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Moisture Resistance of Modified Calcium Carbide Residue as Void Filler in Asphalt Concrete.

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Abstract: Moisture is the greatest challenge of flexible pavement; hence, its effects cannot be over emphasized. It has the ability to penetrate through the allowable voids in the pavement, weakening the binder and segregating aggregates from their unified and densified state. Calcium carbide residue (CCR) has been used as in the production of Ordinary Portland cement concrete and it has been proven to be useful because of its pozzolanic properties but its use in asphalt cement concrete has not been harnessed. This study investigates the effect of calcium carbide residue on moisture resistance of asphalt concrete. Asphalt concrete specimens were prepared in accordance with Marshall mix design criteria and subjected to moisture and durability tests like Retained Marshal Stability (RMS), Swelling Index (SI) and Indirect Tensile Strength ratio (ITSR). Specimens were modified using 2 - 10% Calcium Carbide Residue (CCR) and soaked in water for 1 to 5 days adopting the Marshall mix design and soaking procedures. The results of Retained Marshall Stability, Swelling Index and Indirect Tensile Strength Ratio all showed that the resistance to moisture damage increased as the CCR content increased from 2 - 10%. The results also showed that the mix design properties of asphalt concrete modified using CCR meets minimum requirements in terms of Mix design properties in accordance with Asphalt Institute criteria. The study concluded that as the soaking days increased, the pavement absorbed water, but the CCR filled the voids thereby improving moisture resistance of the asphalt concrete as its percentage was increased from 2 – 10% and recommended its use in the production of Hot Mix Asphalt (HMA).

Background*: Asphalt concrete, sometimes referred to as flexible pavement, is a mixture of Asphalt or bitumen (binder), well-graded aggregates (coarse and fine) and mineral filler (mostly ordinary Portland cement), used for the construction and maintenance of all kinds of roads, parking areas, playgrounds and sports areas. The bitumen, which is also known as asphalt cement, acts as a binder to bind the aggregate particles and mineral fillers together into a cohesive mass. It also functions as a waterproof to the mix because it becomes impervious to water. Filler materials are generally selected based on their ability to increase the stiffness of the binder mastic or improve adhesion between the binders and aggregate. (Murana and Sani 2015). The aggregates are the load-carrying material in the mix, which gives the mass a stone framework to impact strength and toughness to the system. (Vinod, 2001). Calcium carbide residue ((Ca (OH))2 (CCR) is a by-product obtained from acetylene (C2H2) gas production, although it's not being classified as dangerous/hazardous, its managing and disposal require special caution, since the highly basic sludge/waste also contain metals like (Mg, Br, Sr, Cd, Cu, Pb, Fe, Mn, Ni and Zn). (Sun, Li, Bai, Memon, Dong, Fang, Xu, and Xing 2015) As such, in the bid of a sustainable recycling method, this research focused on the contribution of calcium carbide residue ((Ca (OH))2 as a void filler material, considering the moisture resistance of Asphalt concrete. The Marshall mix design method procedure for designing hot mix asphalt concrete was adopted for this research.*

Materials and Methods*: The Marshall method entails a laboratory experiment to develop a suitable asphalt mixture through stability/flow and density/air voids, void in mineral aggregate (vma) analysis.*
The samples were prepared using Marshal Design Procedures for asphalt concrete mixes as presented in Asphalt Institute (1956), National Asphalt Pavement Association (1982) and Roberts et al. (1996). The procedures involved the preparation of a series of test specimens for a range of asphalt (bitumen) contents such that test data curves showed well-defined values. Tests were scheduled based on 2 percent increments of asphalt. In order to provide adequate data, three replicate test specimens were prepared for each set of asphalt content used. During the preparation of the unmodified asphalt concrete samples, the aggregates were first heated for about 5 minutes before the asphalt was added to allow for absorption into the aggregates. After which, the mix was poured into a mould and compacted on both faces with 75 blows using a 6.5kg-rammer falling freely from a height of 450mm. Compacted specimens were subjected to bulk specific gravity test,

stability and flow, density and voids analyses at a temperature of 600C as specified by AASHTO Design Guide (2002). The results obtained were used to determine the optimum asphalt content of the unmodified asphalt concrete. Calcium carbide content was then added at varying amounts (0 – 10 percent by weight of the fine.

***Results**: The moisture resistance characteristics such as Retained Marshal Stability (RMS), Swelling Index (SI) and Indirect Tensile Strength Ratios (ITSR) under immersion days, from 1 - 5 CCR performed better than that of the conventional (Unmodified) HMA concrete. Mix design properties such as stability, flow, density, air voids, and VMA obtained from Calcium Carbide Residue modified asphalt concrete also performed better than that of the conventional (Unmodified) HMA concrete.*

***Conclusion:** The study concludes based on objectives and general findings. While the research was aimed was aimed to carry out an assessment using calcium carbide residue as void filler material, to fill the tiny voids of an asphalt concrete pavement, the findings proved that CCR is a suitable void filler material for HMA concrete. This means, the moisture resistance, durability characteristic and mix design properties, all improved significantly, when calcium carbide residue was introduced to the asphalt concrete.*

***Key Word**: Calcium Carbide Residue; HMA; Indirect Tensile Strength Ratio; Mineral filler; Retained Marshal Stability; Swelling Index.*

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I. Introduction

Asphaltic mixes are a composition of aggregates and bituminous cement, in which the bituminous cement (named mastic) consists of bitumen, sand and fine filler particles and could include modifiers such as polymers, phosphoric acid or hydrated lime. In asphaltic pavements which are exposed to moisture infiltration, separation of the aggregates from the mix is a commonly encountered problem. The continuing action of moisture-induced weakening and traffic load-induced mechanical damage causes progressive dislodgement of the aggregates, and, in some cases, this damage pattern becomes a dominant mode of failure and a cause for diminished road safety. This damage phenomenon is known as stripping or ravelling of the asphalt wearing surface and is contributed to a combined weakening of the mastic and a weakening of the aggregate–mastic bond.

II. Material and Methods

The materials used for this study were calcium carbide residue (CCR), asphalt, coarse and fine aggregates. The CCR used were obtained from automobile workshops within and around the Port Harcourt City Local Government Area of Rivers State, Nigeria. On the other hand, the asphalt used was collected from a private asphalt plant company MCC situated at Rumuigbo, in Obiakpo Local Government Area of Rivers State, Nigeria. After sampling the materials, laboratory tests - specific gravity, grading of asphalt and sieve analysis of the aggregates used for mix-proportioning by straight-line method - were carried out.

This laboratory research was carried out in the Department of Civil Engineering materials laboratory, Rivers State University, Nkpolu Oroworukwo, Port Harcourt, Rivers State, Nigeria, from March 2019 to November 2020. A total of 216 briquette samples (modified and unmodified) were used for the study.

Study Design: Experimental research design

Study Location: The Department of Civil Engineering materials laboratory, Rivers State University, Nkpolu Oroworukwo, Port Harcourt, Rivers State, Nigeria.

Study Duration: March 2019 to November 2020.

Sample size: 216 briquettes.

Sample size calculation: The sample size was estimated on the basis of modified and unmodified samples. The total sample for both modified and unmodified for each test was 108, two separate batches of samples were prepared. The first 108 samples were used for the preparation of the preliminary tests; stability, flow, density, air void and VMA, RMS. The second sample was used to calculate the Indirect tensile strength ratio.

3.1 Collection of Data

The data collection process involves the testing of materials to obtain the physical properties of the materials used. It involves carrying out particle size distribution (gradation analysis) for both coarse and fine aggregates. Also, an aggregate combination using the straight line method was also used to obtain the necessary results and relevant data for analysis. The sample was prepared, allowing for further analysis to obtain bulk specific gravity, stability, flow, density, and voids, which were further used for the pavement analysis.

3.1.1 Materials Used

The following materials were used during this research work;

- Bitumen (Penetration grade 50/60)
- Coarse aggregate (Granite)
- Fine aggregate (White river sharp sand)
- Calcium carbide residue (Modifier/ Void filler material)

3.2 Methods

- Sampling of the materials
- Laboratory tests/experiments
- Analysis of the results obtained

3.2.1 Material Sampling

The material sample for this research project were all obtained from Port-Harcourt. The bitumen was gotten from MCC, the aggregates, coarse and fine, were bought at Mile 3 market, port Harcourt. The calcium carbide residue was obtained from different automobile workshops within and around Port Harcourt township. They were then taken to the Civil engineering materials laboratory at the Rivers State University for necessary laboratory preparations. Laboratory tests were carried out on all the samples.

3.2.2 Laboratory Tests and Experiments

The laboratory tests and experiments carried out in this research include the classification of materials used for sample preparation, blending of aggregates, and sample preparation of specimens representative of asphalt concrete pavement under investigation.

3.2.2.1 Classification Tests of Materials

Physical property tests were carried out to classify the materials used for this research. These tests include the specific gravity test for the modifier, coarse and fine aggregates and the bitumen. Also, for the bitumen, penetration, viscosity and softening point tests were carried out.

(a) Bituminous Cement

The bituminous cement used as the binder was subjected to four physical property tests as follows;

- **Specific Gravity**

For the binder (asphalt cement), the pycnometer method was used to obtain the weight of a given volume of the binder and also used to obtain the weight of an equal volume of water. Specific gravity was thus obtained by dividing the weight of an equal volume of binder by the weight of an equal volume of water. The result of the specific gravity of the binder used is as shown in Table 3.1 below.

- **Penetration or Grading of Bituminous Cement**

The penetration test involved determining the extent to which a standard needle penetrated a well-prepared sample of the bituminous cement under definitely specified conditions of temperature load and time. The Penetrometer was used, which allowed a 100gram needle to move vertically downward without friction and the distance moved by the needle in units of tenths of millimetres was recorded as the penetration of the bitumen. However, the procedure was repeated four times, and the average value of the penetration was obtained and recorded for further analysis. The result of the penetration of the asphalt cement obtained is presented in Table 3.1 below.

- **The viscosity of Bituminous Cement**

The viscosity of the bituminous cement was measured using the Say-Bolt Furol viscometer in order to obtain the resistance to the flow of the asphalt cement. The test procedure involved measuring the time for 50ml of the binder to flow through a specified orifice at a predetermined temperature. The result obtained for the viscosity of the bituminous cement is presented in Table 3.1 below.

- **Softening Point of Bituminous Cement**

The softening point test involved placing a steel ball on a mass of the asphalt cement contained in a brass ring and heated in a water bath until the ball dropped through the bituminous cement. The temperature at which the ball dropped was recorded as the softening point of the bitumen. The result is presented in Table 3.1 below.

Table 3.1: Physical properties of Asphalt Cement

TEST	SPECIFIC GRAVITY (g)	GRADE OF BINDER	PENETRATION (mm)	VISCOSITY (Secs)	SOFTENING POINT (^{0}C)
RESULTS	1.020	50/60	53℃, 100bgm, 0.1mm	14.5	50℃
SYMBOL	Gs	G	Pe	V	SP
ASTM DESIGNATION NO.	D-70	D-5			D-36

It is possible to grade bitumen based on the result of its penetration. Thus, from the rheological property test, as shown in Table 3.1, the result of the bitumen penetration indicates a penetration grade of 50/60. Hence, the bitumen was classified as hard.

(b) Aggregates

The aggregates used for the entire research work was subjected to the following tests as follows;

- **Specific Gravity**

The specific gravity test was conducted for the coarse and fine aggregates, and their results were recorded. However, the test procedure involved soaking a specified weight of the aggregates in distilled water for 24hours and then weighed in water. The soaked sample was then surface dried and weighed in air, after which it was oven-dried at 105^0C for 24hours and weighed again in the air. Thus, the specific gravities of samples were obtained by dividing the weight of the oven-dried samples in the air by the loss of weight of the saturated sample in water. Results of the specific gravity of the aggregates are presented in Table 3.2 below.

Table 3.2: Physical properties of Coarse and Fine aggregates

AGGREGATE	COARSE	FINE	Test method
Bulk specific gravity	2.87	2.70	ASTM C - 127
%Water absorption	1.2	0.8	ASTM C - 128
*% Wear (Loss Angeles)	1		ASTM C – 131

- **Aggregate Gradation/Sieve Analysis**

Aggregate gradations for coarse and fine aggregates were carried out, and the results were recorded with their corresponding particle size distribution based on graphical plots. The laboratory procedure involved measuring specified weights of both aggregates and shaking them for not less than two minutes on each sieve size. By calculation, the percentage retained on each sieve size was obtained. Similarly, by calculation, the cumulative percent passing on each sieve was obtained by subtracting the cumulative percent retained on each sieve from 100 percent from each sieve size. In addition, the particle size distributions were obtained by plotting the cumulative percent passing on each sieve size by the corresponding sieve size. However, it is pertinent to state that the coarse aggregate used was granite while the fine aggregate was sand. Furthermore, the sieve analysis results obtained are presented in Tables 3.3 and 3.4, while their corresponding particle size distributions are shown in

Figures 3.1 and 3.2, respectively.

Table 3.3: Gradation of Granite (Weight of Dried Sample = 1152 g)

Sieve sizes (mm)	Mass retained	Percentage on Sieve	Percentage passing
19.0	0	0	100
12.5	153	13.3	86.6
9.5	369.8	32.1	54.5
6.3	355.6	30.9	23.6
4.75	166.9	14.4	9.2
2.36	56.8	4.9	4.3
1.18	13.3	1.2	3.1
0.6	11.4	1	2.1
0.3	5.5	0.47	1.6
0.15	6.0	0.5	1.1
0.075	7.5	0.65	0.5
Pan	6.2	0.5	0
Total	1152		

Table 3.4: Gradation of Sand (Weight of Dried Sample = 1192 g)

Sieve size (mm)	Mass Retained	Percentage on sieve	Percentage passing
19.0	0	0	100
12.5	0	0	100

9.5	0	0	100
6.3	0	0	100
4.75	11	0.9	99.1
2.36	40	3.4	95.7
1.18	52	4.4	91.3
0.6	262.9	22	69.3
0.3	490.6	41.2	28.1
0.15	257.1	21.6	6.5
0.075	74.4	6.2	0.3
Pan	4	0.3	0
Total	1192		

Table 3.5: Schedule of Mix proportion for Aggregates

Sieve sizes	Sieve size (Inch)	Specification limit	Aggregate A (Granite)	Aggregate B (Sand)	Mix proportion (0.61A+0.39B)
19.0	½	100	100	100	100
12.5	¾	86-100	86.6	100	92.0
9.5	3/8	70-90	54.5	100	72.3
6.3	¼	45-70	23.6	100	54.9
4.75	No. 4	40-60	9.2	99.1	46
2.36	No. 8	30-52	4.3	95.7	41.7
1.18	No. 16	22-40	3.1	91.3	39.2
0.6	No. 30	16-30	2.1	69.3	29.6
0.3	No. 50	9-19	1.6	28.1	12.4
0.15	No. 100	3-7	1.1	6.5	3.2
0.075	No. 200	0	0.5	0.3	0.4
PAN					

(c) MODIFIER

The modifier used for this research is shredded calcium carbide residue, and the specific gravity test for this was carried out.

- **SPECIFIC GRAVITY OF MODIFIER**

For the modifier, the pycnometer method was used to obtain the weight of a given volume of the modifier and also used to obtain the weight of an equal volume of water. Specific gravity was thus obtained by dividing the weight of an equal volume of the modifier by the weight of an equal volume of water. The result of the specific gravity of the modifier used is as shown in Table 3.6 below.

Table 3.6: Specific Gravity Test Results of Modifier (calcium carbide residue)

TEST	SPECIFIC GRAVITY
RESULT (g)	2.25

Table 3.7 Chemical Composition of Calcium Carbide Residue and Ordinary Portland Cement.

Elemental Oxide	Percentage Composition (%)	
	Calcium Carbide Residue	Ordinary Portland Cement
Lime (CaO)	60.41	64.8
Magnesia (MgO)	0.80	1.94

Alumina (Al_2O_3)	2.45	5.75
Iron oxide (Fe_2O_3)	3.27	4.50
Silica (SiO_2)	6.49	20.40
Sulphur trioxide (SO_3)	0.96	2.75
K_2O	7.89	0.6
LOI	1.31	1.20

Calcium carbide residue can be seen to possess an almost similar chemical composition to Ordinary Portland cement, a traditional filler material due to its cementitious properties.

Table 3.8: Summary of Mix Design Properties for Unmodified Asphaltic Concrete

Bitumen (%)	Stability (N)	Flow (0.25mm)	Density (kg/ m^3)	Pa Air Void (%)	VMA (%)
0	18861	8.27	2.608	4.41	9.1
2	19210	7.37	2.613	4.21	10.83
4	20304	6.76	2.619	4.00	11.58
6	21985	5.81	2.628	3.65	12.19
8	22162	4.55	2.629	3.63	13.12
10	23975	3.98	2.634	6.44	14.9

3.4.1 Retained Marshal Stability (RMS)

The Retained marshal Stability can simply be referred as the percentage of the stability retained by the sample after it must have been submerged in water over a stipulated period. It can be calculated using the equation below (Putri and Suparma, 2009)

$$\frac{S_i}{S_o} \times 10 \qquad 3.11$$

Where;

S_i= maximum stability in the condition set based on times series (i.e. 1-14 days)

S_o=maximum stability in unconditioned set (0 days)

3.4.2 Swelling Index (SI)

The swelling index can simply be defined as the percentage increase in the volume of the sample as a result of absorption of water after submergence. And it can be evaluated using the equation below

$$SI = [\frac{V_1 - V_0}{V_0}] \qquad 3.12$$

Where; V_0 = Volume of the sample before soaking

V_1 = Volume of the sample after soaking

Also

$$V_1 = W_{a1} - W_{w1} \qquad 3.13$$

$$V_0 = W_{a0} - W_{w0} \qquad 3.14$$

Therefore;

$$SI=[\frac{(W_{a1} - W_{w1}) - (W_{a0} - W_{w0})}{(W_{a0} - W_{w0})}]x100 \qquad 3.15$$

Where;

W_{a0} = Weight in the air before soaking

W_{a1} = Weight in the air after soaking

W_{w0} = Weight in water before soaking

W_{w1} = Weight in water after soaking

3.4.5 Indirect Tensile Strength

$$ITS = \frac{200\ x\ P}{\pi\ x\ T\ x\ D} \qquad 3.18$$

Where;

- ITS = Indirect tensile strength (Kpa)
- P = Maximum load resistance at failure, N
- D = Diameter of specimen, mm.
- T = Thickness of specimen immediately before test, mm.

The direct tensile strength ratio was calculated using

$$TSR = \frac{S\,wet}{S\,dry} \quad 3.19$$

Where;

- TSR = Indirect tensile strength ratio%
- S dry = Average ITS for unconditioned spacemen Kpa
- S wet = Average ITS for moisture-conditioned specimen Kpa

III. Result

Below is a presentation of both the unmodified and the calcium carbide residue (CCR) modified asphalt concrete sample results, evaluating their performance under different days of saturation. The analysis also includes the results of the unsaturated samples, which served as a control.

The results obtained from the laboratory experiment were presented in the categories of the different tests for an easy illustration. These categories include the results obtained for the Retained Marshal Stability, Swelling Index and Indirect tensile strength ratio were considered for this research concerning the increase in the modifier content (calcium carbide residue) from 2-10 percent, for heavy Traffic volume study, in line with the objectives of this research.

Table no 1: Shows the effect of Calcium carbide residue modified bitumen on Retained Marshal Stability for unsaturated and saturated conditions.

Retained Marshal Stability (RMS) of Asphalt Concrete Made from Calcium Carbide Residue.

IMMERSION PERIOD (DAYS)	CALCIUM CARBIDE RESIDUE (%)					
	0%	2%	4%	6%	8%	10%
Day 0	100	100	100	100	100	100
Day 1	95.71	95.78	96.01	96.32	96.35	96.47
Day 2	95.51	95.6	95.84	96.17	96.21	96.35
Day 4	95.3	95.4	95.66	96.02	96.06	96.21
Day 7	95.07	95.17	95.47	95.86	95.89	96.06
Day 14	94.81	94.93	95.25	95.68	95.72	95.9

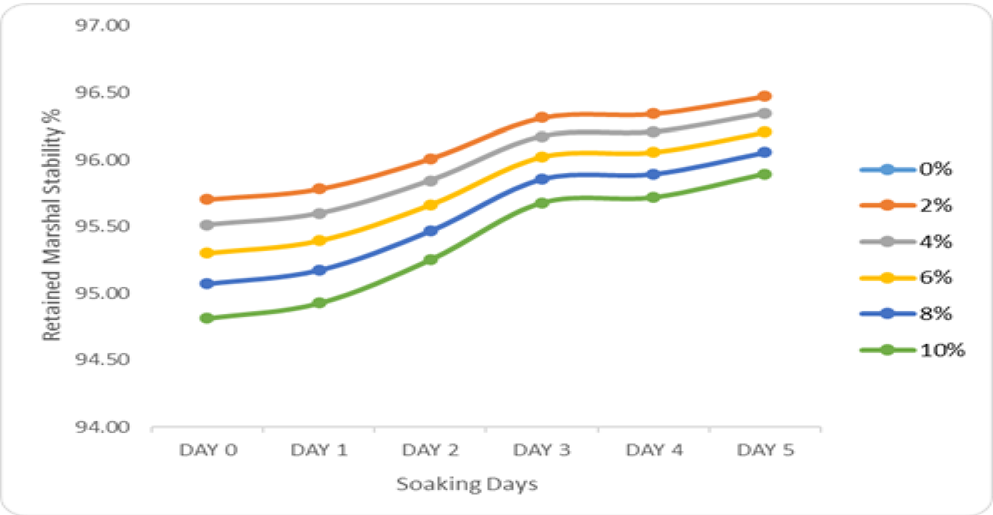

Figure 4.1: Variation of Retained Stability Index with Soaking days at 0% - 10% CCR.

Table no 2: Shows the effect of Calcium carbide residue modified bitumen on Swelling Index (SI) for unsaturated and saturated conditions.

Swelling Index (SI) of Asphalt Concrete Made from Calcium Carbide Residue.

IMMERSION PERIOD (DAYS)	CALCIUM CARBIDE RESIDUE (%)					
	0%	2%	4%	6%	8%	10%
Day 0	2.13	0.17	0.15	0.13	0.07	0.04
Day 1	3.36	0.28	0.22	0.15	0.09	0.07
Day 2	5.16	1.65	1.29	1.18	1.06	0.91
Day 3	5.86	1.8	1.55	1.29	1.1	0.95
Day 4	6.17	2.04	1.68	1.51	1.39	1.13

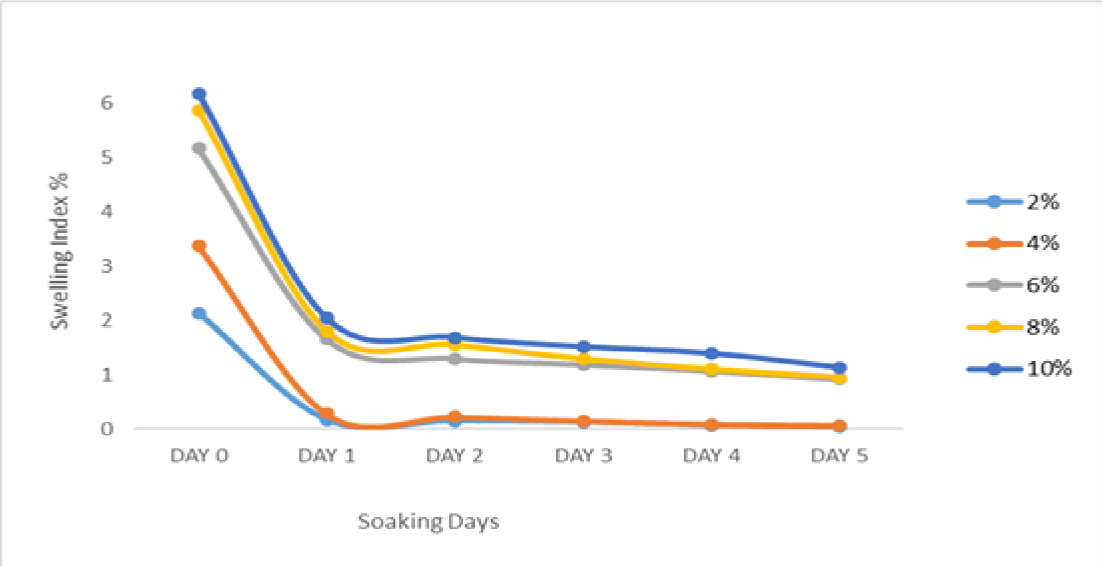

Figure 4.2: Variation of Swelling Index with Soaking days at 0% - 10% CCR.

Table no 3: Shows the effect of Calcium carbide residue modified bitumen on Indirect Tensile Strength Ratio (ITSR) for unsaturated and saturated conditions are shown in Figure 4.5.

Indirect Tensile Strength Ratio (ITSR) of Asphalt Concrete Made from Calcium Carbide Residue.

Calcium carbide residue (%)	INDIRECT TENSILE STRENGTH RATIO					
	0%	2%	4%	6%	8%	10%
Day 0	82.28	82.31	82.33	82.35	82.37	82.39
Day 1	80.18	80.34	80.48	80.60	80.71	80.81
Day 2	78.16	78.44	78.69	78.91	79.11	79.29
Day 3	76.99	77.34	77.66	77.94	78.19	78.42
Day 4	75.17	75.65	76.08	76.46	76.80	77.11
Day 5	73.36	74.01	74.58	75.07	75.51	75.91

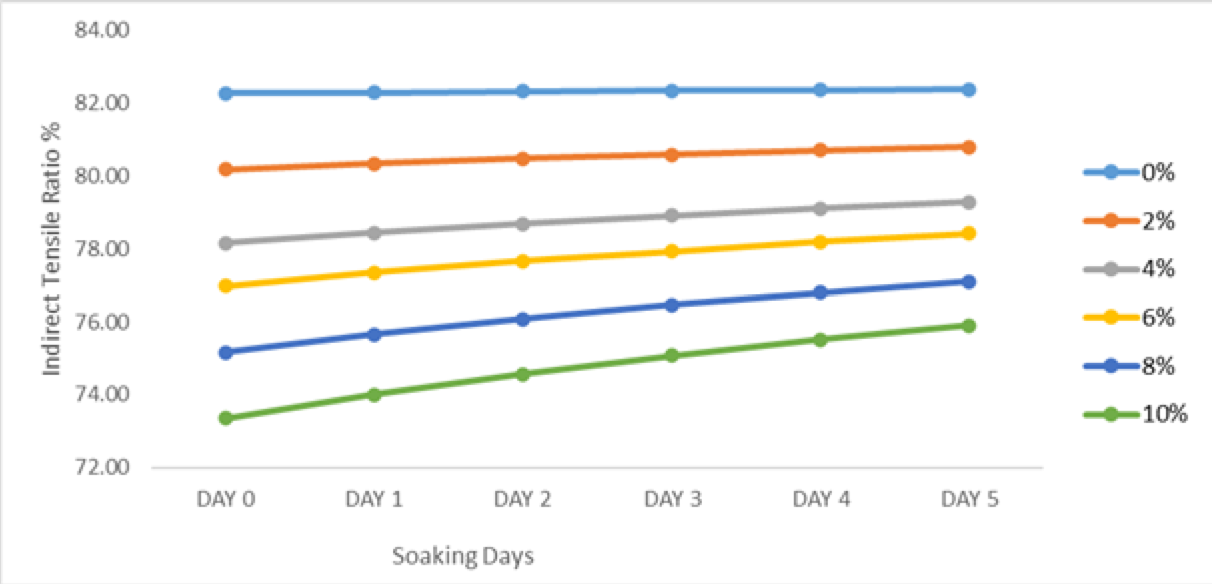

Figure 4.5: Variation of Indirect Tensile Strength Ratio (ITR) with Immersion days at 0%-10% CCR.

IV. Discussion

The effects of Calcium Carbide Residue (CCR) on Retained Marshall Stability (RMS) of asphalt concrete for samples soaked in water from 1 – 5 days, shown in Figure 4.1. It was observed that at soaking day 1, the Retained Marshall Stability (RMS) increased from 95.71% at 0% CCR content to 96.47% at 10% CCR content. Similarly, for soaking day 5, the RMS increased from 94.81% at 0% CCR content to 95.9% at 10% CCR content.

Generally, the results show that for each soaking day, the RMS increased as the CCR content increased which implied that CCR enhanced the resistance to moisture damage of asphalt concrete. However, for each CCR content, the RMS decreased as the number of soaking days increased.

The effects of Calcium Carbide Residue (CCR) on Swelling Index (SI) of asphalt concrete for samples soaked in water from 1 – 4 days, in Figure 4.2. We noticed the volume change, that at soaking day 1, the (SI) decreased from 3.36% at 0% CCR content to 0.07% at 10% CCR content. Similarly, for soaking day 4 the SI decreased from 6.17% at 0% CCR content to 1.13% at 10% CCR content.

Finally, the results show that for each soaking day, the Swelling index decreased as the CCR content increased which implied that CCR improved the moisture resistance damage of asphalt concrete. However, for each CCR content, the SI decreased as the number of soaking days increased.

The effect of Calcium Carbide Residue (CCR) on Indirect Tensile Strength Ratio (ITSR) of asphalt concrete for samples soaked in water from 1 – 5 days, in Figure 4.3. It was observed that at soaking day 1, the (ITSR) increased from 82.28% at 0% CCR content to 82.39% at 10% CCR content. Similarly, for soaking day 5 the ITSR increased from 80.185 at 0% CCR content to 80.81% at 10% CCR content.

Finally, the results show that for each soaking day, the Indirect Tensile Strength Ratio increased as the CCR content increased which implied that CCR enhanced the asphalt concrete resistance to moisture damage. However, for each CCR content, the ITSR increased as the number of soaking days increased.

V. Conclusion

The study concludes based on objectives and general findings. While the research was aimed was aimed to carry out an assessment using calcium carbide residue as void filler material, to fill the tiny voids of an asphalt concrete pavement, the findings proved that CCR is a suitable void filler material for HMA concrete. This means, the moisture resistance, durability characteristic and mix design properties, all improved significantly, when calcium carbide residue was introduced to the asphalt concrete.

The significant findings and conclusions based on the objectives of the research are as follows:

i. Moisture resistance: As the soaking days increased from 0 - 5 days, the pavement absorbed moisture which showed in the tests such as (Swelling Index and Indirect Tensile Strength Ratio) but as the CCR content increased from 2 - 10%, the pavement exhibited a reduction of in the absorption of moisture.

ii.

The result of the study indicated that the improved mixed design properties of Asphalt concrete were within minimum requirements as stipulated by Asphalt Institute.

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