



Extending the mechanical-durability performance of hot mix asphalt modified with waste aluminum scrape powder

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Abstract

Moisture damage in terms of stripping; and aging surface in terms of raveling and abrasion are among the primary distresses that lead to the deterioration of asphalt pavement, diminishing the overall quality and functionality of road surfaces. This study investigates the impact of using low-cost and locally available waste aluminum scrape powder (WASP) with a particle size ranging from sieves No.8 to No.200. WASP exhibits a high bulk specific gravity and melting point temperature on HMA mixtures, which could also potentially enhance the density and stiffness of modified mixtures. Five quantities of additives 0.5, 1.0, 1.5, 2.0, and 2.5% have been used to enhance the mechanical-durability features. The aggregate sources of AlDoz and AlNibaa'e were chosen, and different mixtures were produced utilizing Marshall and Roller compaction methods. The study's findings indicated that WASP enhanced mechanical-durability characteristics and reduced the asphalt mixture's sensitivity to abrasion, moisture damage, and aging. The optimal amount of WASP was determined to be 1.5%. In addition, based on the influence of the aggregate source and compaction technique, it is visible that the AlNibaa'e source and roller compaction mode provide superior outcomes compared to the AlDoz aggregate source and the Marshall method.

Keywords: Roller Compaction, Aldo_z Aggregate Psource, WASP, TSR, CAL.

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1. Introduction

A material's mechanical characteristics describe the correlation between the applied load, or stress, and the resulting displacement or strain. Essential material qualities refer to those properties that are derived from fundamental units and are not influenced by the physical dimensions of the measuring or sample geometry [1]. Enhancing the durability of the Hot Mix Asphalt (HMA) to improve pavement performance is imperative to develop its functional features further. This advancement is directly linked to an increase in the pavement's life expectancy. Notable modifications include improved serviceability, increased skid resistance, reduced noise levels, decreased water spray, and enhanced visibility of road markings while minimizing glare and reflections. Furthermore, it plays a role in enhancing the pavement's strength by strengthening its impermeability features. It, in turn, reduces the detrimental effects of moisture and aging caused by water seepage and oxidation by air, respectively [2]. The top layer of the asphalt mixture may peel or ravel if exposed to moisture. Road surfaces can swiftly transition from the early stages of degradation to the more advanced phases of layer disintegration that lead to the formation of potholes. These potholes pose a

significant risk to the overall safety and integrity of the road pavement. From an economic perspective, the expenditure required to preserve and restore highways affected by moisture deterioration amounts to millions of dollars [3]. The water significantly impacts the physical and mechanical properties of asphalt pavement mixes in Iraq. Indeed, the issue of moisture deterioration in asphalt concrete pavements is a matter of worldwide concern. Moisture-induced damage in asphalt mixtures is characterized by the reduction in resistance, durability, and stiffness caused by the presence of moisture, thereby ultimately resulting in bonding failure [4]. Study information on the possibility of using aluminum dross as a cement or fine aggregate substitute must be more comprehensive. Incorporating dross into cement enhances its stiffness, abrasion resistance, and ability to regulate micro-cracking within the material. There is a significant effect to study the characterization and assessment of mechanical-durability characteristics of aluminum waste, with the aim of potentially using it as an important structure-building components [5]. Milled filler fractions smaller than 0.063 mm were subjected to microstructural investigations to better understand the basis of alternative and control fillers. The effects of substituting limestone filler with aluminum dross filler on asphalt mix performance were

investigated by conducting performance-based and performance-related mechanical tests. According to the study, the asphalt mix's stiffness might be improved by replacing 50% of the limestone filler with dross. [6]. Šušteršič, E., et al. [7] demonstrated the addition of waste polymethylmethacrylate/aluminum trihydroxide (PMMA/ATH) powder to an asphalt mixture. It was used as a modifier for asphalt binder in one case and as a partial replacement for the fine aggregate percentage in another. Considerable advancements in the performance aspects of the asphalt mixture were obtained using both modification approaches, increasing the durability of road pavements. In conclusion, it can effectively create an asphalt mixture with noticeably better mechanical properties by using waste PMMA/ATH ingredients. With this combination, tests on moisture-sensitive materials also demonstrate a lower risk for environmental harm. According to the findings of Hasan, J., et al. [8], aluminum filings may partly replace fine aggregate in hot asphalt mixes. However, Recycled Concrete Aggregate (RCA) may partly replace coarse aggregate. Marshall produced hot asphalt mixes using waste materials like RCA and Aluminum Filings (AF) that performed similarly to standard hot asphalt. The study examined four mix designs: RCA retained on sieve No. 9.5mm, AF retained on sieve No. 50, 25% of AF retained on sieve No. 50, and RCA and 15% of AF retained on sieve No. 50. Hot asphalt compositions with limestone dust infill were compared. The results suggest that RCA might substitute coarse aggregate in hot asphalt mixes. Furthermore, AF may partially replace fine aggregate in the same production process. Vacková et al. [9] discovered improperly compacted HMA concrete layers accelerate surface degradation and reduce strength, durability, and cracking resistance due to asphalt oxidation and deeper water penetration. Radzi et al. [10] stated that laboratory compaction of asphalt concrete specimens should accurately reflect field performance in particle orientation, permeability, and mechanical characteristics. Cheung and Dawson [11] found significant variations in aggregate structure and particle orientation in specimens compacted by different procedures. Based on aggregate form, interlocking and contact affect compaction. Many 25°C tests show that the compaction approach affects asphalt concrete's Indirect Tensile Strength ITS. Roller compaction has the lowest tensile strength. It may be due to aggregate particle orientation and horizontal particle migration without restrictions. Marshall hammer compaction has the greatest tensile strength. The mold's limited aggregate particle mobility may explain this [12-15]. In the same way, Roller-compacted asphalt concrete has lower tensile strength than hammer-compacted specimens. Tarefder and Ahmad observed similar behavior [16]. The primary objective of this study is to analyze and classify reference and modified mixes that are appropriate for the local roads and highways network, intending to achieve sufficient resistance to pavement damage from moisture and abrasion loss.

2. Aims and Objectives

The study's key objectives stated as follows:

1. Enhance the mechanical-durability performance of reference and modified asphalt mixtures improved with the waste aluminum

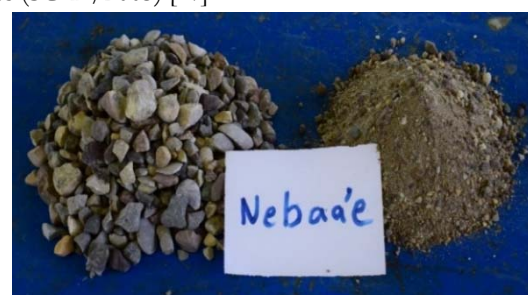
scrape powder (WASP) with a particle size ranging from sieves No.8 to No.200. It will be achieved by investigating the influence of various factors, such as different aggregate sources and kinds of compaction.

Assessing the mechanical characteristics of the optimized mixes have the potential to be characterized in terms of their resistance to tensile strength (ITS) and resistance to abrasion (CAT). Additionally, the durability properties of these mixtures can be evaluated in terms of their resistance to moisture damage (TSR) and ageing (CAR).

3. Materials

3.1. Coarse Aggregate (CA) and Fine Aggregate (FA)

As shown in Fig. 1, AlDoz and AlNibaa'e crushed CA and FA were utilized. Table 1 provides the standard physical properties which effect on the performance of HMA. The procedure was conducted per the requirements set out by the American Society for Testing and Materials (ASTM) and the State Corporation of Roads and Bridges (SCRB/2003) [17].



(a) Aggregate of AlNibaa'e Source's



(b) Aggregate of AlDoz Source's

Figure 1. Selected Sources of CA and FA

Table 1. Physical Properties of CA and FA [18]

Characteristic	Coarse Aggregate (CA)			(Stand.) [Ref.]
	AlDoz	AlNibaa'e	Limits [17]	
Specific Gravity (Bulk)	2.62	2.584	≥ 2.5	(C127) [19]
Specific Gravity (Apparent)	2.63	2.608	≥ 2.6	(C127) [19]
Absorption of Water (%)	0.51	0.57	≤ 2	(C127) [19]
Wear Abrasion (%)	12.1	13.08	≤ 28	(C131) [20]
	Fine Aggregate (FA)			
Specific Gravity (Bulk)	2.63	2.604	≥ 2.4	(C128) [21]
Specific Gravity (Apparent)	2.64	2.664	≥ 2.5	(C128) [21]

Absorption of Water (%)	2.66 7	1.419	≤ 3	(C128) [21]
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Fig. 2 shows the significant mixes' aggregate gradation proportions for wearing course (type III) with 12.5mm NMAS. The control mix was in the middle of the specification's range. However, the lower and higher limits were used to prepare mixtures for determining the additive's optimal percentage.

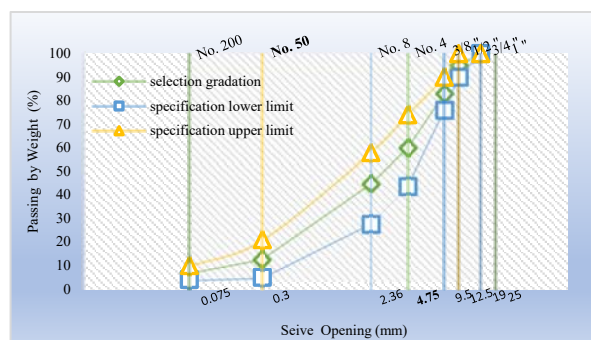


Figure 2. Standards of Aggregate Grading Limits

3.2. Asphalt Cement (AC)

The different mixes were prepared with AC (40-50) from AlDaurah refinery. It passed all of the testing and was determined to be by the SCRB [17] requirements. Table 2 lists the particular parameters of AC's physical properties.

Table 2. Physical Properties of AC [18]

Before Thin Film Oven Test (TFOT)			
Characteristic with Conditions	Test Results	Limits [17]	(Stand.) [Ref.]
Penetration (0.1mm), (25 °C, 100gm, 5sec)	45	40-50	(D5) [22]
Softening Point (5 °C/min)	49	-	(D36) [23]
Ductility (cm), (25 °C, 5cm/min)	+ 150	≥ 100	(D113) [24]
Specific Gravity at 25 °C	1.04	-	(D70) [25]
Flash Point	290	≥ 232	(D92) [26]
Rotational Viscometer, (Pa.sec), (135 °C)	0.6	≤ 3	(D4402) [27]
Rotational Viscometer, (Pa.sec), (165 °C)	0.144	-	(D4402) [27]
After Thin Film Oven Test (TFOT)			
Retained Penetration of Residue, (% for 0.1mm), (25 °C, 100gm, 5sec)	60	≥ 55	(D5) [22]
Ductility of Residue, (cm), (25 °C, 5cm/min)	85	≥ 25	(D113) [24]
Loss on Weight (163 °C, 50gm, 5 hr)	0.3	-	-

3.3. Filler (CKD)

Cement Kiln Dust (CKD) was given as a filler in the study, which is produced by the Karbala Cement Factory, a division of French cement manufacturer Lafarge, as can be seen in Fig. 3. The physical data is displayed in Table 3.

Table 3. Physical Properties of CKD's Filler [18]

Characteristic with Conditions	Test Results	Limits [17]	(Stand.) [Ref.]
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Specific Gravity (Bulk)	3.14	≥ 2.6	(D854) [28]
Passed Sieve No.200 (%)	96	≥ 90	(C117) [29]



Figure 3. Selected CKD's Filler

3.4. Additive (WASP)

A Waste Aluminum Scrape Powder (WASP) with a particle size ranging from sieves No.8 to No.200 as shown in Fig. 4 selected samples from Baghdad's scrap metal and prepared it for the present study using techniques from the aluminum factory, such as sizing and filing. The resistance behavior of asphalt mixtures was modified by including WASP as an additive. The physical characters are shown in Table 4.

Table 4. Physical Properties of WASP [18]

Character with Conditions	Test Results
Specific Gravity (Bulk)	2.68
Temperature of Melting Point, (°C)	658



Figure 4. Selected WASP's Additive

4. Study Methodology

Fig. 5 illustrates the overall structure of the procedural sequence used in this study. It is based on the findings of Al-Obaidi, M. K., & Abed, A. H. [30] for comparing the laboratory compaction as to the field compaction of the two-dimensional digital image analysis (DIA).



(f) Compacted Sample of AC Mixture

Figure 6. The Standard Steps of Marshall Compaction Process

The pneumatic Roller Compactor, shown in Fig. 7, is a new device for compacting asphalt slabs using pneumatic power following EN 12697 - 33 [32]. depending on Marshall required density and AC for the two sources of aggregate, the appropriate mix was heated to 165°C before being transported to the (300*400*50) mm roller compaction mould and compacted. The ideal air void of $7\pm 0.5\%$ and density were achieved with an applied force of 5kN and a specified number of roller cycles. The slabs were taken out of the mould after 24 hours. The control mixes prepared from aggregate sources of AlNibaa'e and AlDoz, utilizing Marshall compaction, are denoted as N/M and D/M for compaction mode. Similarly, these mixes are referred to as N/R and D/R for Roller compaction mode. On the other hand, the modified mixes incorporating WASP, obtained from the same sources and compaction method, are labeled as N/WASP/M, D/WASP/M, N/WASP/R, and D/WASP/R, respectively. The addition of WASP at varying percentages of 0.5, 1, 1.5, 2, and 2.5% to the overall mix. The analysis of Marshall stability-flow stiffness analyses has indicated that the optimal value for the design of modified samples is 1.5% of the entire mix



(a) 2 hr of Agg. and CKD Heating



(b) Mould Cleaning by air pressure



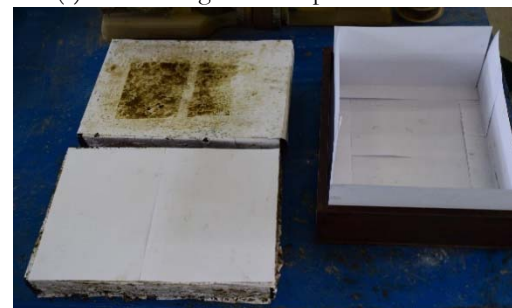
(c) Mould Greasing and Mix Pouring



(d) Installing the Mould in Device



(e) Controlling and Compaction Process



(f) Compacted Slabs of AC Mixture

Figure 7. The Standard Steps of Roller Compaction Process

5. Tests Preparation

A total of 24 Marshall samples were prepared, as shown in Fig. 8. In contrast, 4 slabs were produced using the roller compactor, as illustrated in Fig. 9. A total of 24 samples were extracted, with a distribution of 6 samples per slab.

The specimens were classified into two distinct categories: conditioned and unconditioned samples. The first set of mixtures consists of control mixes, whereas the subsequent set comprises improved mixtures



Figure 8. The Prepared Reference and Modified Samples of the Marshall Method



a. Preparing Slabs for Coring



b. Cored Samples Per Slab



c. Prepared Slabs by Roller Compaction



d. Compacted Slabs after Coring

Figure 9. The Standard Steps of Roller Compaction Process and Coring

5.1. Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR) Tests

This test measured HMA's ITS. A cylindrical specimen is loaded with a constant compressive force across its vertical diametric plane at a predetermined deformation rate and test temperature to determine the bituminous mixtures ITS. The measurements may be utilized with laboratory mix design tests to assess HMA mixture quality and estimate cracking. The test adheres to ASTM D6931 [33]. Moisture sensitivity tested according to ASTM D4867 [34] for asphalt pavement is essential and needs to be examined. It is the HMA durability and strength decrease due to water, detected by mechanical property loss. Poorly compacted, dense-graded pavement with greater than 8% air void exposed to repeated traffic loading with surface water such as rainwater causes separating. Scouring hydraulic pressure variations in linked spaces removes binder from aggregate particles. Stripping is the most common water damage mechanism caused by adhesion failure between the aggregate and asphalt, but other damage mechanisms include aggregate cohesion failures, moisture-induced asphalt binder cohesion failures, freezing of entrapped water, and asphalt emulsification. The ratio of indirect tensile strength (TSR) for conditioned to unconditioned specimens is measured for the evaluation of moisture damage's resistance. The approved TSR range is 0.7 to 0.9 [1]. specimens were prepared and separated into unconditioned (dry state) and conditioned (saturated state) subsets. Applying a vacuum of (13-67) kPa absolute pressure saturated the conditioned specimens with water to 70-80%. After that, conditioned samples were frozen at (-18oC/16 hrs). Their tensile strength seems to decline after 24 hours in 60°C water. When results are obtained on both dry and wet specimens, the ITS test may be utilized to determine the likely field pavement damage caused by moisture as shown in eq.(1) and (2)

$$ITS = (2000 F) / (\pi t D) \quad (1)$$

$$TSR = ITS_2 / ITS_1 \quad (2)$$

Where ITS is indirect tensile strength (kPa), F is the maximum failure load (kN), t is the sample thickness (mm), D is the sample diameter (mm), TSR is the tensile strength ratio (%), ITS1 and ITS2 are the ITS for unconditioned and conditioned samples respectively (kPa). Fig.10 shows the procedure of Test.



(a) Samples in Freezer



(b) Samples in Water Bath



(c) Samples in Vacuum System



(d) Tested Samples



(e) Samples Under Test

Figure 10. The Standard Procedure of ITS and TSR Tests

5.2. Cantabro Abrasion Loss (CAL) and Cantabro Abrasion Ratio (CAR) Tests

The Cantabro Abrasion test shown in Fig.11 evaluates the effects of traffic abrasion and suction on a material's cohesiveness, bonding, and overall durability in terms of CAL. This test was also used to guarantee sufficient durability when comparing conditioned and unconditioned specimens in terms of CAR. Cantabro abrasion testing has been used for decades in Europe but is seldom performed in the United States. The abrasion loss value of bituminous mixes is calculated using a Los Angeles abrasion machine and tested following ASTM C131 [20]. The test is conducted at 25°C, and the device is run at about 300 rotations per minute. At least 6 hours must pass at the test temperature before the samples may be used. The specimens are put into the abrasion machine without the charge of steel balls.

Abrasion wear occurs when a vehicle's tires scrape, skid, rub, or slide on an asphalt roadway. The Cantabro test was used to examine the abrasion loss resistance of mixes, and it may be used to determine the durability if two sets of samples are constructed. Depending on the durability aspect, two settings of samples are used: aged and unaged. Examine how aging affects samples' ability to withstand abrasion. Therefore, the Cantabro abrasion test should also be performed on old compacted specimens. Three specimens are compacted and aged in an oven at 60°C for 168 hours for seven days. The Cantabro test is performed on the samples after they have been cooled to 25 °C and kept for 4 hr; the percentage of abrasion loss is calculated in the same way for both old and unaged samples.

$$CAL = \frac{m_1 - m_2}{m_1} * 100 \quad (3)$$

$$CAR = \frac{CAL_2}{CAL_1} \quad (4)$$

Where CAL is the Cantabro abrasion loss percentage (%), CAR is the Cantabro abrasion ratio (%), m_1 , m_2 , CAL_1 and CAL_2 are the mass and Cantabro abrasion loss for unaged and aged samples (%), respectively



(a) Samples before Ageing Process



(b) Abrasion Assessment in Los Angeles Device



(c) Aged Samples in an Oven at 60°C/24 hrs



(d) Aged and Unaged Tested Samples
Figure 11. The Standard Steps of Marshall Compaction Process

6. Results and Discussion

6.1. Assessment the Optimum WASP's Value

During the first stage, the Marshall samples for coarse and fine AlNibaa'e and AlDoz aggregate sources were prepared with the lower and upper limits of SCRB gradation, and an optimum air void, then subjected to a curing process of 30 minutes in a water bath kept at a temperature of 60°C before performing the test. The parameter known as Marshall stability ($M_{Stability}$) represents the maximum permissible load that may be applied at the fracture

zone, whereas flow (M_{Flow}) refers to the extent of deformation occurring at the time of fracture. Marshall stiffness ($M_{Stiffness}$) assessment is conducted chiefly by dividing the stability by the flow as presented in Table 5

An increase in Marshall stiffness suggests an increase in the mixture's stiffness, indicating that the whole mixture exhibits more significant resistance to long-term deformation. According to the data in Table 5, the Marshall properties of reference and modified asphalt concrete indicate that the stability increased with the addition of WASP content up to the optimal level of 1.5% of the total mix. However, beyond this point, the stability decreased. Simultaneously, there was a similar rise in the flow. Moreover, the findings indicate that the $M_{Stiffness}$ exhibited a marginal gain of up to 1.5% WASP, followed by a significant fall. The addition of 1.5% WASP to the mixture has been determined to impact the characteristics of Marshall significantly. As a result, the mechanical-durability criteria were evaluated using the ideal conditions: 1.5% WASP, 7 ± 0.5 air void, and the mid-class of SCRB aggregate gradation limits. The findings are consistent with the perspective of [6].

Table 5. Physical Properties of WASP's Additive

	$M_{Stability}$ (kN)					
	Reference	0.5% WASP	1% WASP	1.5% WASP	2% WASP	2.5% WASP
N/CM	7.1	9.3	11.8	14.3	12.8	10.2
N/FM	6.7	8.8	10.1	12.7	11.3	9.8
D/CM	6.8	9.9	11.3	13.9	11.9	9.7
D/FM	6.5	9.6	10.3	12.8	10.8	8.8
	M_{Flow} (mm)					
N/CM	2	2.3	2.6	2.9	3.1	3.4
N/FM	2.3	2.5	2.9	3.1	3.9	4.4
D/CM	1.7	2.2	2.4	2.7	3	3.1
D/FM	2.1	2.8	2.9	3.4	4	4.6
	$M_{Stiffness}$ (kN/mm)					
N/CM	3.6	4	4.5	4.9	4.1	3
N/FM	2.9	3.3	3.5	4.1	2.9	2.2
D/CM	4	4.5	4.7	5.1	4	3.1
D/FM	3.1	3.4	3.6	3.8	2.7	1.9

6.2. Assessment The Mechanical Parameters of ITS and CAL Tests

The outcome of the ITS test on modified mixes containing 1.5% WASP is shown in Fig. 12, in comparison to reference mixtures. The analysis includes various compaction modes and aggregate sources. According to the test findings, including 1.5% WASP as a sole component in modified mixes leads to higher ITS values than reference mixtures. It implies that mixes containing WASP exhibit higher tensile strength at failure, indicating enhanced resistance to cracking. This modification can be attributed to the advanced density and adhesion properties of the modified mixes, which enhance the cohesion and adhesion of the asphalt binder and prevent the stripping of binder from the aggregate surface. The advancement in the aggregate interlocking leads to an increase in the ITS. There is a correlation between the internal strength of materials associated with the aggregate source,

gradation, and compaction process and their impact on the orientation of the aggregate system. The internal resistance of Hot Mix Asphalt (HMA) is enhanced due to the aggregate interlock and mastic transporting mechanisms. The primary factor contributing to the internal resistance in Hot Mix Asphalt (HMA) is the internal contact between particles of coarse and fine aggregates. This phenomenon may be attributed to the increased confinement of aggregate particles in the mixes due to additives. Consequently, there is a greater chance of a higher percentage of micro-fractures occurring in reference mixes compared to the modified mixture situations

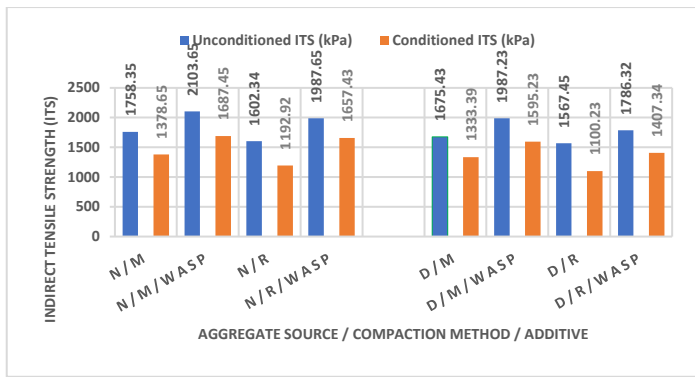


Figure 12. Results of Unconditioned and Conditioned ITS

The Cantabro test is usually used for evaluating open and dense graded mixes. The abrasion loss seen in this test should remain below 20% for specimens that have not undergone aging. Additionally, the maximum allowable percentage of loss after aging is 30%. These values signify the acceptable criteria for this particular test. The test findings of CAL for both unaged and aged conditioned mixes are shown in Figure 13. The findings indicate that the CAL of the modified mixture containing 1.5% WASP is comparatively lower than that of the unmodified mixture. The potential explanation for this phenomenon may be attributed to the inclusion of WASP in the mixture, which leads to an increase in the density of the mixture. Consequently, this forms a thicker mastic film and a more brittle film around the aggregate. Several factors contribute to the observed improvements. These include variations in aggregate orientation based on the source of the aggregate and the mode of compaction, which impact the overall structure of the aggregate skeleton in the asphalt mix. Consequently, these factors also influence the percentage of abrasion loss in the mix. Additionally, a thicker mastic film is another contributing factor in this regard. All of the aforementioned explanations are supported by studies [1, 2, 4, and 5]

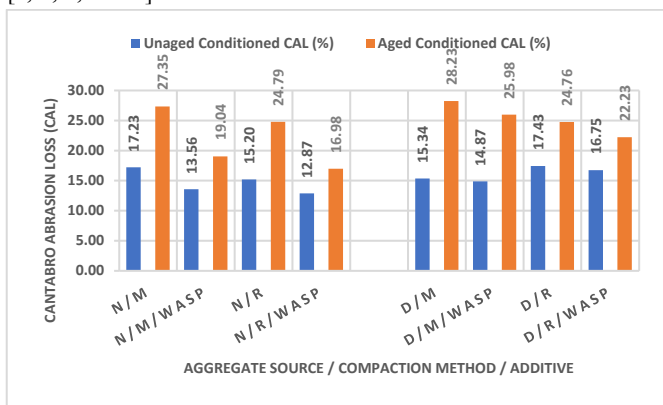


Figure 13. Results of Unaged and Aged Conditioned CAL

6.3. Assessment The Durability Parameters of TSR and CAR Tests

Durability refers to the tendency of building products to withstand the effects of time and resist substantial degradation over extended periods. The longevity of asphalt paving materials is significantly affected by age hardening and moisture degradation. Over time, the material qualities undergo changes as

the mixture gradually increases in stiffness due to the hardening of the asphalt cement. The results suggest that the tensile strength at 25°C is lower for conditioned samples than unconditioned samples across all control combinations. The Tensile Strength Ratio (TSR) is used as a predictive measure for assessing the susceptibility of a material to moisture sensitivity. According to ASTM D4867 [34], the recommended range for TSR is 70-85%. This range is used to distinguish between combinations susceptible to moisture and those resistant to moisture. The findings of the unconditioned and moisture-conditioned mixes TSR are shown in Fig. 14. Launched on the effects of the test, it can be seen that the incorporation of 1.5% WASP as the single constituent in modified mixtures yields greater TSR values than the reference mixtures under both aggregate source and compaction mode conditions. The results indicate a notable disparity between the impact of roller and Marshall compaction on the aggregate sources. The findings suggest that the ITS of conditioned specimens is lower than that of unconditioned specimens. This observation indicates that the degradation of the mixtures occurred due to water conditioning, which significantly reduces the tensile strength of the mixes

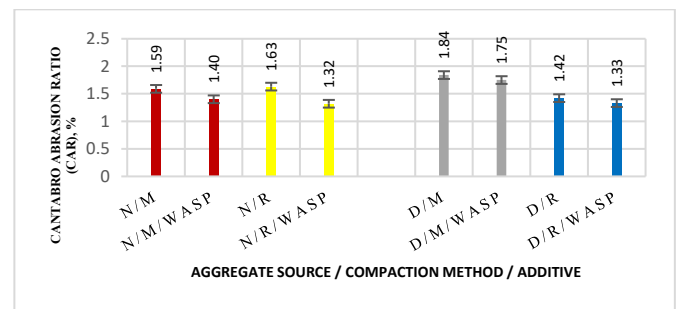


Figure 14. Results of TSR According to Aggregate Source and Compaction Method

Based on a review of findings as shown in Fig. 15, it was observed that the Cantabro abrasion Ratio (CAR) of the modified mixture incorporating 1.5% WASP was comparatively lower than that of the reference mixture. Besides, it is worth remarking that the abrasion loss in aged specimens exhibited a tremendous increase compared to unaged samples. It can be attributed to the influence of aging or oxidation effects. On the other hand, this observation suggests that the modification of the mixture by WASP leads to an increase in stiffness, primarily attributed to the beneficial effects of its particles, hence contributing to the enhancement of density. As a result, incorporating WASP in the combinations resulted in a more significant enhancement of the abrasion resistance. Results complying with study [7]

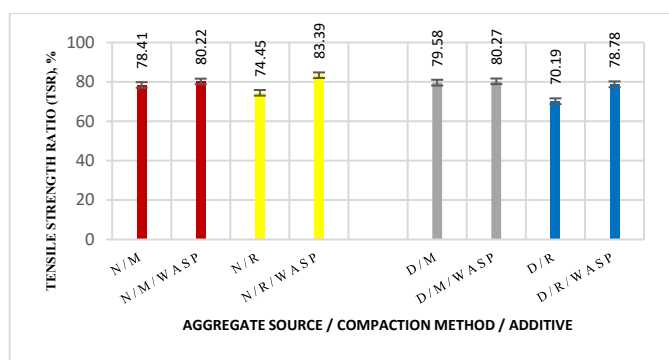


Figure 15. Results of CAR According to Aggregate Source and Compaction Method

6.4. Effect of Aggregate Source on Mechanical-Durability Parameters

The average strength of Hot Mix Asphalt (HMA) is frequently evaluated via Indirect Tensile Strength (ITS) testing, as indicated by the aggregate source. The above findings demonstrate the influence of unconditioned and conditioned mixtures on the Indirect Tensile Strength (ITS) of reference and modified mixtures using AlNibaa'e and AlDoz aggregate sources. The findings indicate that the conditioned AlNibaa'e aggregate mixes exhibit decreased resistance compared to the unconditioned mixes at an ITS of 25 °C. Specifically, the N/M, N/M/WASP, N/R, and N/R/WASP mixes show reductions in resistance of 21.6%, 19.8%, 25.6%, and 16.6% correspondingly. On the other hand, the results indicate that conditioned AlDoz aggregate mixes exhibit decreased resistance compared to unconditioned mixes, with reductions of 20.4%, 20.7%, 29.8%, and 21.2% seen for D/M, D/M/WASP, D/R, and D/R/WASP mixes, respectively. Overall, the TSR indicator is used while evaluating the impact of moisture damage. In the case of AlNibaa'e and AlDoz sources, Marshall compatibility resulted in a slight increase in TSR. The modifications were 2.3% and 0.9% for the modified mixes of N/M/WASP and D/M/WASP, respectively, compared to the reference N/M and D/M mixes. There is a noticeable increase of 10.7% and 10.9% in the N/R/WASP and D/R/WASP mixes, respectively, compared to the reference N/R and D/R mixes.

Additionally, it has been shown that the proportion of CAL in aged specimens presents higher levels than in unaged specimens. It may be attributed to aging or oxidation, making the mixture more susceptible to weakness and brittleness. The results showed that the AlNibaa'e aggregate mixes, which were subjected to aging, had greater amounts of CAL compared to the mixes that were not aged. The CAL values of the N/M, N/M/WASP, N/R, and N/R/WASP mixtures exhibit respectively increases of 58.7%, 40.4%, 63.1%, and 31.9%. Furthermore, the findings show that aggregate mixes of aged-conditioned AlDoz demonstrate a significant increase in CAL compared to unaged-conditioned mixes. Specifically, there was an observed rise in 84%, 74.7%, 42.1%, and 32.7% for D/M, D/M/WASP, D/R, and D/R/WASP mixes, respectively. In general, the CAR indicator is used to assess the abrasion loss resistance of mixtures in both unaged and aged conditions. Using AlNibaa'e and AlDoz

sources in the context of Marshall's adaptability led to a significant decrease in the CAR. The modified mixes of N/M/WASP and D/M/WASP exhibited improvements of 13.6% and 5.1%, respectively, compared to the reference N/M and D/M mixes. The N/R/WASP and D/R/WASP mixes exhibit a significant decrease of 23.5% and 6.8%, respectively, compared to the reference N/R and D/R mixes. All of the factors listed above are in line with what was found in [8, 11].

6.5. Effect of Compaction Mode on Mechanical-Durability Parameters

The evaluation process also involves comparing the results of the Roller with the Marshall Methods (R/M) in terms of compaction. This comparison is based on calculating the difference in values between modified mixes, and the reference mixes for both unconditioned and conditioned cases. In evaluating the performance of ITS, the unconditioned data reveals a notable 10.4% rise in the disparity between N/R/WASP and N/R mixtures in comparison to N/M/WASP and N/M mixtures. Simultaneously, there is a substantial reduction of around 42.5% in the disparity between D/R/WASP and D/R mixes, compared to the D/M/WASP and D/M mixes. In the case of conditioning, the findings indicate a significant enhancement in resistance to ITS. Specifically, there is an observed increase of about 33.5% and 21.3% for the AlNibaa'e and AlDoz aggregate sources, respectively. In summary, to assess the resistance to stripping using the TSR indicator to compare the impact of different (R/M) compaction modes, the findings exhibited a substantial and statistically significant improvement of around 79.8% and 103.6%, respectively.

Likewise, upon assessing the effectiveness of CAL, it is seen that the unaged conditioned data demonstrates a significant reduction of 57.5% in the discrepancy between N/R/WASP and N/R mixes, as compared to N/M/WASP and N/M mixtures. There has been a considerable rise of around 30.9% in the difference between the D/R/WASP and D/R mixes compared to those who identify as D/M/WASP and D/M mixes. Regarding the aging process and its impact on conditioning, the study's results demonstrate a noteworthy improvement in the ability to withstand CAL. More precisely, the AlNibaa'e aggregate sources observe a decrease of around 6.4%, whereas the AlDoz aggregate sources observe a rise of 11.1%. In conclusion, the study aimed to evaluate the resistance to abrasion and scraping by using the CAR indicator to compare the effects between different compaction modes (R/M). The results indicated a significant rise of around 38.7% in the case of the AlNibaa'e source. However, no significant impact appeared for the AlDoz source. All of the above justifications match up with the studies of [12-16].

7. Conclusions and Recommendations

Based on the results of this study, the subsequent main conclusions are drawn within its scope:

1. The findings demonstrated the significance of WASP additive within the impact of aggregate source and compaction technique in improving the mechanical characteristics of mixes such as ITS and CAL and the durability qualities of TSR and

CAR. According to the study results, WASP improved the mechanical-durability qualities and decreased the asphalt mixture's susceptibility to abrasion, moisture damage, and aging. It was established that 1.5% WASP was the ideal amount. In addition, when comparing the AlNibaa'e source and roller compaction mode to the AlDoz aggregate source and the Marshall method, it is clear that the first approach produces better results.

2. Based on aggregate source impacts on mechanical-durability. At 25 °C ITS, conditioned AlDoz and AlNibaa'e aggregate mixes had lower resistance than unconditioned mixes. Marshall's approach increased TSR relatively for modified mixes compared to reference mixes. Compared to reference mixtures, roller compaction improves. Furthermore, it has been shown that the amounts of CAL in aged specimens is more significant than in unaged ones. The findings revealed that the aged AlNibaa'e aggregate mixes contained more CAL than those not. Furthermore, aggregate mixes of aged-conditioned AlDoz exhibit a considerable increase in CAL compared to unaged-conditioned mixes. In general, the changed mixes outperformed the reference mixes regarding CAR. Compared to the reference mixes, it shows a considerable reduction in roller compaction.

3. Based on compaction method impacts on mechanical-durability. The Roller's compaction results are compared to Marshall Methods (R/M) during assessment. In assessing ITS performance, unconditioned data shows a significant increase in the difference between reference and modified AlNibaa'e aggregate source mixes. The difference between reference and modified AlDoz aggregate source mixes decreases significantly. Conditioning increases ITS resistance significantly. TSR improved significantly and quantitatively. When CAL is evaluated, the unaged conditioned data shows a considerable decrease in the disparity between (R/M) samples of the AlNibaa'e aggregate source. Compared to AlDoz mixes, the differences have increased. Aging along condition case improved CAL resistance, according to the study. The AlNibaa'e aggregate sources decline, whereas the AlDoz sources grow. The CAR indicator showed a significant increase for AlNibaa'e. No notable effect was seen for AlDoz.

4. This study's recommendations acquired numerous concerns requiring more inquiry by applying a trial section structure and using local materials under inherited conditions of the environment and traffic demand. Also, it would prefer to use the Superpave mix design for compaction method comparisons. Studying the impact of sustainable fillers, polymers, and aggregate materials may help assess the potential for an environmentally friendly approach in the road construction sector.

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