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Moisture Resistance of Olive Husk Ash Modified Asphalt Mixtures

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ABSTRACT

In agricultural nations such as Jordan, olive oil production generates substantial quantities of a byproduct known as olive husk. Traditionally utilized for heating purposes, olive husk is now being employed in the production of cleaning solutions and cosmetic products. This study investigates the potential use of olive husk ash (OHA) as a filler in bitumen, when combined with aggregate to produce asphalt mixtures typically employed in road pavement construction. The impact of moisture on the properties of asphalt mixtures containing OHA filler was examined using the Marshall Stability test method. OHA was incorporated as a replacement for bitumen at varying volumes (0, 5, 10, 15, 20%). The optimum bitumen content was added to limestone aggregate to prepare asphalt mixture specimens. Furthermore, the effect of Dryback on the properties of asphalt mixtures was assessed. Findings indicate that the inclusion of OHA in bitumen (by volume) reduced the moisture resistance of specimens, with an optimal performance observed at 10-15% replacement. Additionally, it was found that the moisture effect on asphalt mixtures was reversible, and the observed degradations in strength and stiffness after wet conditioning were not predominantly due to the adverse effects of water. Consequently, the utilization of OHA as a pavement material in the field could potentially reduce production costs and enhance performance, leading to notable environmental benefits.

1. INTRODUCTION

Moisture has been known to reduce the strength of asphalt mixtures by causing a weakening of bitumen and/or a loss of the bitumen–aggregate bond. The weakening of bitumen is attributed to the loss of its cohesive strength, which is a function of the interaction between the mineral filler and bitumen [1, 2]. An increase in moisture content has been observed to elevate saturation and void swelling or expansion [3]. The loss of the adhesive bitumen–aggregate bond can lead to stripping or raveling [4-7], with the loss of adhesion being influenced by the material properties of both bitumen and aggregate (fine and coarse). Bituminous pavement is subjected to heavy traffic loads throughout its service life, necessitating the use of bituminous materials with favorable properties such as stability and stiffness.

Airey et al. [8] investigated the impact of filler type on asphalt moisture damage. It was demonstrated that the effectiveness of acidic aggregate asphalt mixtures against moisture damage was influenced by the filler type. Performance was marginally worse when granite filler was utilized instead of the conventional 2% by mass limestone filler, but it was noticeably improved when hydrated lime was used as a substitute. Similar findings were reported by Lesueur and Little [9] and Kim et al. [10]. These studies [11-14] were also used to examine the effect of active fillers and antistripping agents like hydrated lime on the moisture resistance of asphalt mixtures, both in the laboratory and in the field. To reduce the extent of stripping, various techniques have been employed, including the addition of fillers, polymers, and amine antistripping agents [15, 16]. Organosilanes have also been successfully used by Gemayel [16], Schmidt and Graf [17] to prevent stripping of asphalt mixtures.

Nejad et al. [18] studied the effect of a nanomaterial called Zycosoil on asphalt mixture moisture damage. In their research, two types of aggregate—limestone and granite—were utilized. Mixtures with and without Zycosoil were tested under dry and wet conditions using indirect tensile-strength and fatigue testing methods to assess the influence of Zycosoil on the moisture damage of hot mix asphalt. The results indicated that limestone had a lower propensity for moisture damage than granite. The wet-to-dry ratio values of both tests for mixtures with Zycosoil were higher than those for mixtures without Zycosoil for the two types of aggregate. Zycosoil increased the fatigue life of asphalt mixtures by 6% and 25% with limestone and granite aggregates, respectively.

Cui et al. [19] examined the effect of water on bitumen's adhesion to aggregates (limestone, marble, and granite) in order to study the durability of asphalt mixtures. The adhesive fracture energy of a medium penetration grade bitumen and aggregates was measured using a peel test. Under wet conditions, limestone and marble aggregates exhibited a smaller loss of adhesion than granite acidic aggregates. The chemical composition of the aggregates was found to be more significant than the porosity of the aggregates, even though the latter was also important. It was also concluded that mixing adhesion promoters such as silane, amine, or rubbery polymer into the bitumen improved interfacial adhesion in wet conditions. Other research [20-23] employed computational methods to model the in-service circumstances faced by asphalt mixtures, consequently predicting their durability and water resistance.

AlKofahi and Khedaywi [24] conducted laboratory tests to predict stripping of asphalt mixtures. Stripping was investigated via fatigue testing of Marshall specimens using a Universal Testing Machine. Uncrushed valley gravel, crushed limestone, and crushed basalt were used as aggregates. A polyamine liquid and hydrated lime were employed as additives. Aggregate type was identified as the most significant factor affecting stripping. In situations with a high likelihood of stripping, anti-stripping chemicals were found to be beneficial. All aggregate types demonstrated a propensity for stripping at high saturation levels. Basalt and valley gravel were less resistant to stripping than limestone. The authors concluded that asphalt mixture stripping could be predicted through fatigue testing, providing the necessary indicator of moisture potential and additive effects performance. Earlier experiments by Khedaywi and White [25] on the impact of segregation on the fatigue performance of asphalt paving mixtures revealed that fatigue life decreased with increasing segregation degree, particularly with increasing coarse aggregate. The potential for fatigue in beams was examined [25].

Dimter et al. [26] investigated the characteristics of an asphalt mixture with wood ash filler. The properties of Marshall Stability, quotient and deformations, and the indirect tensile strength of water-conditioned samples and dry samples were studied on asphalt specimens of an AC16 surf mixture with various amounts of wood ash as the filler. According to the measured values of Marshall Stability and Marshall Quotient, adding 50% more bio ash to the filler increased the stability and stiffness of the mixture. The moisture susceptibility of the mixtures was evaluated using the indirect tensile strength test, and the results showed that mixtures with higher amounts of wood ash filler exhibited higher resistance to moisture damage.

Modeling the moisture susceptibility of asphalt mixtures has been the focus of several studies [27-31]. Although their models appear to simulate and predict the moisture susceptibility effectively, they are highly dependent on the calibration of various parameters related to the mixture's components and their bond. As a composite material, an asphalt mixture possesses a wide range of properties, and its material properties may vary due to different compaction methods and levels. Controlling the calibration parameters in such models can be time-consuming.

In addition to the aforementioned research, numerous studies have been conducted to assess the moisture susceptibility of asphalt mixtures [32-44] as well as recent investigations on Oxidized Heavy Aromatic (OHA) [45-47]. The latest studies [45-47] examined the impact of incorporating OHA on the properties of asphalt binder and mixture, as well as the dynamic creep of the mixture. The researchers found that replacing 10-15% of OHA in asphalt binder improved the Marshall Stability and void in mineral aggregate, while reducing flow, retained stability, stiffness, and retained stiffness. Moreover, the resilient modulus and creep stiffness were enhanced, and the accumulation of strains at various frequencies and temperatures was reduced.

To date, no studies have explored the effect on moisture resistance of asphalt mixtures when using OHA as a replacement for bitumen. This paper aims to evaluate the influence of moisture on the properties of asphalt mixtures incorporating OHA filler. Moisture damage in asphalt concrete pavements can cause problems that lead to expensive repairs. Furthermore, utilizing OHA in pavement construction presents a sustainable solution that may prevent the depletion of natural resources.

2. OBJECTIVES

The planning, construction, operation, and administration of transportation facilities using technological advances and concepts could result in an infrastructure to transporting individuals and items that would be safe, quick, appropriate, simple, cost-effective, and socially and environmentally acceptable. Olive husk became an environmental issue as waste products produced in Jordan in great amounts. OHA could be used in bitumen when added to aggregate to produce asphalt mixture that could be used in paving roads.

The objectives of the current research were:

(1) To investigate the effect of moisture on properties of asphalt mixture with OHA as a filler in bitumen binder.

(2) To investigate the effect of moisture reversibility on properties of asphalt mixture with OHA as a filler in bitumen binder.

The Marshall Stability testing method was used to achieve these objectives. The Marshall Stability test could provide a reliable estimate of the stiffness of asphalt mixture. The mixture density, voids in mineral aggregate (VMA), voids filled with bitumen (VFB), and absorbed asphalt might all be found out through the volumetric analysis of the tested specimens. These factors would be crucial for understanding how asphalt mixture would behave. The Marshall Stability test, an available and inexpensive testing technique, had the benefit of requiring less testing time. As a result, it had been employed in the current study.

3. MATERIALS AND TESTS

To prepare a design mix that met the desired specifications, the following materials were used:

3.1 Aggregate

Limestone aggregate were taken out from Al-Huson quarries located in Northern Jordan. These natural aggregates were obtained by mechanical crushing a large rock taken out from the quarry into the usable sizes. In grading, the specifications of Jordanian Ministry of Public Works and Housing (MPWH), Directorate of Planning and Development [48] were used. The gradation of the limestone aggregate was shown in Figure 1. The properties of the limestone aggregate were provided in the study [49, 50].

3.2 Bitumen

Bitumen penetration grade 60-70 was obtained from petroleum Refinery Company in Zerqa, Jordan. The bitumen's physical properties with the MPWH specifications [48] were provided in the study [51].

3.2.1 Penetration

At 25°C for 5 seconds, a penetration needle producing a 100 gm equivalent force was utilized. The needle's penetration depth, measured in units of 0.1 mm was reported. The penetration depth was in the range 60 to 70 at regular test settings [49].

3.2.2 Ductility

When two ends of a briquette specimen were pulled apart at a particular speed and temperature, ductility was measured as the distance to which it stretched before cracking. The test were performed at a speed of 5 cm/minute ± 5.0% at a temperature of 25 ± 0.5°C [50].

3.2.3 Softening point

A ring and ball equipment in an ethylene glycol bath was used to determine the asphalt's softening point in the range of 30 to 175°C. A steel ball of specified weight was located upon a disk of a sample contained within horizontal equipment. The component was heated in the path. The temperature at which a bitumen sample could not withstand the weight of a 3.5 gm steel ball was referred to as the softening point [51].

3.2.4 Flash and fire point

For flash and fire point, the sample was first added to the test cup until it reached a particular level. The temperature of the sample was then raised quickly at first, and then slowly and steadily as the flashpoint was attained. After that, a small test flame was passed over the cup at predetermined intervals. The flashpoint was determined to be the lowest temperature at which the test flame application allowed the vapors to ignite on sample's surface. Additionally, the test was carried out until the oil ignites and burns for at least 5 sec. in order to determine the fire point [52].

3.2.5 Specific gravity

Two primary purposes drive the utilization of bitumen's specific gravity. First, because bitumen expands when heated and contracts when cooled, a particular quantity of bitumen would have a different volume depending on the temperature. Therefore, certain measures must be taken to modify the temperature-volume relationship. Second, the percentage of voids in the compacted pavement must be found. A variety of percentages of OHA were added to bitumen. These percentages were reported [53].

3.3 Olive husk ash

Olive husk ash (OHA) was obtained by burning the olive husk at 400°C. The ash was sieved through the No. 200 sieve. The corresponding specific gravity of the OHA was 2.23. The chemical composition and gradation of the OHA [54] were provided in the study [49].

The resistance of paving mix to deformation under traffic load was referred to as stability. The Marshall Stability of bituminous materials was related to their resistance to rutting, displacement, distortion, and shear stresses. Internal friction and cohesion played a major role in stability. Internal friction explained the interlocking and friction resistance of aggregates, while cohesion was related to the binding force of binder material. The aggregates must be coated with binder, and the binder must provide adequate liquid friction. In addition, Marshall Stiffness could be used to evaluate asphalt paving mixtures under deformation. High values of stiffness indicated stiffer mixtures, offering higher resistance to deformation. Therefore, good stability and stiffness were essential for bituminous materials.

Durability was defined as the mixture's resistance to abrasion and weathering effects. The retained Marshall Stability and Stiffness values could be used to assess how well paving asphalt mixtures withstand moisture. The Marshall Stability tests were conducted at Transportation Engineering Laboratory at Jordan University of Science and Technology in Irbid – Jordan using the following apparatus: Marshall Testing Machine, Marshall Testing Rig, Marshall Compactor, Asphalt Mixer, Water Bath with constant temperature, Mold, Balance, Extrusion Jack, and Oven.

Voids in mineral aggregate (VMA) was defined as the volume of inter-granular void spaces between the aggregate particles of a compacted paving mixture, which included the air voids and the effective asphalt content. VMA was represented as a percentage of the total sample volume. Between the coated aggregate particles in the final compacted mixture, there were tiny pockets of air called air voids. The average value of bitumen content that satisfied the max. unit weight, optimum stability, and four percent of air voids, was the optimum bitumen content that was equal to 5.25 of the asphalt mixture according to the procedure described in the MS-2 Manual [55] and ASTM D1559 [56] standards for Marshall mix designs. The percentages of the bitumen by volume of the asphalt mixtures were equal to 5%, 5.5%, 6%, 6.5%, and 7%. Three samples from each of the Marshall mix designs were tested for flow, stability, air voids, VMA, and unit weight.

For mixture preparation, aggregate sieved according to MPWH specifications [48] was oven dried to 149°C for one day. The mold was heated at the same temperature. The ash and asphalt were heated seperately at the same temperature for one hour. The precise amount of ash (0, 5, 10, 15, and 20% by volume of binder) and asphalt-cement that complied with the required ash to asphalt-cement ratio was mixed in the lab mixer for 1 hour at 1,600 RPM. The propeller was positioned 1.5 cm above the beaker's base. While mixing, splashing that could cause air bubbles was prevented.

The heated aggregate was placed in the mixer and blend dry for one or two minutes. The appropriate amount of ash-asphalt-cement binder was added and mixed with the aggregate. Before compaction, the ready bulk mix temperature for compaction was equal to 140°C. The mold, scoop and spatula were pre-heated as well. The scoop was to transfer the asphalt mix to the mold. Next, the heated spatula was used to rod the mix vigorously 15 times around the perimeter of the mold and 5 times over the interior. This process ensured a smoother specimen and eliminated any bridging of the rock. The specimen was compacted carefully using the Marshall compactor for 50 blows on each face.

The specimens were forced out of the Marshall molds after one day. An extruder was used to remove each specimen by jacking the specimen up through the hole, keeping the specimen as perpendicular as possible so that the specimen was not distorted. The specimens were heated in a water bath to a temperature of 60°C for 40 minutes. Next, each specimen was placed in the Marshall testing rig. Three specimens from each mix were prepared. The specimen was loaded at a constant rate of strain of 50.8 mm/minute (2 in/minute) to obtain the results.

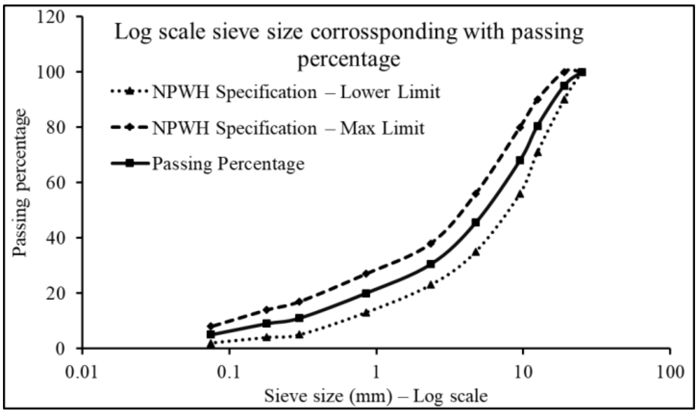


Figure 1. Gradation of limestone aggregate [48]

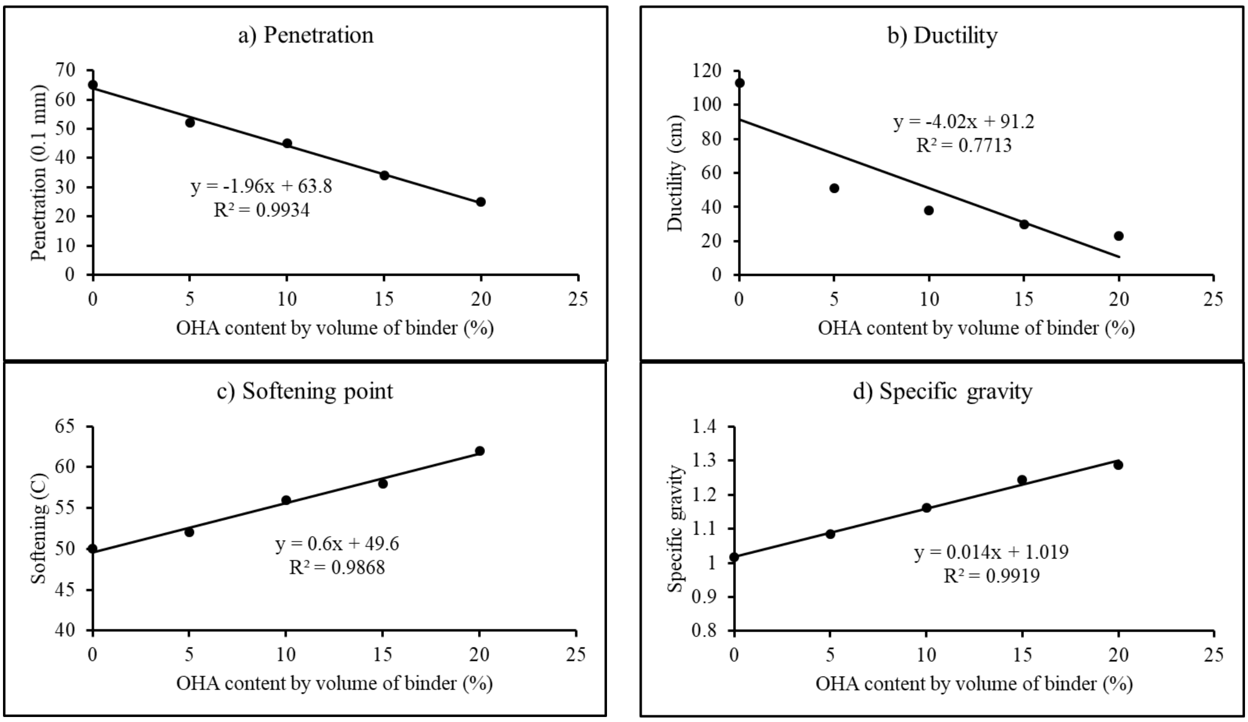
4. RESULTS AND DISCUSSION

In the current study, Marshall specimens were tested at various wet conditioning time beginning with the dry condition to the end of a 30-day time. In particular, the specimens were removed from the water bath and tested at the end of days: 3, 8, 15, and 30. To study the effect of reversed moisture, additional specimens were removed from the water path at the end of day 15, left to dry for the following 15 days, and tested at the end of day 30. The idea was to check the effect of specimens Dryback on the values of Marshall Stability and Stiffness. All previous Marshall Stability tests were conducted on asphalt concrete specimens with OHA replacing bitumen at (0, 5, 10, 15, 20%) by volume. The impact of OHA addition on properties of asphalt binder and asphalt mixture in addition to the moisture performance of specimens were presented in this section.

4.1 Properties of binder and asphalt mixture

The average value of three tests were considered for penetration, ductility, softening point, specific gravity, fire and flash point for each percent (0%, 5%, 10%, 15%, and 20%) of OHA content by volume of binder. The effects of OHA percentage on the penetration, ductility, softening point, specific gravity, fire and flash point of the OHA bitumen binder were shown in Figure 2, respectively with the R^2 values of the linear regression curves shown. Increased OHA content led to a decrease in ductility and penetration. However, it resulted in increase in all of the softening point, specific gravity, and the fire and flash point. Increased OHA content led to decrease penetration and ductility of binder and increase in specific gravity, softening point and fire and flash point. A 10-15% replacement of OHA to bitumen by volume for better performance was suggested in the study [49].

Similarly, the average value of three tests were considered to study the influence of OHA content on Marshall Stability, flow, air voids, and voids in mineral aggregate as shown in Figure 3(a) through (d), respectively with the R^2 values of the linear regression curves shown. Increased OHA content had no effect on air voids, but increased Marshall Stability and voids in mineral aggregate and decreased flow. Increased OHA content had no effect on air voids, but increased Marshall Stability and voids in mineral aggregate and decreased flow. These results agreed well with the study [50].



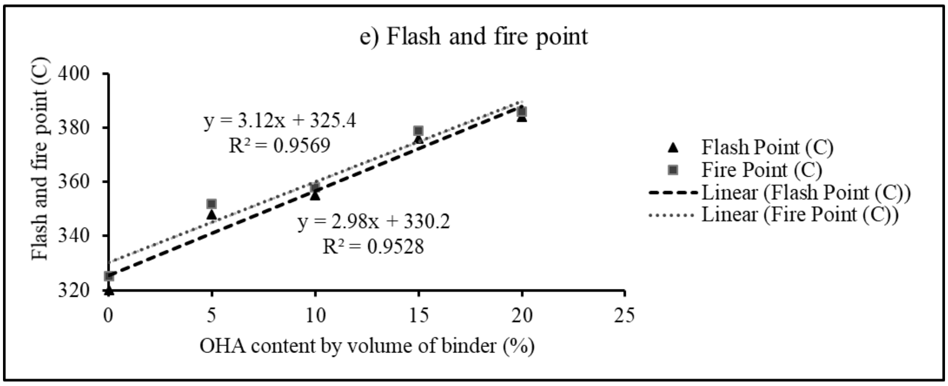


Figure 2. Effect of OHA on properties of binder

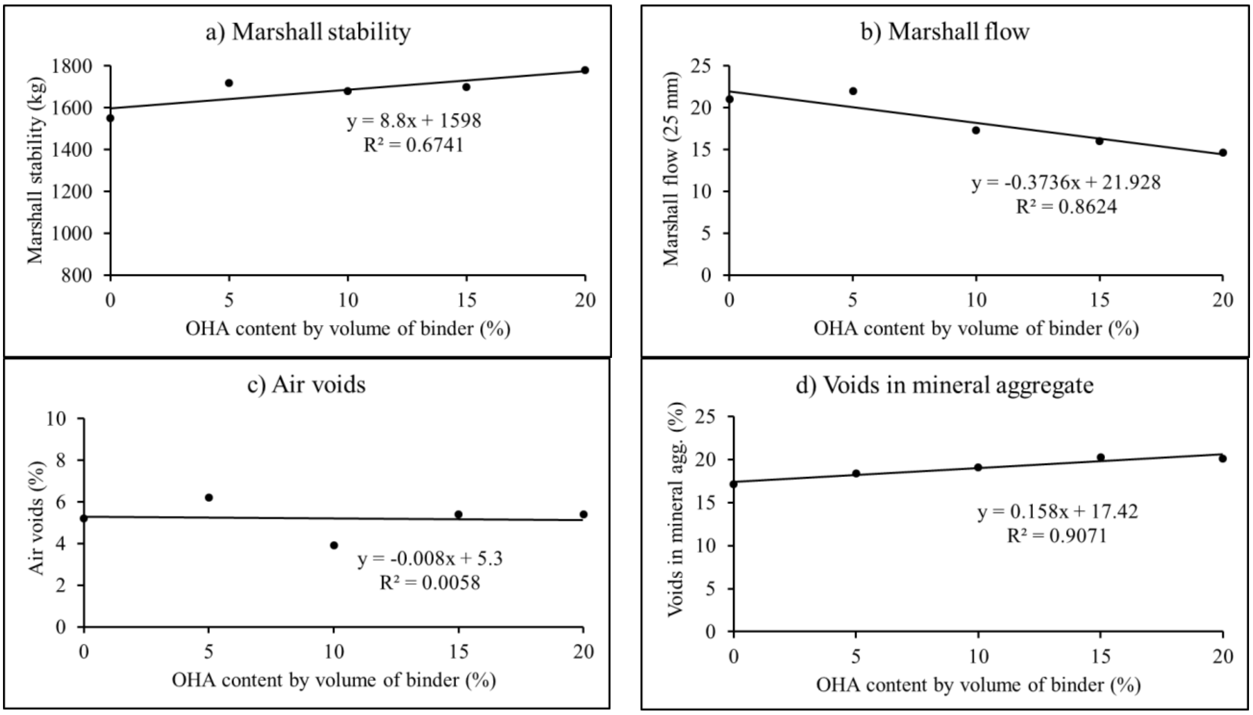


Figure 3. Effect of OHA on properties of asphalt mixtures

4.2 Effect of moisture on properties of asphalt mixture

The effects of wet conditioning and OHA levels on Marshall Stability of the asphalt mixtures were shown in Figure 4. As shown, Marshall Stability decreased with the 5% OHA replacement and increased with the 10, 15, 20% OHA replacement for conditioning time (3, 8, 15, and 30 days). This suggested that the increase in the effective asphalt binder content as part of VMA was the reason behind the increase in Marshall Stability for the 10, 15, 20% OHA replacement. The air voids showed constant trend with the addition of OHA as a replacement to bitumen by volume [50]. Also, it could be seen from Figure 4 that Marshall Stability decreased with the increase of the conditioning time. The percentages of the Marshall Stability reduction values for conditioning time of 3, 8, 15 and 30 days with respect to wet conditioning were 86.15, 72.15, 63.32, 58.90%, respectively for OHA with 10% replacement and 86.86, 73.29, 64.47, 60.19%, respectively for OHA with 15% OHA replacement. Thus, it could be assumed that 15% OHA replacement had the same effect on Marshall Stability as the 10% OHA replacement with respect to moisture. In dry condition, Marshall Stability was greater for asphalt mixtures with the addition of the OHA compared to control mix (without the addition of OHA as a replacement to bitumen by volume). A 10-15% replacement of OHA to bitumen by volume for better performance was presented in the study [49]. Asphalt concrete pavements should not be too strong or too soft under traffic loading.

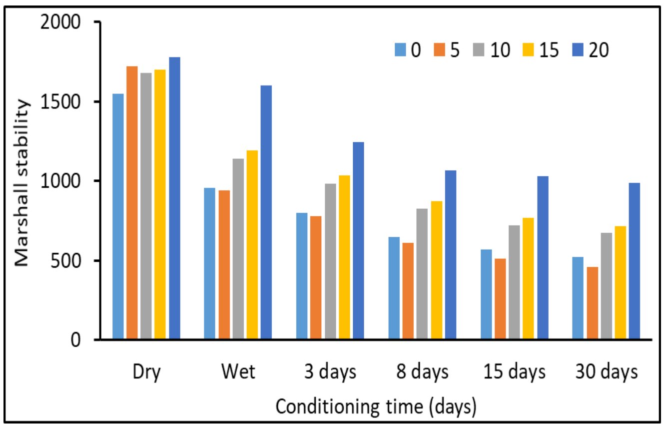


Figure 4. Effect of conditioning time and OHA levels on Marshall Stability for asphalt mixtures

The effect of wet conditioning and OHA levels on retained Marshall Stability of the asphalt mixtures were shown in Figure 5. Retained Marshall Stability could be used to assess the resistance of asphalt mixtures with OHA as filler to moisture. As shown, retained Marshall Stability decreased with the increase of conditioning time; the average values of retained Marshall Stability were 57.37, 47.63, 42.58, 39.79% for days 3, 8, 15, and 30, respectively with respect to dry condition. The rate of decrease in retained Marshall Stability was inversely proportional to the conditioning time. In other words, the rate of decrease was sharp for the short conditioning time (3 days). Then, it slowed down with the long conditioning time (8, 15, and 30 days).

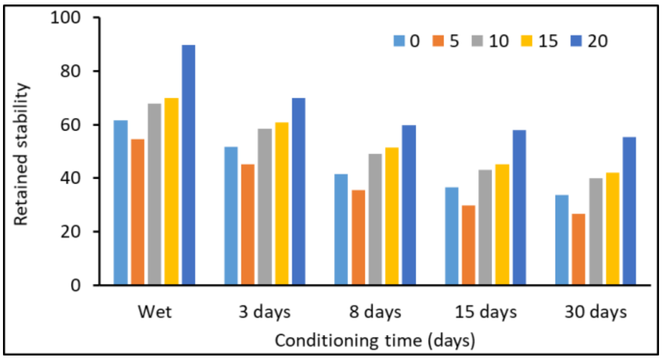


Figure 5. Effect of conditioning time and OHA levels on retained Marshall Stability for asphalt mixtures

Marshall Stability of asphalt mixtures subjected to three conditioning time considering the differ levels of OHA replacing bitumen (0, 5, 10, 15, 20%) by volume was shown in Figure 6. The reversible moisture-induced stability degradation was shown in Figure 6. Dry refer to original specimens without moisture exposure; wet (15 days) referred to specimens subjected 15 days of wet conditioning at 60℃; and Dryback (15 days) referred to previously wet (15 days) specimens that were subsequently dried for 15 days. Marshall Stability was determined at 20℃.

Marshall Stability of specimens with no moisture exposure (dry) dropped by approximately 42.68% from an average of 1686.00kg to 719.63kg after 15 days of wet conditioning, as indicated in Figure 6. The mixture stability increased to 1576.74kg when the wet specimens were dried for 15 days at ambient 20℃ (Dryback), almost all of the stability that had been lost.

The findings in Figure 6 were significant because they reveal that asphalt mixtures could experience reversible stability degradation. Thus, it could be suggested that the stability degradation after wet conditioning was not necessarily or mostly due the adverse effects of water. The chemical and physical properties of bitumen and aggregate would play a role in the performance of asphalt mixture under moisture conditioning [57]. Weakening of bitumen (cohesive), rather than loss of bitumen–aggregate bond (adhesive) was the main damage mechanism [58]. Also, the properties OHA would play a positive role in the performance of asphalt mixture under wet conditioning with a 10-15% replacement of OHA to bitumen by volume for better performance as shown in Figure 6 (Dryback). OHA affected positively by increasing the thickness of the film that coated the aggregate particles.

Marshall Stiffness was related to the resistance of specimens to shear stresses, permanent deformation and rutting. The effects of wet conditioning and OHA levels on Marshall Stiffness of the asphalt mixtures were shown in Figure 7. Marshall Stiffness decreased with the 5% OHA replacement and increased with the 10, 15, 20% OHA replacement for conditioning time (3, 8, 15, and 30 days). Marshall Stiffness decreased with the increase of the conditioning time. The percentages of Marshall Stiffness reduction values for conditioning time of 3, 8, 15 and 30 days with respect to wet conditioning were 83.18, 66.19, 55.47, 49.03%, respectively for OHA with 10% replacement and 94.60, 75.93, 63.81, 56.70%, respectively for OHA with 15% OHA replacement. For the 10% and 15% OHA replacement, the average percentage reduction of retained stiffness values were 88.89, 71.06, 59.64, 52.87% which were similar to the average percentage reduction of retained stability values 86.86, 73.29, 64.47, 60.19%. In dry condition, Marshall Stiffness increased with the increase in the percentage of OHA replacement to the bitumen by volume. Thus, the increase of OHA would increase the hardness and cohesion of bitumen binder.

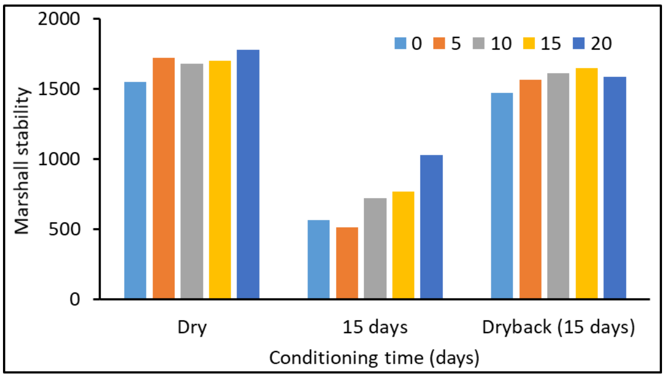


Figure 6. Effect of reversed conditioning and OHA levels on Marshall Stability for asphalt mixtures

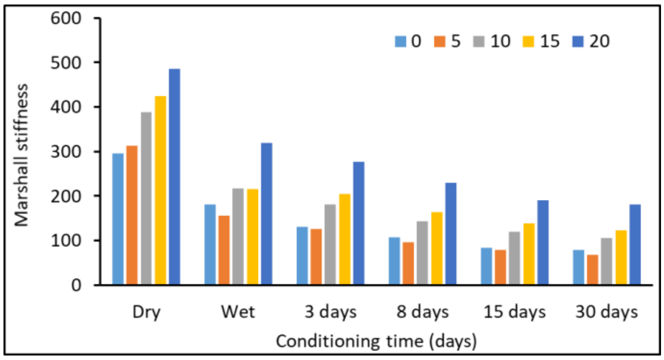


Figure 7. Effect of conditioning time and OHA levels on Marshall Stiffness for asphalt mixtures

The effects of wet conditioning and OHA levels on retained Marshall Stiffness of the asphalt mixtures were shown in Figure 8. Retained Marshall Stiffness could be used to assess the resistance of asphalt mixtures to moisture. As shown, retained Marshall Stiffness decreased with the increase of conditioning time; the average values of retained Marshall Stability were 48.24, 38.92, 32.13, 29.19% for days 3, 8, 15, and 30, respectively with respect to dry condition. The rate of decrease in retained Marshall Stiffness was inversely proportional to the conditioning time. In other words, the rate of decrease was sharp for the short conditioning time (3 days). Then, it slowed down with the long conditioning time (8, 15, and 30 days).

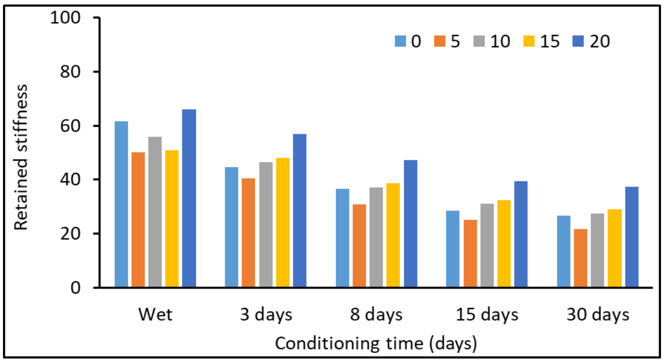


Figure 8. Effect of conditioning time and OHA levels on retained Marshall Stiffness for asphalt mixtures

Marshall Stiffness of asphalt mixtures subjected to three conditioning time considering the differ levels of OHA replacing bitumen (0, 5, 10, 15, 20%) by volume was shown in Figure 9. Figure 9 illustrated the moisture-induced stiffness degradation that was reversible. After 15 days of wet conditioning, the stiffness of specimens with no moisture exposure (dry) dropped by around 32.13%, from an average of 381.38kg/mm to 122.54kg/mm. The mixture stiffness increased to 339.29kg/mm when the wet specimens were subsequently dried for 15 days at ambient 20℃ (Dryback), nearly all of the lost stiffness was regained. The findings in Figure 9 were significant because they revealed that asphalt mixtures could experience reversible stiffness degradation for the same reasons of reversible stability degradation.

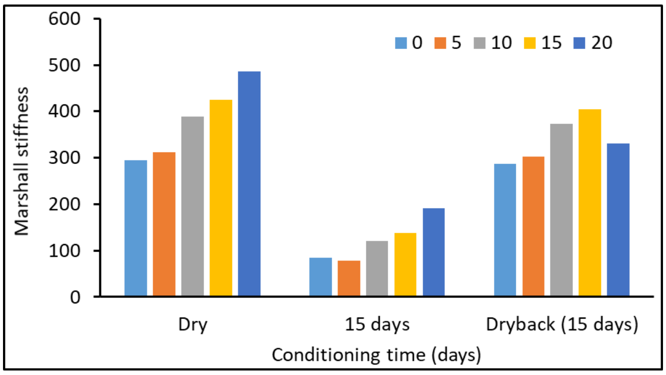


Figure 9. Effect of reversed conditioning and OHA levels on Marshall Stiffness for asphalt mixtures

5. CONCLUSIONS

The Marshall Stability test method was used to investigate moisture resistance of asphalt mixtures with OHA replacement to bitumen by (0, 5, 10, 15, 20%) by volume. Increased OHA content led to decrease penetration and ductility of binder and increase in specific gravity, softening point and fire and flash point. Increased OHA content had no effect on air voids, but increased Marshall Stability and voids in mineral aggregate and decreased flow. The following conclusions were reached based on the results presented in this paper:

(1) Marshall Stability decreased with conditioning time. Depending on OHA replacement percentage to bitumen by volume, Marshall Stability of asphalt mixtures exposed to 30 days of wet conditioning reduced by 26.73-55.39% for the 5-20% OHA replacement to bitumen, respectively with respect to corresponding dry condition.

(2) Marshall Stiffness decreased with conditioning time. Depending on OHA replacement percentage to bitumen by volume, Marshall Stiffness of asphalt mixtures exposed to 30 days of wet conditioning reduced by 21.59-37.41% for the 5-20% OHA replacement to bitumen, respectively with respect to corresponding dry condition.

(3) Marshall Stability and Stiffness were almost all recoverable (above 90%) upon drying the specimens.

In summary, Marshall stability/stiffness decreased ~22-55%/% after 30 days wet conditioning. Upon drying, >90% stiffness/stability recovered, indicating reversible damage. However, limited data replication/characterization and absence of statistics limit conclusions to the specific materials and tests used.

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