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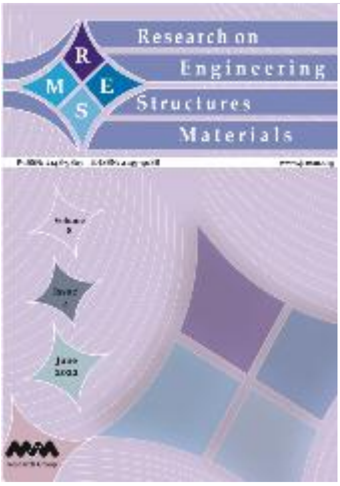

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Technical Note

Moisture susceptibility of waste ceramic tiles modified asphalt mixtures

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Abstract

Waste ceramic tiles have been recognized as viable in producing asphalt mixtures. However, the primary concern is the assurance of its durability, especially in terms of moisture damage. Therefore, this research aims to investigate the moisture susceptibility of asphalt mixtures incorporating waste ceramic tiles (WCT). The coarse aggregates of 25 mm size were partially replaced with WCT at 0%-50% proportions. The Marshall Method of mix design was used to calculate the optimum bitumen content (OBC) at various levels of WCT replacement. Utilizing the retained strength index (RSI) and tensile strength ratio (TSR) tests, the moisture susceptibility of the mixes compacted at OBC was assessed. The results indicate that the continuous increase of WCT leads to decreased TSR and RSI values. The RSI ranges from 91.10%-81.90%, 74.91%-61.07% and 47.89%-41.05% at 1, 3, and 7-day curing, respectively. The TSR ranges from 89.27-74.73%, 71.48-63.81% and 58.02-46.79% at 1, 3, and 7-day curing, respectively. Nevertheless, it was determined that the WCT-modified asphalt mixtures met the TSR and RSI standards for asphalt mixtures with satisfactory moisture resistivity performance at 1 and 3 days of curing. For satisfying performance of WCT-modified asphalt mixtures, the study recommends an optimum proportion of 30% WCT.

1. Introduction

Most of the construction and demolition (C&D) wastes produced by Nigeria's building industry throughout time is solid waste; ceramic tiles contribute the highest percentage of waste within the C&D wastes [1-2]. According to Ramirez et al. [3] about 54% of the C&D waste in the stony fraction comes from ceramic tiles. Most of these waste ceramic tiles are not recycled and instead end up in landfills, taking up valuable space and costing money in landfilling [4-5]. However, disposal of waste ceramic tiles in landfill can be minimized if it can be re-utilized. For instance, waste ceramic tiles can be recycled into aggregate, which has a better crushing value, impact value, and abrasion value than natural crushed stone [6]. It is also relatively hard and has a significant specific gravity value [7]. Hence, utilizing used ceramic tiles instead of expensive or scarce natural resources will save expenses, consecutively decrease the amount of space needed for disposal, and minimize other costs [8-9].

Past research has addressed asphalt mixture production using waste ceramic tiles in several forms. In Muniandy et al. [10], the performance of recycled ceramic waste as aggregates in asphalt mixtures was conducted. Marshall characteristics and resilient

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modulus were used as the performance indicators. It was demonstrated that ceramic waste aggregates could be employed in the pavement construction industry and provide cost and environmental efficiency advantages. The waste ceramic powder was investigated for viability as an alternative filler for asphalt mastics by Rochlani et al. [11]. They discovered ceramic powder could be employed as an efficient filler substitute in asphalt, having comparable fatigue performance to that of limestone mastic while having higher stiffness, better ageing properties, increased bitumen-filler interaction, and rutting resistance. While waste ceramic tiles have been recognized as viable in the production of asphalt mixtures, the primary concern is the assurance of their durability concerning their moisture damage. To provide excellent service, the asphalt mixtures must remain durable over their intended life span. However, the durability of the asphalt mixtures is seriously affected due to moisture-induced damage [12]. According to Soenen et al. [13], one of the main reasons flexible pavements fails is their vulnerability to moisture, which lowers their durability. Moisture damage in asphalt mixtures is defined as the "degradation of mechanical properties of the material due to the presence of moisture in a liquid or vapour state" [14]. Moisture weakens the cohesiveness in the asphalt mixtures and the adhesion between the aggregate and the asphalt in asphalt mixtures [15]. Hence, the aggregates' type and properties are crucial in preserving the solid bond with asphalt in the presence of water [15]. Therefore, to better understand how moisture affects the performance of WCT-modified asphalt mixtures, this study aims to investigate the effect of moisture on the hot mix asphalt mixtures incorporating waste ceramic tiles as aggregate for sustainable pavement works. For this purpose, WCT was used to replace granite at a proportion of 0-50% for the asphalt mixtures. Marshall immersion and indirect tensile strength assessed the asphalt mixtures' moisture susceptibility.

2. Materials and Methods

2.1. Materials

2.1.1. Waste Ceramic Tiles

The waste ceramic tiles (WCT) were obtained from the Landmark University, Omu-Aran, Nigeria, construction site. The waste ceramic tiles were crushed and graded (as shown in Fig. 1). The properties of the waste ceramic tiles are shown in Table 1.

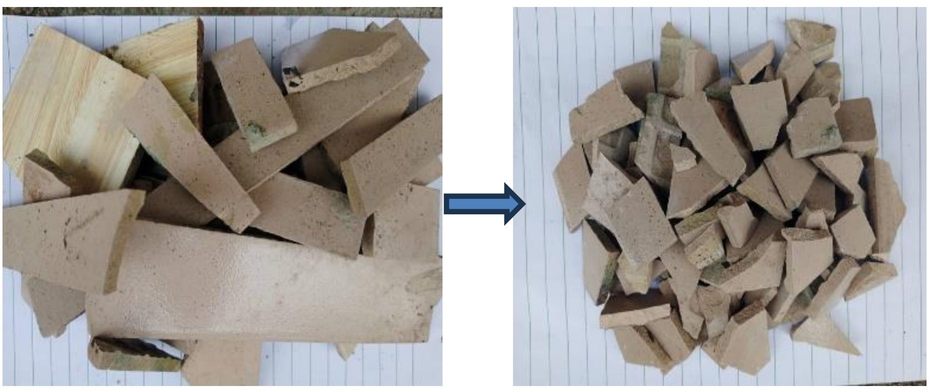


Fig. 1 Waste ceramic tiles

2.1.2. Aggregate

The coarse aggregates utilized were granite with particle sizes of 25 mm for a typical binder course. The fine aggregate used was the stone dust. The coarse and fine aggregate was sourced from a quarry site in Omu-Aran, Nigeria. The properties of the aggregates are shown in Table 1, and the aggregate gradation for the bituminous mixtures is shown in Fig. 2.

Table 1. Aggregate properties

Test	Specification	Results	
		Granite	WCT
Abrasion test	<=35	20.7	18.0
Flakiness	<=35	11.6	17.9
Aggregate crushing value	<=30	17.2	14.33
Water Absorption	<=0.5	0.10	0.18
Aggregate impact value	<=30	16.8	24.2
Fine Aggregate			
Specific Gravity	<=3	2.7	2.7
Bulk Density		217.3 kg/m3	

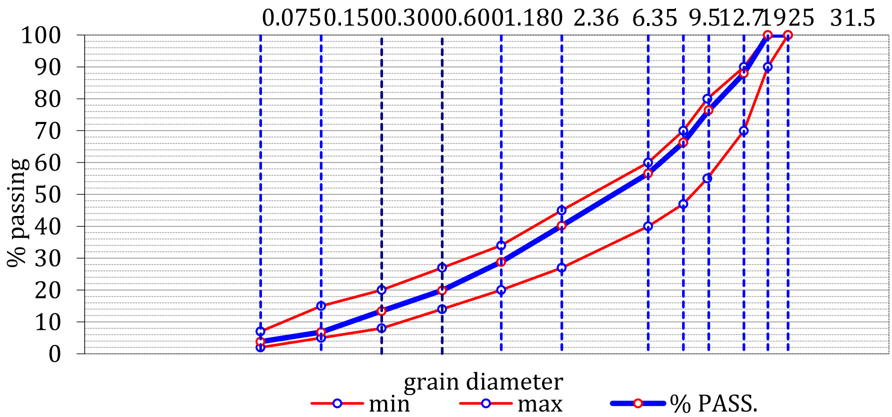


Fig. 2 Aggregate gradation for the asphalt mixtures

2.1.3. Bitumen

The bitumen used was grade 60/70, sourced from a local market in Omu-Aran, Nigeria. The bitumen properties are shown in Table 2.

Table 2. Bitumen properties

Test	Specification	Result
Specific Gravity	1.01-1.06	1.03
Penetration (mm)	60-70	63
Softening Point (^{0}C)	45-56	52.4
Ductility (cm)	Min. 75	110
Solubility in CS_2 (Petrol was used)	Min. 99.5	99.9
Flash and fire point (^{0}C)	Min. 250	Flash=311 Fire=320
Minimum Loss on Heat for 5 hours at 163^{0}C	Max. 0.2	0.08
Drop in Penetration after heating	Max. 20	13.1

2.2. Materials

Table 3 displays the material quantities utilized to create the asphalt mixtures. Stone dust and HWA were used as fillers in 1200 g aggregates pre-heated between 160 and 1780C. At 1500C, the chosen bitumen content was melted. The steel bowl was used to combine the bitumen and aggregates. A mixing temperature of roughly 1850C was used to combine the mixture completely. The mixture was compressed in a fore-heat Marshall mould by giving each face of the sample 75 blows. In Kara and Karacasu [16], an optimum of 30% WCT was achieved for the HMA. This study considered a variation in the WCT between 0% and 50% at an interval of 10% to replace 25 mm granite in the preparation of the asphalt mixtures.

Table 3. Mix proportion

SN	% WCT	CA: 25mm (%)	CA: 20mm (%)	FA (%)	MF (%)
1	0	40	20	25	15
2	10	40	20	25	15
3	20	40	20	25	15
4	30	40	20	25	15
5	40	40	20	25	15
6	50	40	20	25	15

Note: WCT= waste ceramic tiles, CA= Coarse Aggregate, FA= Fine Aggregate and MF= Mineral Filler

2.3. Laboratory Investigations

2.3.1 Marshall Test to Determine the Optimum Bitumen Content (OBC)

To produce hot mix asphalt (HMA) with the appropriate qualities, the optimum bitumen content was determined using a Marshall method for designing hot asphalt mixtures. Using six different bitumen concentrations (ranging from 5% to 8%), three of 1200 g in weight were prepared per the ASTM D1559 [17] standard. For different bitumen amounts, the Marshall properties of the asphalt mix, including stability, flow, density, the percentage of air voids in the entire mix, and the proportion of voids filled with bitumen, were obtained.

2.3.2 Tensile Strength Ratio (TSR) Test

The tensile strength ratio test is a technique for calculating the strength loss resulting from damage caused by stripping (of the asphalt from the aggregate) while subject to accelerated water conditioning that is controlled in a laboratory. AASHTO T 283 [18] evaluates stripping in Hot Mix Asphalt (HMA) using the indirect tensile strength test (Fig. 3a). After sample conditioning, strength retention is assessed using the Tensile Strength Ratio (TSR). The TSR is performed on two different types of HMA samples. One kind is used as a control (unconditioned) and kept at 25°C temperature. The other type is conditioned by submerging in water and soaking for 1, 3, and 7 days. The TSR value was calculated using Eq. 1.

$$TSR = \frac{T_{wet}}{T_{dry}} \times 100 \quad (1)$$

Where: TSR = Tensile strength ratio, T_{dry} = Average tensile strength of unconditioned samples, T_{wet} = Average tensile strength of conditioned samples.

Fig. 3 Specimen under (a) ITS test (b) Marshall Stability test.

2.3.3 Marshall Immersion Test

The Marshall Immersion test establishes how much cohesiveness is lost when water contacts compacted asphalt mixtures made with asphalt cement. This technique measures the strength loss brought on by water's impact on compacted bituminous mixtures. The specimens are divided as part of the conditioning procedure before the test. One pair is kept in a water bath at 60 °C for 1, 3, and 7 days. The other pair, however, is kept at ambient temperature.

Both specimens are put under a simple compression load after the curing days, with a constant deformation speed of 5.08 mm/min, until they break (as illustrated in Figure 2b). The maintained strength value for each set can be found in this method. The retained strength index (RSI) is the test's outcome, which assesses the specimens' susceptibility to water action. This index is calculated using Eq. 2.

$$RSI = \frac{S_1}{S_2} \times 100\% \tag{2}$$

Where; RSI = Retained Strength Index; S_1= Marshall Stability with soaking time of 30 min at a temperature of ±60°C; S_2= Stability after immersion at a temperature of ±60°C.

2.3.4 Statistical Analysis

Analysis of variance (ANOVA) single factor test was conducted to check the statistical significance of the different proportions of WCT on the moisture susceptibility of the asphalt mixtures. The probability or p-value was considered 0.05 as the level of significance for the hypothesis test.

4. Results and Discussion

4.1. Effects of WCT on the Marshall Properties

The result obtained from study the effect of waste ceramic tiles replacement on the optimum bitumen content (OBC) is shown in Fig. 4. There was an increase in OBC up to 20% addition of WCT and a decrease with further addition of WCT. Nevertheless, the obtained bitumen contents are all within the acceptable variation of 4-7% for a binder course application as stipulated by the General Specification for Roads and Bridges of

Nigeria [19]. Furthermore, this variation in OBC as the proportion of WCT increases was also noted by Huang et al. [20].

The Marshall properties of WCT-modified asphalt mixtures at OBC are depicted in Fig. 5. It was observed that, whilst the stability and flow values of WCT-modified asphalt mixtures are within the acceptable variation (minimum 3.5 kN and 3-5 mm for stability and flow, respectively) as per General Specification for Roads and Bridges of Nigeria [19], a decrease in stability and an increase in flow and volume of mineral aggregates (VMA) as the proportion of WCT increases is observed. It can be said that the large sizes of WCT reduced the stability in the asphalt mix and increased the voids and flow in the mixture resulting from the bitumen content. This result is in contrast to the study conducted by Muniandy et al. [10]. Their study observed an increase in stability for the WCT-modified mixtures compared to the control.

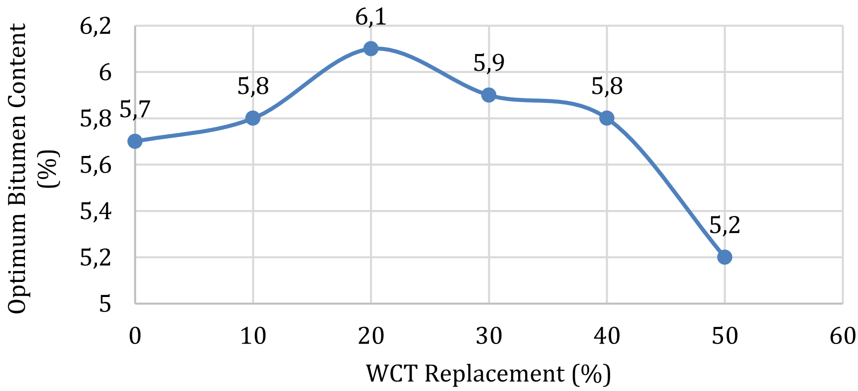
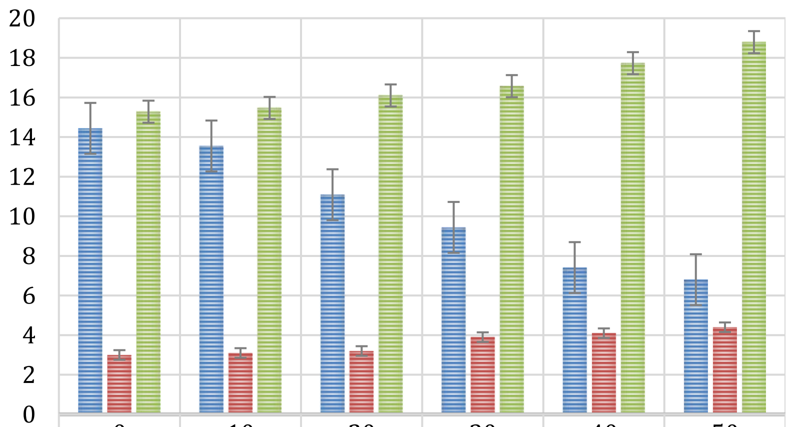


Fig. 4 OBC of WCT-modified asphalt mixtures



	0	10	20	30	40	50
stability (kN)	14,44	13,55	11,09	9,44	7,41	6,8
flow (mm)	3	3,1	3,2	3,9	4,1	4,4
VMA (%)	15,28	15,47	16,1	16,57	17,73	18,79

WCT Replacement (%)

Fig. 5 Marshall Properties of WCT-modified asphalt mixtures

4.2. Tensile Strength Ratio of WCT-modified Asphalt Mixtures

Fig. 6 shows the WCT-modified mixes' indirect tensile strength (ITS) values for both wet and dry conditions. Results showed that increasing WCT steadily until it reaches 30% causes an increase in the tensile strength of the unconditioned samples and then decreases afterwards. Also, for the conditioned samples, an increase in the WCT decreased the tensile strength of the modified mixtures. The strength reduction may result from bitumen and aggregate losing their adherence [21-22].

Fig. 7 depicts the TSR values obtained for WCT-modified asphalt mixtures. It can be seen that the addition of WCT decreases the TSR of the modified asphalt mixtures, which could be due to the loss of adhesion between the binder and aggregate [21-22]. Generally speaking, a higher TSR value means that the mixture will work well and have good resistance to moisture damage [23]; hence, WCT as an aggregate in asphalt mixtures will not guarantee a suitable performance and will likely be susceptible to moisture damage. In the study conducted by Silvestre et al. [24], they also reported a poor behaviour of WCT-modified asphalt mixtures to moisture. Furthermore, the TSR value decreases as the soaking duration increases. However, adding WCT up to 30% at 24-hour soaking duration meets the criteria of a minimum TSR value of 80%.

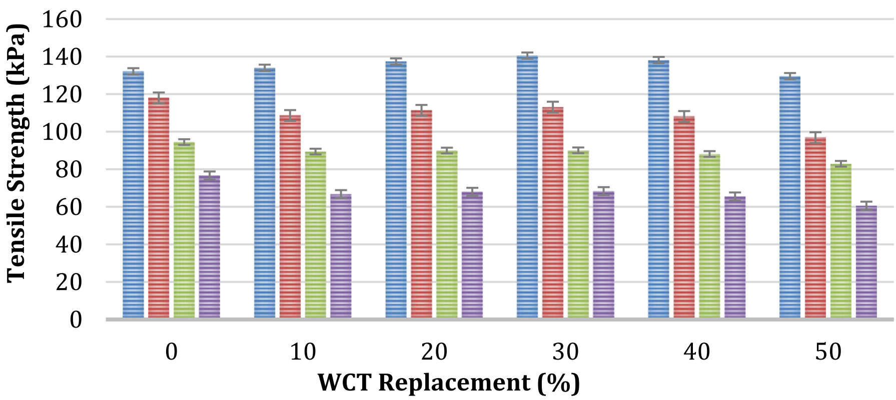


Fig. 6 ITS of WCT-modified asphalt mixtures

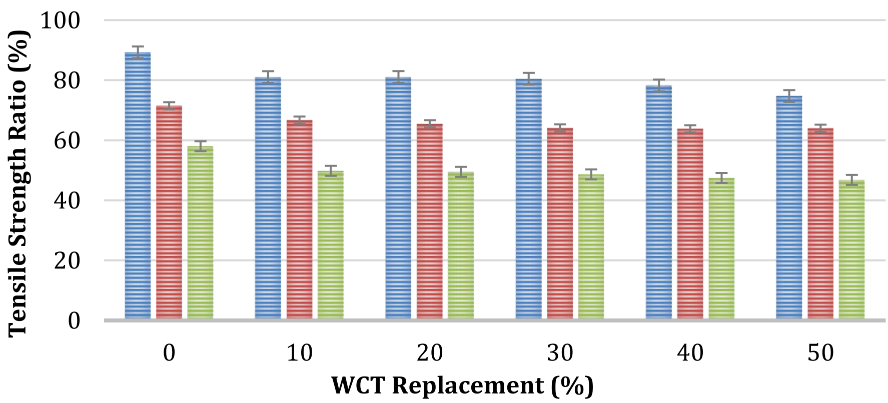


Fig. 7 Tensile strength ratio of WCT-modified asphalt mixtures

4.4. Retained Strength Index of WCT-Modified Asphalt Mixtures

Fig. 8 shows the RSI values obtained for WCT-modified asphalt mixtures. It can be seen that the RSI values decreased on the increment of the WCT at day 1, 3, and 7 days of curing. The decrease in the RSI indicates the WCT-modified mixture's vulnerability to water attack [25]. The RSI ranges from 91.10-81.90%, 74.91-61.07% and 47.89-41.05% at 1, 3, and 7-day curing, respectively. The Marshall Immersion test uses an RSI value of a minimum of 70% to assess whether a mixture is sensitive to moisture. Therefore, except for 50% WCT at 3-day curing, the RSI of all the mixtures at 1, 3-day curing are above 70% and, consequently, durable and suitable for use.

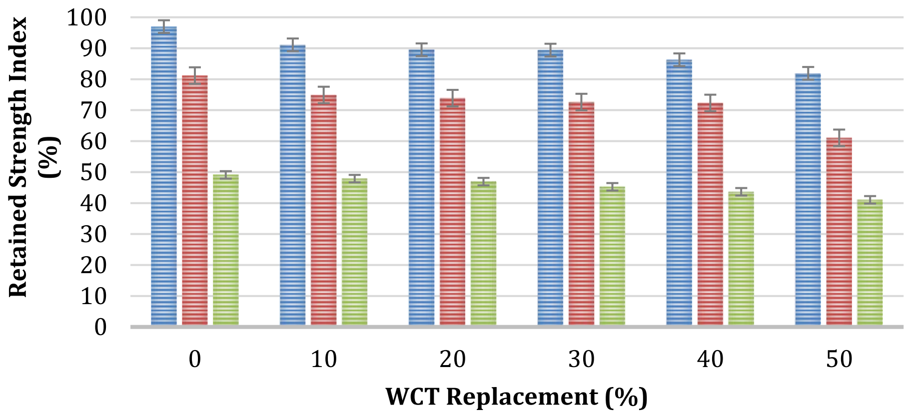


Fig. 8 RSI properties of WCT-modified asphalt mixtures

4.5. ANOVA Results of WCT-Modified Asphalt Mixtures

The ANOVA test results for the proportion of WCT on the moisture susceptibility properties of asphalt mixtures is shown in Table 4. The proportions of WCT are, as indicated in the Table, significantly different at a 5% probability level. This implies that the WCT proportions greatly influence the asphalt mixtures moisture damage properties such as tensile strength, TSR and RSI.

Table 4 ANOVA test for the influence of WCT on Asphalt mixture moisture susceptibility

Properties	Source of variation	Degree of freedom	Sum of squares	Mean square	F test	P Value	Significance
ITS	Between groups	5	383.87	76.77	0.0913	0.9926	Yes
	Within groups	18	15138.69	841.04			
TSR	Between groups	5	225.92	45.18	0.189	0.961	Yes
	Within groups	12	2858.44	238.20			
RSI	Between groups	5	339.38	67.88	0.1394	0.979	Yes
	Within groups	12	5843.91	486.99			

5. Conclusions

To provide excellent service, the asphalt mixtures must remain durable over their intended life span. However, the durability of the asphalt mixtures is seriously affected due to moisture-induced damage. Due to the susceptibility of asphalt mixtures to moisture deterioration, many kinds of distress are accelerated, reducing the pavement's lifespan. In this study, the moisture performance of waste ceramic tiles modified asphalt mixtures was conducted. For this purpose, the Marshall test determined the asphalt mixture's properties and the asphalt mixes' susceptibility to moisture by the Marshall immersion and indirect tensile strength (ITS) tests. The significant findings of this study are as follows:

- There was an increase in OBC up to 20% addition of WCT and a decrease with further addition of WCT. The obtained OBC are all within the acceptable variation of 4-7% for a binder course application as stipulated by the General Specification for Roads and Bridges of Nigeria.
- There was a decrease in stability from 14.44-6.8 kN as the proportion of WCT increases. Nonetheless, the stability values of WCT-modified asphalt mixtures are within the acceptable limits as per General Specification for Roads and Bridges of Nigeria.
- The unconditioned samples' tensile strength increases as WCT increases to 30% and then decreases; indicating that 30% WCT is the optimum value for WCT in WCT-modified asphalt mixtures.
- The TSR of the modified asphalt mixtures decreases from with the addition of WCT, which could be due to the loss of adhesion between the binder and WCT aggregate. The TSR ranges from 89.27-74.73%, 71.48-63.81% and 58.02-46.79% at 1, 3, and 7-day curing, respectively.
- The RSI values decreased on the increment of the WCT, which indicates the WCT-modified mixture's vulnerability to a water attack. The RSI ranges from 91.10-81.90%, 74.91-61.07% and 47.89-41.05% at 1, 3, and 7-day curing, respectively.
- The mixes were found to satisfy the TSR and RSI standards for asphalt mixtures with adequate moisture resistivity performance at 1 and 3 days of curing duration, even though the inclusion of WCT reduces the TSR and RSI.
- The ANOVA test proved that statistically, the proportion of WCT have significance on the moisture susceptibility of asphalt mixtures.
- Future research is recommended to improve the moisture damage of WCT-modified asphalt mixtures.

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