*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 23, Issue 1 Ser. 1 (Jan - Feb 2026), PP 87-94*
*www.iosrjournals.org*

# Evaluating Moisture Resistance Of Asphalt Concrete Using A Dual Blend Of Waste Engine Oil And Calcium Carbide Residue

Captain Gospel Otto And Isioma Abraham Okafor
*Department Of Civil Engineering, Rivers State University*
*Nkpolu-Oroworukwo, Port Harcourt.*

***Abstract***
*This research examines the moisture resistance of an asphalt concrete that is modified using a blend of two types of waste engine oil (WEO) and calcium carbide residue (CCR). The Marshall Mix method was used to prepare trial mixes which led to optimum asphalt content of 5.4% and WEO content of 0.3%. CCR modified samples contained 2% to 10% CCR, based on aggregate weight. Following submersion, the indirect tensile strength (ITS) was found to have a 41% increase in strength for the WEO-CCR blend for both 0.3% WEO and 10% CCR which showed a great enhancement of the resistance to moisture. The indirect tensile strength ratio (ITSR) ratio after submersion was up to 79% which was higher than the 75% benchmark while the retained Marshall stability (RMS) in each submersion category was improved by up to 10% that was always higher than that of the minimum threshold of 75%. The swelling index (SI) was improved by 29.3% by the addition of 10% CCR. These findings show the availability of 0.3% WEO and 10% CCR as the best results in terms of moisture resistance, making its use as an alternative material for paving. It should be noted that the study was carried out under laboratory conditions, which may not be totally representative of the performance in the field. The variability of wastes needs to be focused on in future studies as well as the long-term impacts of the waste materials on pavement durability.*
***Keywords:*** *Moisture Resistance; Indirect Tensile Strength Ratio; Retained Marshal Stability; Swelling Index; Hot Mix Asphalt.*

Date of Submission: 17-01-2026 Date of Acceptance: 27-01-2026

## I. Introduction

The strength, moisture resistance, and durability of asphalt concrete are largely determined by the type and quality of the asphalt binder and aggregates (Jitsangiam et al., 2018). Performance under different environmental conditions, especially resistance to damage due to moisture is an important factor affecting the life span of the pavement (Ottos & Amadi-Oparaeli 2018; Otto & Amadi-Oparaeli, 2019; Brown & Heitzman, 2013). The incorporation of additives like shredded tyre chips, polymer modifiers, fibres or candle wax has been proven to greatly increase the performance of asphalt concrete (Igwe & Ottos, 2016; Otto et al., 2020; Otto & Akpila, 2020). These modifications include the increase of adhesive and cohesive strength of the binder, decrease of permeability and improve aggregate resistance to moisture damage and consequently make the pavements more durable and resilient (Diedfenderfer & Hearon, 2011; Igwe et al., 2016; Otto & Awarri, 2021; Igwe & Ottos, 2017). Increasing the moisture resistance capacity of asphalt concrete is known to increase the life of pavements (Abd-Alkhaleq and Ismael, 2025). Current research focuses on the application of additives, especially sustainable or waste-based materials, in order to manage moisture-induced problems such as stripping, rutting and cracking (Ismael et al., 2024). Mohammed & Ismael (2021) associate a higher tensile strength ratio (TSR) with improved asphalt moisture stability. Wei et al. (2022) examine the durability of asphalt mixtures exposed to acid rain erosion, although they do not provide specific findings on the relationship between varying acidity and moisture resistance.

The evaluation of acid eroded, acid rain resistant asphalt mixtures give some ideas to be applied to the evaluation of some innovative modifiers such as waste engine oil and calcium carbide residue for sustainable and durability asphalt concrete (Wei et al., 2022). Waste engine oil as a viscous and adhesive substance can improve the flexibility and durability of asphalt binders (Zhu et al., 2020). Poor management, however, can lead to pollution of the environment, and its vulnerability to oxidative aging is a cause of concern to its durability. Calcium carbide residue is a by-product of acetylene gas production, which can be used as potential filler additive with improved aggregate properties and less moisture susceptibility (Iwo et al., 2021; Li et al., 2018). However, its alkalinity requires the careful dosage to avoid diminishing moisture resistance and loss of toxic compounds. The combined use of these materials may have a synergistic effect and improve the performance of asphalt concrete further. Such a strategy is not only a way of taking care of the environment through recycling of waste materials, but it is also a way through which the cost-effectiveness can be achieved to enhance the pavement durability and service life. It needs additional research on the long-term effect of the environment and structure (Isa et al., 2024).

The main aim of the research is to investigate the qualities of asphalt concrete in relation to the resistance to moisture when it is modified with the waste engine oil (WEO) and calcium carbide residue (CCR) during submerged conditions. The specific objectives are to find the tensile strength, indirect tensile strength ratio, retained Marshall stability and swelling index of the modified samples subject to submersion.

## II. Materials And Methods

**Materials**

The materials used for this study, including their respective sources, are shown in Table 1:

**Table 1: Material and Sources**

| S/N | Material | Source |
|---|---|---|
| 1 | Gravel | Building Material market in Mile III Port Harcourt |
| 2 | Sand | Building Material market in Mile III Port Harcourt |
| 3 | Asphalt Binder | Setraco Asphalt Plant, Elele |
| 4 | Waste engine oil | Local mechanic workshop with Port Harcourt |
| 4 | Calcium carbide residue | Gas welding workshop within Port Harcourt. |

**Methods**

**Material Properties and Classification**

Material property classification tests were conducted in line with ASTM (2010), and the following results were obtained:

Table 2: Material Properties

| | Materials | | | | |
|---|---|---|---|---|---|
| **Test** | **Bitumen** | **Gravel** | **Sand** | **WEO** | **CCR** |
| Penetration (mm) | 63.3 | - | - | - | - |
| Specific gravity (G) | 1.01 | 2.60 | 2.78 | 0.79 | 2.57 |
| Softening point ($^0$C) | 52 | - | - | - | - |
| Vaac. Capillary Viscosity | 3.0 | - | - | 41.2 | - |
| Mix proportion (%) | - | 60 | 40 | - | - |

Table 3: Aggregates Combination

| Sieve size (mm) | Upper Limit | Lower Limit | (%) passing A | | (%) passing B | Mix proportion |
|---|---|---|---|---|---|---|
| 19 | 100 | 100 | 100 | | 100 | 100.0 |
| 12.5 | 86 | 100 | 95.7 | | 100 | 97.4 |
| 9.5 | 70 | 90 | 62.5 | | 100 | 77.5 |
| 6.3 | 45 | 70 | 15 | | 100 | 49.0 |
| 4.75 | 40 | 60 | 1.5 | | 99 | 40.5 |
| 2.36 | 30 | 52 | 0.5 | | 95.8 | 38.6 |
| 1.18 | 22 | 40 | 0.5 | | 88.1 | 35.5 |
| 0.6 | 16 | 30 | 0.5 | | 77.5 | 31.3 |
| 0.3 | 9 | 19 | 0.5 | | 25.4 | 10.5 |
| 0.15 | 3 | 7 | 0.5 | | 3.4 | 1.7 |
| 0.075 | 0 | 0 | 0.5 | | 0.3 | 0.4 |

**Preparation of Samples**

Samples were prepared following the Marshall HMA Design procedures outlined by the Asphalt Institute (2014). The mix design process included the determination of the correct proportions of coarse and fine aggregates and additives in which the mix design was described by Kim et al. (1992). Briquette samples were made following the procedure of Schuler & Huber (1992) with different contents of asphalt binder (4% to 6%) in 0.5% steps to determine the optimum asphalt content (OAC) of 5.4% which gave maximum stability, density and 4% air voids. (Marshall and Balanced Mix Design in Determining the Asphalt Content for Hot Mix Asphalt Mixture: A Comparative Study, 2024) The design of a dual blend approach has been implemented with WEO incorporated in binder at 0.1% increments up to 0.5%, as shown in Table 4 in detail.

Table 4: Blending Schedule for Determination of Optimum Binder & WEO Content

| | **WEO (%)** | | | | |
|---|---|---|---|---|---|
| | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
| **Bitumen (%)** | **Proposed WEO-CCR Blends** | | | | |
| | **A** | **B** | **C** | **D** | **E** |
| 4.0 | 4.0: 0.1 | 4.0: 0.2 | 4.0: 0.3 | 4.0: 0.4 | 4.0: 0.5 |
| 4.5 | 4.5: 0.1 | 4.5: 0.2 | 4.5: 0.3 | 4.5: 0.4 | 4.5: 0.5 |
| 5.0 | 5.0: 0.1 | 5.0: 0.2 | 5.0: 0.3 | 5.0: 0.4 | 5.0: 0.5 |
| 5.5 | 5.5: 0.1 | 5.5: 0.2 | 5.5: 0.3 | 5.5: 0.4 | 5.5: 0.5 |
| 6.0 | 6.0: 0.1 | 6.0: 0.2 | 6.0: 0.3 | 6.0: 0.4 | 6.0: 0.5 |

Optimal content of asphalt was used to cast representative samples of both control and WEO-modified mixes. WEO-CCR-modified mixes were made by adding 2, 4, 6, 8 and 10 percent CCR in aggregate weight. The samples were kept in water 0-5 days. Density and void analysis was done after all soaking periods. The Marshall Test apparatus was then used to determine stability and flow at 60 °C.

Table 5: Mix Design Properties for Trial Mix

| **Binder %** | **Stability (kN)** | **Density (kg/m$^3$)** | **Flow (mm)** | **VTM (%)** | **VMA (%)** | **VFA (%)** |
|---|---|---|---|---|---|---|
| 4.0 | 27.1 | 2337 | 2.20 | 6.700 | 12.5 | 46.2 |
| 4.5 | 27.6 | 2354 | 2.26 | 5.284 | 11.8 | 55.2 |
| 5.0 | 30.5 | 2364 | 2.53 | 4.141 | 11.4 | 63.7 |
| 5.5 | 30.6 | 2378 | 2.75 | 2.856 | 10.9 | 73.8 |
| 6.0 | 30.8 | 2359 | 2.93 | 2.913 | 11.6 | 74.9 |

**Indirect Tensile Strength (ITS) and Indirect Tensile Strength Ratio (ITSR)**

Tensile strength and ITSR of the prepared specimens were obtained from the equations below.

$$ITS = \frac{2P}{\pi dt} \quad (1)$$

$$ITSR = \frac{S_2}{S_1} \quad (2)$$

Where: P = Load at sample failure
d = Diameter of sample (mm)
t = Thickness of specimen (mm)
**$S_1$** = Indirect Tensile Strength of dry Specimen
**$S_2$** = Indirect Tensile Strength of submerged specimen

**Retained Marshall Stability (RMS)**

The Retained Marshall Stability measures the loss in Marshall Stability of the HMA after submergence and is expressed in Equation 3:

$$RMS = \frac{S_1}{S_0} \times 100\% \quad (3)$$

Where, RMS = Retained Marshall Stability
**$S_0$** = Stability of dry Specimen
**$S_i$** = Stability of submerged specimen

**Swelling Index**

The swelling index (SI) measures the percentage change in specimen volume due to water absorption during submersion. SI was obtained according to the equation:

$$SI = \frac{V_2 - V_1}{V_1} \times 100\% \quad (4)$$

and Volume (V) of the soaked specimen was obtained from the Equation 5.

$$V = \frac{W_a}{\frac{W_a - W_w}{W_a} \times 1000} \quad (5)$$

Where, $V_1$ = dry specimen volume
$V_2$ = soaked specimen volume

$W_a$ = specimen weight in air
$W_w$ = specimen weight in water

## III. Results

**Indirect Tensile Strength**

The ITS results for unmodified and WEO-CCR-modified samples under various soaking conditions are shown in Table 6 and Figures 1 and 2

Table 6: ITS of Submerged Samples

| Indirect Tensile Strength (N/mm²) | | | | | | |
|---|---|---|---|---|---|---|
| **CCR** | **day 0** | **day 1** | **day 2** | **day 3** | **day 4** | **day 5** |
| 0% | 3.09 | 2.99 | 2.75 | 2.72 | 2.35 | 2.23 |
| 2% | 3.28 | 3.09 | 2.98 | 2.92 | 2.53 | 2.40 |
| 4% | 3.37 | 3.33 | 3.09 | 3.07 | 2.63 | 2.52 |
| 6% | 3.69 | 3.65 | 3.47 | 3.40 | 2.92 | 2.74 |
| 8% | 3.75 | 3.74 | 3.64 | 3.45 | 2.98 | 2.83 |
| 10% | 3.97 | 3.93 | 3.76 | 3.66 | 3.20 | 3.14 |

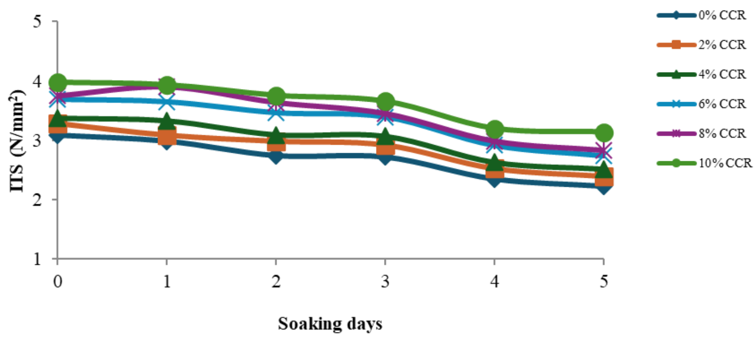


Figure 1: *Graph of ITS against soaking days*

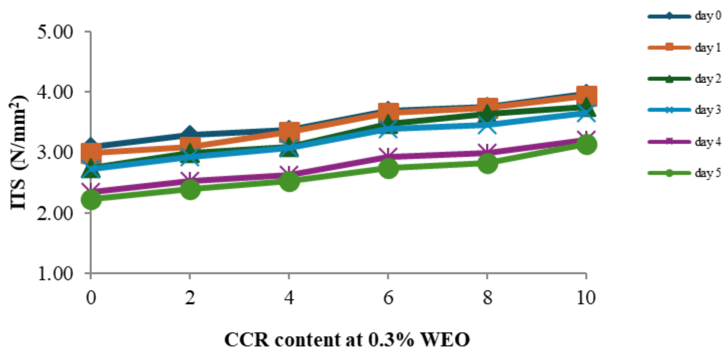


Figure 2: *Graph of ITS against CCR*

Figures 1 and 2 shows that, in the unsoaked category, ITS increased by 28.5%, from 3.09 N/mm² at 0% CCR to 3.97 N/mm² at 10% CCR. For samples soaked for one day, ITS increased by 31.6%, from 2.99 N/mm² at 0% CCR to 3.93 N/mm² at 10% CCR. Five days into the soaking, ITS rose up by 41%, starting with 2.23 N/mm² at 0% CCR to 3.14 N/mm² at 10% CCR. The findings reveal that submersion has the potential to decrease the tensile strength of hot mix asphalt (HMA): overtime but the inclusion of calcium carbide residue (CCR) elevates the resistance of the mixture to water destruction and elevates the mechanical performance relative to the conventional HMA containing limestone filler. This finding is consistent with Dulaimi et al., (2024) findings.

The results indicate that submersion can reduce the tensile strength of hot mix asphalt (HMA) over time; however, the addition of calcium carbide residue (CCR) improves the mixture's resistance to water damage and enhances its mechanical performance compared to traditional HMA with limestone filler. This result supports Dulaimi *et al*., (2024) findings.

**Indirect tensile Strength Ratio**

Table 7 and Figures 3 and 4 show the variation of ITSR of WEO-CCR modified HMA under various soaking conditions.

**Table 7: ITSR of Specimens after Soaking**

| ITSR (%) | | | | | | |
|---|---|---|---|---|---|---|
| **CCR** | **day 0** | **day 1** | **day 2** | **day 3** | **day 4** | **day 5** |
| 0% | 100 | 96.7 | 88.8 | 88.0 | 76.0 | 72.0 |
| 2% | 100 | 94.1 | 90.9 | 89.0 | 77.0 | 73.0 |
| 4% | 100 | 98.7 | 91.7 | 91.0 | 78.0 | 74.6 |
| 6% | 100 | 98.9 | 93.9 | 92.0 | 79.0 | 74.3 |
| 8% | 100 | 99.7 | 97.0 | 92.0 | 79.5 | 75.4 |
| 10% | 100 | 99.0 | 94.5 | 92.0 | 80.5 | 79.0 |

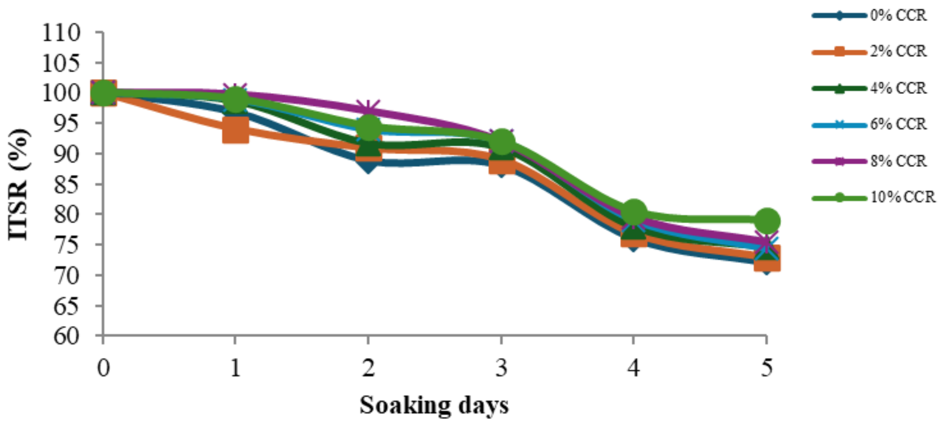


Figure 3: *Graph of ITSR against soaking days*

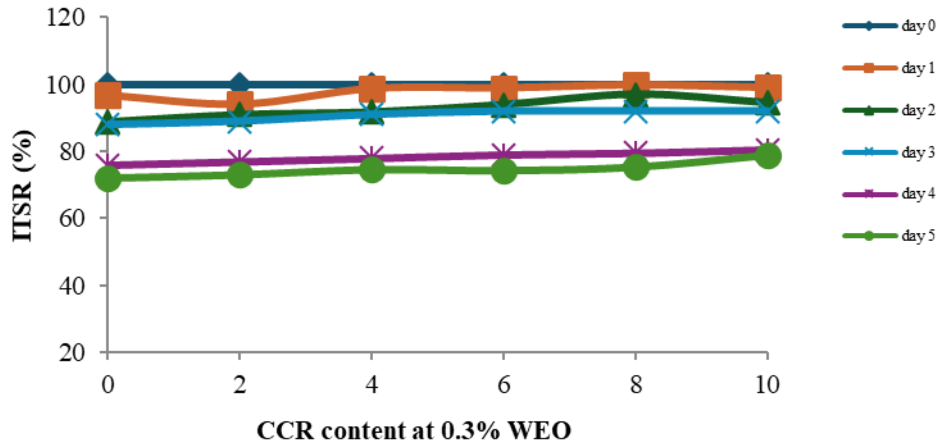


Figure 4: *Graph of ITSR against CCR*

At 24 hours, the ITSR was 96.7% in the unmodified sample and 99% in the CCR-modified samples, which is a 3.3 percent drop. Nevertheless, the 10% CCR additive made sure that ITSR would increase by 2.3% as opposed to the plain mix. Following 5 days of submersion, the ITSR of the unmodified sample was 72% with the CCR-modified samples being 79% which is a drop in ITSR of 28%. Nevertheless, by increasing it up to 10% CCR, there was a 9.7% change in increase in ITSR than in the unmodified mix. Ismael *et al*., (2024) in similar study observed same trend when using WEO in asphalt mixes.

**Retained Marshall Stability**

Table 8 and Figures 5 and 6 show the variation of Retained Marshall Stability of CCR modified HMA under various soaking conditions.

**Table 8: Retained Marshall Stability of the specimen after soaking**

| Retained Marshall Stability (%) | | | | | | |
|---|---|---|---|---|---|---|
| **CCR** | **day 0** | **day 1** | **day 2** | **day 3** | **day 4** | **day 5** |
| 0% | 100 | 96.7 | 88.8 | 88.0 | 76.0 | 72.0 |
| 2% | 100 | 94.1 | 90.9 | 89.0 | 77.0 | 73.0 |
| 4% | 100 | 98.7 | 91.7 | 91.0 | 78.0 | 74.6 |
| 6% | 100 | 98.9 | 93.9 | 92.0 | 79.0 | 74.3 |
| 8% | 100 | 99.7 | 97.0 | 92.0 | 79.5 | 75.4 |
| 10% | 100 | 99.0 | 94.5 | 92.0 | 80.5 | 79.0 |

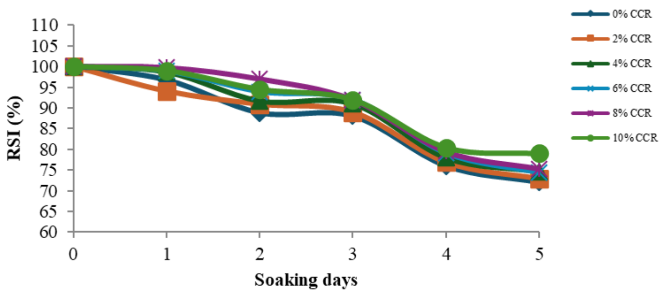


Figure 5: *Graph of RSI against soaking days*

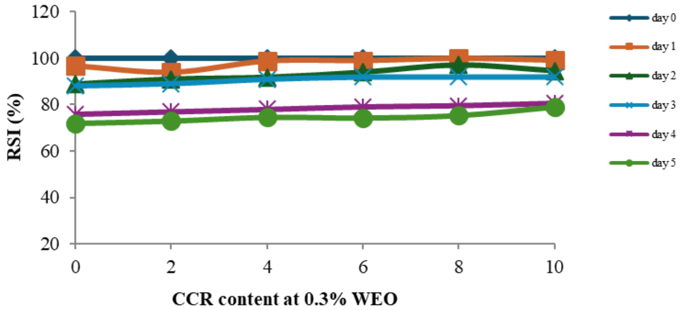


Figure 6: Graph of RMS against CCR

From Figures 5 and 6, the addition of WEO-CCR blends in varying percentages influenced RSI for each category. After 1 day of submersion, the retained strength of the modified mixture ranged from 96.7% for the unmodified sample to 99% for the CCR-modified samples, indicating that 3.3% of its strength was lost after 24 hours. However, adding up to 10% CCR increased RSI by 2.3% compared to the unmodified mix. After 5 days of submersion, the retained strength of the modified mixture ranged from 72.0% for the unmodified sample to 79.0% for the CCR-modified samples, indicating a loss of strength of 21%-28.0% after 5 days. However, adding up to 10% CCR increased RMS by 9.7% compared to the unmodified mix. This aligns to the study of Ismael *et al*., (2024).

**Swelling Index**

Table 9 and Figures 7 and 8 show the variation of the Swelling Index of WEO-CCR modified HMA after submergence.

Table 9: Swelling Index of specimens after Soaking

| Swelling Index | | | | | | |
|---|---|---|---|---|---|---|
| **CCR** | **day 0** | **day 1** | **day 2** | **day 3** | **day 4** | **day 5** |
| 0% | 0.00 | 1.511 | 2.248 | 3.436 | 4.010 | 4.363 |
| 2% | 0.00 | 1.465 | 2.070 | 2.953 | 3.619 | 4.377 |
| 4% | 0.00 | 1.348 | 1.820 | 2.434 | 2.794 | 3.549 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6% | 0.00 | 1.263 | 1.601 | 2.351 | 2.710 | 3.466 |
| 8% | 0.00 | 1.087 | 1.425 | 2.311 | 2.670 | 3.426 |
| 10% | 0.00 | 1.023 | 1.360 | 1.972 | 2.330 | 3.085 |

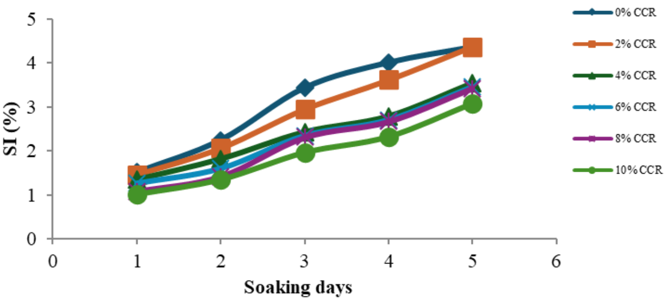


Figure 7: *Graph of swelling index against soaking days*

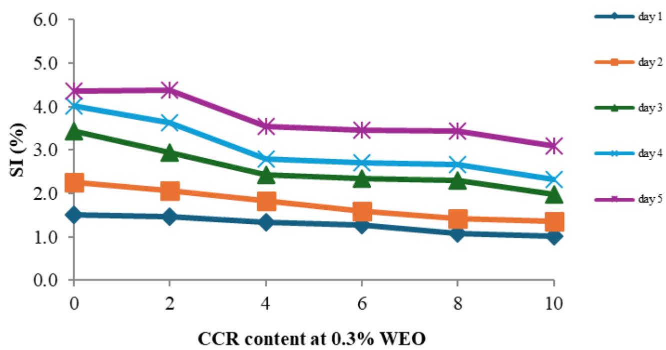


Figure 8: *Graph of swelling index against CCR*

Figures 7 and 8 show the changes in swelling due to WEO-CCR content and soaking condition for both modified and unmodified samples. The swelling index after 1 day of submersion ranged from 1.02 to 1.51, indicating a 32.3% increase with the addition of 2% to 10% CCR. The lowest swelling index value was, however, observed at 10% CCR. This shows that CSA addition reduced the HMA's swelling potential to 10% CCR in the 24-hour soaking category. After five soaking days, SI ranged from 3.09 to 4.36, indicating a 29.3% decrease with 2% to 10% CCR content. The minimum values, however, were observed at 10% CCR across all soaking categories. This was also observed in Isa *et al*., (2023).

Overall, the swelling index increased with longer submersion periods. However, the addition of WEO and CCR blends reduced SI values, indicating that the WEO-CCR combination lessened the impact of submersion on the modified HMA samples.

## IV. Conclusion

The indirect tensile strength of WEO-CCR modified mixes was found to increase with the addition of 10% CCR. As a result, the indirect tensile strength (ITSR) after 5 days of submersion was 79% which exceeded the minimum requirement value of 75% for moisture resistance. The Retained Marshall Stability (RMS) of WEO-CCR-modified mixes reduced with increasing submerge time. However, a CCR content of 10% ensured retained strength index to 79% after submersion, which is more than permissible limit of 75%. Swelling index (SI) of WEO-CCR modified mixes increased with increase of submersion times. However, 10% CCR content contained the swelling index by 29.3% after submersion.

## References


[1]. Abbas, A., Suresha, S. N., Veeraragavan, A., & Uday, V. (2016). Laboratory Investigation On The Influence Of Waste Engine Oil On The Properties Of Bitumen And Hot Mix Asphalt. Construction And Building Materials, 127, 122-128. Https://Doi.Org/10.1016/J.Conbuildmat.2016.09.036.

[2]. Abd-Alkhaleq, W. A. & Ismael, M. Q. (2025). Enhancing The Moisture Resistance In Asphalt Mixtures Using Epoxy Resin. Engineering 15(5). Https://Doi.Org/10.48084/Etasr.12476

[3]. Asphalt Institute (2014). Asphalt Mix Design Methods (Seventh Edition), Manual Series No.2 (MS-2). Lexington, KY.

[4]. ASTM (2010). Annual Book Of ASTM Standards. ASTM International: West Conshohocken, PA.

[5]. Brown, E. R., & Heitzman, M. (2013). "Thin Asphalt Concrete Overlays In Maintenance Applications: What, Why, And How." Transportation Research Record: Journal Of The Transportation Research Board, 2369(1), 16-26. Doi:10.3141/2369-03.

[6]. Diefenderfer, S., & Hearon, A. (2011). "Enhancing The Durability Of Asphalt Pavements With Modifiers." Virginia Transportation Research Council. Http://Www.Virginiadot.Org/Vtrc/Main/Online_Reports/Pdf/11-R10.Pdf.

[7]. Dulaimi, A., Nuh, B. P. & Al-Mashaqbeh, M. A. (2024). An Evaluation Of The Performance Of Hot Mix Asphalt Containing Calcium Carbide Residue As A Filler. TRID. Https://Doi.Org/10.3141/1718882

[8]. Ghabchi, R., & Sheikhzadeh, M. (2017). Investigating The Effects Of Waste Engine Oil On The Properties Of Hot Mix Asphalt. Construction And Building Materials, 134, 240-249. Https://Doi.Org/10.1016/J.Conbuildmat.2016.12.113.

[9]. Igwe, E. A., Ottos, C. G. And Ekwulo, E. O (2016). "The Role Of Candle Wax As Non-Bituminous Modifier In Material Recharacterization Of Bituminous Concrete Used Synonymously For Flexible Pavement – Study On Voids And Flow", IOSR Journal Of Mechanical And Civil Engineering (IOSR -JMCE) 13(5), 74-81.

[10]. Igwe, E. A., And Ottos C. G. (2017). "Increasing Durability Of Bituminous Pavements Using Hydrocarbon Void Fillers Produced From Recycled Polyethylene Wastes (RPEW)", Journal Of Scientific And Engineering Research 4(12), 24-30.

[11]. Igwe, E. A., And Ottos C. G. (2016). "Investigating The Effect Of Air Voids Content In Fatigue Life Of Hot Mix Asphalt Mixtures: A Case Study Of Rubberized Asphalt Concrete", International Journal Of Innovative Science, Engineering & Technology 3(5), 6-64.

[12]. Igwe, E. A., Ekwulo, E. O. And Ottos, C. G. (2016). "Moisture Effect On Stiffness Of Asphalt Concretes For Low Volume Roads: Comparative Study Of Asphalt Institute And Witczak 1-40D Models", International Journal Of Constructive Research In Civil Engineering (IJCRCE) 2(4), 1-8.

[13]. Iwo, E.O., Ekwulo, E.O. & Igwe, E.A. (2021). Moisture Resistance Of Modified Calcium Carbide Residue As Void Filler In Asphalt Concrete. International Journal Of Research In Engineering And Sciences, 9(9), 57-66.

[14]. Isa, N., Olowosulu, A. & Joel, M. (2024). Mechanistic Evaluation Of The Effect Of Calcium Carbide Waste On Properties Of Asphalt Mixes. Nigerian Journal Of Technological Development 15(1), Pp. 1-8. Https://Doi.Org/10.63746/Njtd.V15i1.141

[15]. Ismael, M. Q., Sahib, Z. A. & Rasheed, A. H. (2024). Utilizing Waste Engine Oil And Soft Binder As Additives To Mitigate The Moisture Damage Of Asphalt Mixtures. Engineering 14, Pp. 17604-17612. Https://Doi.Org/10.48084/Etasr.7451

[16]. Isa, N., Olowosulu, A. & Joel, M. (2023). Mechanistic Evaluation Of The Effect Of Calcium Carbide Waste On Properties Of Asphalt Mixes. Nigerian Journal Of Technological Development 15(1), Pp. 141-148. Https://Doi.Org/10.63746/Njtd.V15i1.141

[17]. Jitsangiam, P., Nikraz, H. & Nusit, K. (2018). Asphalt Concrete Moisture Damage Resistance: An Evaluation Of The Coating Ability Of Aggregates And Binders. Materials Science Forum 934, Pp. 217-221. Https://Doi.Org/10.4028/Www.Scientific.Net/MSF.934.217

[18]. Khattak, M. J., Mirza, M. W., Mahmood, A., & Ahmed, S. (2019). Use Of Waste Engine Oil In Bituminous Mixes: Environmental Concerns And Recommendations. Journal Of Hazardous Materials, 378, 120739. Https://Doi.Org/10.1016/J.Jhazmat.2019.05.058.

[19]. Kim Y. R., Kim N. And Khosla N. P (1992) Effects Of Aggregate Type And Gradation On Fatigue And Permanent Deformation Of Asphalt Concrete, Effect Of Aggregates And Mineral Fillers On Asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society For Testing And Material, Philadelphia.

[20]. Li, C., Zhang, Y., & Ma, T. (2018). "Recycling Waste Calcium Carbide Slag As A Sustainable Binder For Cement-Stabilized Base." Journal Of Cleaner Production, 185, 141-149. Doi:10.1016/J.Jclepro.2018.03.012.

[21]. Liu, X., Zhang, Z., & Tang, Q. (2019). Effect Of Calcium Carbide Residue On Aging Resistance And Moisture Susceptibility Of Asphalt Mixture. Construction And Building Materials, 212, 709-718. Https://Doi.Org/10.1016/J.Conbuildmat.2019.03.074

[22]. Mashaan, N. S., Ali, A. H., Karim, M. R., & Abdelaziz, M. (2014). Utilization Of Waste Engine Oil In Asphalt Concrete Mixture. Journal Of Cleaner Production, 78, 235-240. Https://Doi.Org/10.1016/J.Jclepro.2014.04.049.

[23]. Mohammed S.F., Ismael M.Q. Effect Of Polypropylene Fibers On Moisture Susceptibility Of Warm Mix Asphalt. Civ. Eng. J. 2021;7:988–997. 10.28991/Cej-2021-03091704

[24]. Otto C. G And Amadi C. P. (2020). "Laboratory Investigation Of The Effect Of Traffic Load Frequency And Moisture On The Fatigue Life Of Asphalt Concrete Pavement" International Journal Of Trend In Research And Development 7(4), 205-208

[25]. Otto, C. G. And Awarri, A. W. (2021). "Comparative Cost-Effectiveness Of Modified Asphalt Concrete Submerged In Moisture As Related To Fatigue Performance", IOSR Journal Of Mechanical And Civil Engineering (IOSR -JMCE) 18(2), 49-54.

[26]. Otto, C. G., And Akpila S. B. (2020). "Performance Analysis Of Candle Wax Modified Asphalt Pavement Wearing Course Submerged In Moisture". International Journal Of New Technology And Research, 6(11), 15-17.

[27]. Otto, C. G., Igwe E. A. And Ekwulo, E. O. (2020). "Fatigue Performance Of Asphalt Pavement Wearing Course In Submerged Condition Modified With Shredded Tyre Chips". International Journal Of Scientific & Engineering Research 11(11), 167-172. ISSN 2229-5518

[28]. Otto, C. G., And Amadi-Oparaeli, K. I.(2019), "Cost Effectiveness Of Waste Polythene Bag Modified Asphalt Concrete Submerged In Moisture" International Journal Of New Technology And Research, 5(6), 01-08.

[29]. Ottos, C. G., And Nyebuchi, D. A. (2018). "Swell Behaviour Of Asphalt Pavement Wearing Course With ESAL >106 Under Sub-Merged Conditions". International Journal Of Trend In Research And Development, 5(2), 242-244. ISSN 2394-9333

[30]. Ottos, C. G., And Amadi-Oparaeli, K. I. (2018) "Influence Of Waste Polythene Bags On The Index Of Retained Stability Of Asphalt Concretes Under Moisture For Low Volume Roads" International Journal Of Trend In Research And Development 5 (2), 209-214.

[31]. Shen, S., Wu, C., Zhou, F., & Scullion, T. (2010). "An Overview Of Moisture Damage In Asphalt Mixtures." Journal Of Testing And Evaluation, 38(4), 362-372. Doi:10.1520/JTE101667.

[32]. Shuler T. S. And Huber G. (1992) Effect Of Aggregate Size And Other Factors On Refusal Density Of Asphalt Concrete By Vibratory Compaction, Effect Of Aggregates And Mineral Fillers On Asphalt Mixtures Performance, ASTM STP 1147, Richard C. Meininger, Ed., American Society For Testing And Material, Philadelphia.

[33]. Wei, J., Chen, Q., Du, J., Liu, K., & Jiang, K. (2022). Study On The Durability Of Acid Rain Erosion-Resistant Asphalt Mixtures. Materials (Basel), 15(5), 1849.

[34]. Wu, S., Cao, D., & Zhao, S. (2018). Effects Of Calcium Carbide Residue On The Properties Of Asphalt Mixture. Construction And Building Materials, 186, 792-799. Https://Doi.Org/10.1016/J.Conbuildmat.2018.07.020.

[35]. Yang, X., Xiao, Y., & Li, N. (2020). Influence Of Calcium Carbide Residue On Asphalt-Aggregate Adhesion And Mixture Performance. Construction And Building Materials, 235, 117450. Https://Doi.Org/10.1016/J.Conbuildmat.2019.117450

[36]. Zhao, Z., Guo, Q., Wang, Z., & Wang, H. (2017). "Moisture Damage Evaluation Of Asphalt Mixtures Based On Surface Free Energy And Thermodynamic Parameters." Materials, 10(10), 1170. Doi:10.3390/Ma10101170.

[37]. Zhu, J., Li, P., & Wang, H. (2020). "Utilization Of Waste Engine Oil (WEO) In Asphalt Pavement: Performance Evaluation And Mechanistic Understanding." Journal Of Cleaner Production, 249, 119375. Doi:10.1016/J.Jclepro.2019.119375.