixtures may be as a result of the increment of maltenes/asphaltenes ratio. Increased TSR values of NZ mixture has also been studied in previous researches [8].

Considering 85% as the lower limit agreeable tensile strength ratio [24], the TSR values of NZ & SZ mixtures are greater than 0.85, which depict more resistance to moisture damage.

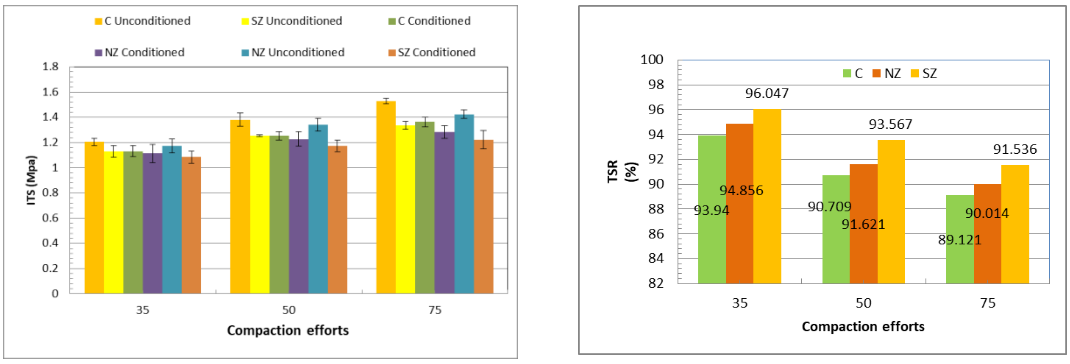


Fig. (4): Tensile strength properties of C, NZ and SZ mixtures
(a- Indirect tensile strength & b- Tensile strength ratio)

5.3. Tensile stiffness modulus (TSM)

Average values obtained for the tensile stiffness modulus (TSM) at 25°C and 60°C are shown in Fig. 5. These finding are the Mean of three measurements for both kind of mixture. The results indicate that the TSM values of NZ and SZ mixes at 25°C are higher than that of the HMA mixes for 35 and 50 compaction efforts, whilst these mixes show lower TSM values for 75 compaction efforts. At 60°C, NZ and SZ show slightly higher TSM values than that of the HMA mixes for 35 compaction efforts, while, they show lower TSM values for 50 and 75 compaction efforts. As able to be seen in the graph, NZ and SZ mixtures tested at 25°C show TSM higher than HMA control mixture, 31.6% and 17.4%, and 42.3% and 8.1%, for 35 and 50 compaction efforts, respectively, with 12.4% and 22.3% lower TSM than the values of HMA mixes at 75 compaction efforts. Similarly, the average TSM values of specimens of NZ and SZ mixtures tested at 60°C increase by 7.2% and 9.0% respectively for 35 compaction efforts with 2.8% and 17.6%, and 23.2% and 22.9% lower TSM than the values of HMA mixes at 50 and 75 compaction efforts, respectively. The decrease in TSM can be as a result of the reduction in viscosity of the WMA mixtures.

In comparison with WMA mixtures, NZ mixtures tested at 25°C show 10.9%, 24% and 11.3% increase in the TSM value of the specimens for 35, 50 and 75 compaction efforts, respectively. NZ mixtures tested at 60°C show approximately similar values of TSM to those of SZ at 35 and 75 compaction efforts, while NZ mixtures show 15.3% increase in TSM value than SZ at 50 compaction efforts. These increases in TSM values are due to the higher viscosity of NZ/asphalt binder.

However, the TSM of SZ specimens were lower than the NZ mixes. This indicates that the SZ mixtures, although not as stiff as the NZ mixes which would imply larger values of strains, nonetheless have lower values of tensile strength at failure ITS. This would further imply that the SZ mixes appear to be able of resisting greater tensile strains prior to cracking.

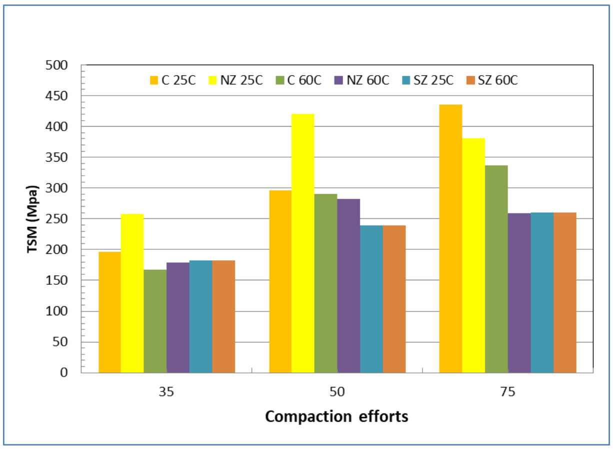


Fig. (5): Tensile stiffness modulus of mixtures

6. CONCLUSIONS

This study was performed to investigate the effect of compaction efforts on the mechanical characteristic of natural zeolite warm mix asphalt (NZWMA) and synthetic Zeolite warm mix asphalt (SZWMA) mixtures. Various tests were conducted, such as Marshall stability, indirect tensile strength, tensile stiffness modulus, and durability (tensile strength ratio) tests. The conclusions depended on the outcomes obtained in this investigation can be summarized as:

1. Compaction efforts significantly affect the performance of the mixtures. NZWMA and SZWMA mixtures display greater resistance to moisture susceptibility and cracking with lesser Marshall stability, and Marshall quotient (rutting) than HMA mixture for all compaction efforts (i.e. 35, 50 and 75blows).
2. Natural zeolite –warm mix asphalt (NZWMA) mixtures display higher conditioned and unconditioned ITS than SZWMA mixtures for all compaction efforts. In addition, both NZWMA and SZWMA mixtures accept the minimum agreeable limits of 85% for TSR, which indicate a lesser moisture damage than hot mix asphalt (HMA).
3. NZWMA mixtures show higher stability with lower Marshall quotient than SZWMA mixtures for all compaction efforts. In addition, the flow value of NZWMA mixes is slightly higher than SZWMA mixtures, indicating that NZWMA specimens are less brittleness comparing with the SZWMA mixes. Generally, NZWMA mixtures are relatively better than SZWMA mixtures.
4. The TSM values of NZWMA and SZWMA mixes at 25°C are higher than that of the HMA mixes for 35 and 50 compaction efforts, whilst these mixes show lower TSM values for 75 compaction efforts. At 60°C, NZWMA and SZWMA show slightly higher TSM values than that of the HMA mixes for 35 compaction efforts, while, they show lower TSM values for 50 and 75 compaction efforts.
5. Using the same optimal binder content, the natural zeolite (WMA) &synthetic zeolite(WMA) mixtures display slightly higher air voids and void in mineral aggregates content when compared to hot mix asphalt for all compaction efforts. In addition, NZWMA and SZWMA mixtures accept the lowest ASTM requests of 8kN stability, 2-4mm flow, and 14% VMA.

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