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Characterisation and Prediction of Softening point and penetration value of Ceramic waste-based Asphalt incorporated with Sasobit and Wetfix B.E for Nigeria Roads

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ABSTRACT
This study focusses on the evaluation of mechanical properties of Ceramic waste-based Modified Bitumen Asphalt (MBA) incorporated with Sasobit and Wetfix B.E with prediction of its Softening point (SP) and Penetration value with Artificial Neural Networks (ANN). The research utilized Ceramics Waste Aggregate (CWA), Sasobit (SB) and Wetfix BE (WB) as modifiers in the development of MBA with natural coarse aggregate replaced with CWA (0, 5, 10, 15, 20, 25 and 30%), bitumen modified with SB and WB (0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0%), to produce asphalt (MBA0, MBA10, MBA20, MBA30, MBA40, MBA50 and MBA60) and a designed asphalt mix of 4.0 mm flow employed in accordance with MS-2 guidelines. The Marshall Stability (MS), Softening Point (SP) and Penetration Value (PV) of MBA were the major parameters measured. The SP and PV were modelled with ANN as the target values of MBA. The obtained results indicated highest MS value of 6.54±2.70 for MBA50 and 6.30±1.1 for the control sample (MBA0). Optimum SP of 62.0 ^{o}C representing 114.8% of SP equivalent were obtained for MBA60. Highest PV of 61.90±1.2 Pen was obtained for MBA0, while MBA10 has PV of 56±2.1Pen. The adopted model adequately predicted the PV and SP properties of MBA (R^2: 0.97-0.99; MSE: 0.8-1.2). Conclusively, CWA, SB and WB incorporation in MBA improved the strength and durability properties which also enhanced its performance against the traffic loading.

Keywords: ANN, Ceramic Aggregate, Sasobit, Wetfix BE, Modified Bitumen Asphalt,

I. INTRODUCTION

The significance of asphaltic concrete pavement in the construction of roads is very crucial and important to national development of many societies worldwide. Asphaltic pavement is one of the most widely applied transportation methods for passengers due to its high evenness, comfort and low noise (Juanet al., 2010). Roads in Nigeria are vital means of transportation, carrying more than 90% of citizens and their goods. There are about 200,000Km of roads paved in Nigeria, out of which 90% are asphaltic concrete roads (C. Wu and M. Zeng, 2012). Majority of these roads have high level of Pavement deterioration such as rutting, stripping, raveling’s, cracks, potholes, swelling and disintegration. Synthetic Modified Bitumen Asphalt (MBA) is gaining prominence for mitigating problems of poor durability, stiffness, viscosity, rutting and fatigue resistances in Asphaltic Concrete Pavement (ACP). Globally, the advent of technological advancement and civilization has resulted to increased rate of depletion of natural resources most especially construction materials and the need for constructing durable and lasting road pavements for mass transit, vehicular movement and transportation is of great significance to the socio-economic development of a nation. Also there has been increase in the rate of environmental pollution thereby posing serious challenges and health risks.

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The overall and resultant effects of the above has made it quite inevitable for renewed efforts by researchers and engineers to place more efforts into finding and developing alternative materials with reliance on renewable resources including industrial waste products, construction waste materials, reclaimable and recyclable waste materials as well as other by-products which inevitably will help toprotect environment, reduce high consumption of natural raw materials and contribute to the growth of the economy. (Juan et al., 2010). The use of ceramic in construction works is increasing day by day, because it is light in weight Utilisation of ceramic waste as natural aggregates replacement in materials design has gained prominence among researcher due to its environmental and economic values. Various researchers (Sutradharet al., 2015; Cornejo- Rojas et al., 2005; Ruiz et al., 2015; Van de Venet al., 2016) have studied and analyzed the effect of ceramic waste aggregate on strength, durability and engineering properties of modified asphalt and the finding result showed that most engineering properties namely; rutting resistance, indirect tensile (IDT) strength, dynamic modulus, and fatigue life of asphalt mixture, were all better than control samples.For these reasons, this research work incorporated renewable natural resources and synthetic adhesive binders (Sasobit and Wetfix B.E)in development of asphalt mixes that can be used at lower construction temperatures without compromising mix standards.

II. MATERIALS AND METHOD

The experimental materials were, Bitumen, aggregate, chemical additives (Sasobit and Wetfix B.E) and waste ceramics tiles. The used waste ceramics tiles for this research were obtained at Ede, Osun State. The recycled Aggregate used were obtained through grading of waste ceramics tiles, where the physical and chemical analysis were carried out on the obtained sample. The grading of aggregates, testing on bitumen and experimental analysis were done at the Federal Polytechnic Ede Osun State. The results of physical and chemical properties of all materials used and the mix designs are shown in tables 1.0, 2.0and 3.0 respectively. The aggregates used were granite stone and well graded waste ceramics tiles that are free from deleterious materials and of 12.5mm and 4.75mm maximum diameters respectively. The softening point of the bitumen used was ascertained using the ring and ball device in line with ASTM D36 and penetration of the samples was carried out in line with appropriate standard. Design procedure in ASTM D1559-89for asphalt was also adhered to by heating the asphalt to 145ºC and then combined with granite particles. All properties of materials were determined using standard methods

Table 1.0: Physical properties of constituent materials in Asphalt Design

Property	Coarse. Aggregate	Stone Dust	Ceramic Waste	Sasobit @25°C	Wetfix BE @25°C	Bitumen @25°C
Water absorption (%)	0.41	1.21		-	-	-
size (mm)	12.5	4.75		-	-	-
Fineness modulus of Aggregates	6.1	3.24	5.88			
Specific gravity	2.81	2.57	2.49	2.41	2.49	2.40
Flashpoint (^{o}C)	----	-----		285	103-218	-
Softening Point (^{o}C)				112-120	---	
Colour				White	Brown	Black
Relative Density (at20^{o}C):				0.95	0.98	1.190
pH (concentrate)				Neutral	11	

Source: Company Manual and laboratory results, 2021.

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Table 2.0: Chemical compositions of waste ceramics and Crushed stone dust

Oxides	WCA	CSA
SiO_2	64.98	64.48
Al_2O_3	22.47	22.42
Fe_2O_3	0.16	0.41
TiO_2	0.02	0.04
Na_2O	4.80	4.78
K_2O	1.51	1.49
CaO	0.20	0.21
MgO	0.03	0.07
MnO	0.04	0.04
$^+$LoI	5.79	6.06

Source: Laboratory analysis results, 2023. $^+$LoI—loss on ignition, Waste Ceramics (WCA) and Crushed Stone(CSA)

Table 3.0: Mix Design of MBA0-MBA60

Mix design	**BITUMEN (%)**	**SASOBIT (%)**	**WETFIX %**	**CERAMIC %**	**CA %**
MBA-0	100	0.0	0.0	0.0	**100**
MBA-10	99	0.5	0.5	5.0	**95**
MBA-20	98	1.0	1.0	10.0	**90**
MBA-30	97	1.5	1.5	15.0	**85**
MBA-40	96	2.0	2.0	20.0	**80**
MBA-50	95	2.5	2.5	25.0	**75**
MBA-60	94	3.0	3.0	30.0	**70**

Source: laboratory analysis, 2023.

2.1 Research Models

The Penetration value (PV) and Softening point value (SPV) of modified Asphalt were modelled using Artificial Neural Network (ANN) at different percentages replacements of aggregates, additive materials, Marshall stability and ductile ability of waste ceramic aggregate modified Asphalt compared with the measured strength values and mixtures bitumen volume of Modified hot mixed Asphalt in the ranges specified in codes (**AASHTO D4 T44-03: 2006**; IS:1203-1212-1978; Gungor et al., ,2017, Pravat and Zhou, 2018). The PV and SPV of Modified Asphalt was modelled using Artificial Neural Network (ANN) and its Adequacy determined using coefficient of determination (R^2) and Mean Square Error (MSE). Data were analysed using ANOVA at $\alpha_{0.05.}$

III. RESULTS AND DISCUSSIONS

3.1 The Effect of Waste Ceramic Content on Marshall Stability

At 0% Waste Ceramic content(MBA-0), the stability was 6.30kN for 4.75 mm Waste Ceramic particle size, as indicated by the results in Table 4.0. While the stability increased to 6.49KN, 6.39KN, 6.36KN, 6.32KN,6.28KN at 5%, 10%, 15%, 20%, 25% Waste Ceramic content respectively, it decreased to 5.93KN at 30% (MBA-60) Waste Ceramic content. From 6.49kN to 5.93kN, the stability decreased as the Waste Ceramic content was raised from 5% to 30%. According to these findings, Marshall stability declines when waste ceramic content (RPS) increases. However, the obtained result is higher than the minimum specified Marshall stability value of 2.0KN for medium volume traffic roads

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(Khoury et al., 2010).Similar patterns have also been documented by various researchers and in the Marshall stability results, which show that the asphalt aggregate-chunk with Waste Ceramic mix would have a poorer stability than the control mix (He et al., 2015; Van de Ven et al., 2015). Waste Ceramic aggregate absorb some of the energy imparted since they are not as hard as crushed stone aggregates, and this weakens the aggregate structure.

3.1.1 The Effect of Waste Ceramic Content on Flow

The test results in column 4 of Table 4.0 indicate the flow characteristic of the Waste Ceramic modified asphaltic concrete, it can be seen that as the Waste Ceramic content is increased, the flow remain constant except at all replacement levels. The flow value for the control mix (0% Waste Ceramic content) and other replacement level were 5mm. The results here are similar to those of He et al., (2015) and Van de Ven et al., (2015) and this is expected for flow property. According to the obtained flow results, incorporating Waste Ceramic aggregate to asphaltic concrete, using the dry process method generally results in a higher flow value, regardless of the size of Waste Ceramic employed (Khoury et al., 2010). The obtained flow values from specimens made with waste ceramic aggregate at varying replacement levels fall within the specified value of 5 mm maximum limit for wearing courses.

3.1.2 The Effect of Waste Ceramic Content on Unit Weight

Table 4.0 shows that the unit weight was 2.36 kg/rn3 at 0% Waste Ceramic content. The unit weight decreased from 2.28 to 2.24 kg/m3 as the waste ceramic content increased from 5% to 10%. When the Waste Ceramic content increased from 20 to 25%, the same pattern of behavior was seen for MBA-30 and MBA-40, whose unit weight decreased from 2.22 kg/rn3 to 2.20 kg/rn3, as well as for MBA-50 and MBA-60, whose unit weight decreased to 2.18 kg/rn3 and 2.190 kg/m3, respectively, for the same increased rate in Waste Ceramic content. The findings support the hypothesis for Waste Ceramic Blended Asphaltic Concrete and are consistent with earlier research by Sutradhar et al., (2015).

3.1.3 The Effect of Waste Ceramic Content on Voids in Mineral Aggregate

The obtained results in Table 4.0 shows that MBA-0 which is control mix gave a Void in Mineral Aggregate (VMA) value of 80.12% and this meets the standard specification given by Asphalt Institute. When 5% Waste Ceramic was added to the specimen, the VMA increased to 81.12% but thereafter, the VMA values generally decreased with increased in percentage substitution. At 10% Waste Ceramic content, the VMA was 80.14% and decreased to 76.19% at 15% Waste Ceramic content. The same pattern of behaviour was observed for 20%, 25% and 30% substitutions levels with 75.52%, 75.48% and 74.19%. The obtained results are similar to those obtained by Khoury et al. (2010), Sutradhar et al. (2015) and Liu et al. (2018) and for their researches on the effects of Using Waste Material as Filler in Bituminous Mix Design, study on asphalt modified with graphene oxide and study on High temperature performance of asphalt modified with Sasobit and Durex respectively. All obtained results fall within the specified standards.

Table 4.0: Values of Marshall Stability test properties of waste ceramics based Asphaltic concrete

Waste Ceramic Content (%)	Waste Ceramic Particle Size (mm)	Marshal Stability (kN)	Flow (mm)	Air voids by Total Mixtures (%)	Unit Weight (kg/m^3)	Voids filled with Bitumen (VMA)(%)	Specific Gravity
MBA-0	4.75	6.30	5	4	2.36	80.12	2.39
MBA-10	4.75	6.49	5	5	2.28	81.12	2.36
MBA-20	4.75	6.39	5	3	2.24	80.14	2.34
MBA-30	4.75	6.36	5	3	2.22	76.19	2.31
MBA-40	4.75	6.32	5	4	2.20	75.52	2.27

MBA-50	4.75	6.28	5	4	2.18	75.48	2.26
MBA-60	4.75	5.93	5	6	2.19	77.12	2.22

3.2 Asphalt Penetration Values

The higher the penetration, the softer is the bitumen. This test is used for classifying bitumen into standard grade. The obtained penetration values in table 5.0 indicate that MBA-0, MBA-10, MBA-20, MBA-30 and MBA-40 mixes fulfilled the minimum required penetration value of 40 pen with 61.9 pen, 56 pen, 51pen, 48 pen and 42 pen respectively. MBA-50 and MBA-60 samples did not fulfil the minimum requirement and falls below the standard grade as obtained in AASHTO-T49 and BS 2000-489: 2009. The result indicates that the MBA-0 is a 60/70 grade and MBA-0 - MBA-40 are 40/70 bitumen and are adequate for use in hot mix asphaltic concrete in tropical climate.

Table 5.0: The result of Asphalt penetration testing

Specimen	Specimen	Penetration Value	Code Specification	Status
MBA-0	Asphalt + 0 % Sasobit+ Wetfix	61.6	60-70	Full filed
MBA-10	Asphalt + 0.5% Sasobit+ Wetfix	56	Min. 40	Full filed
MBA-20	Asphalt +1.0% Sasobit+ Wetfix	51	Min. 40	Full filed
MBA-30	Asphalt + 1.5% Sasobit+ Wetfix	48	Min. 40	Full filed
MBA-40	Asphalt + 2.0% Sasobit+ Wetfix	42	Min. 40	Fulfilled
MBA-50	Asphalt + 2.5% Sasobit+ Wetfix	38	Min. 40	Not Fulfilled
MBA-60	Asphalt + 3.0% Sasobit+ Wetfix	34	Min. 40	Not Fulfilled

3.3 Asphalt Softening Point Testing

The result in Table 6.0 above indicates the results of softening point test which was carried out in line with appropriate standard. Tested in a water bath, all of the binders exhibited a softening point below 80°C. The softening point of the unmodified bitumen increased by around 9°C when 0% Sasobit+ Wetfix was added, while the modified binders increased by approximately 1°C, 3°C, 6°C, and 8°C for MBA-30, MBA-40, MBA-50, and MBA-60, respectively. The other two altered binders, MBA-10 and MBA-20, did meet the minimum specification value required by the code, which is higher than 54°C. The comparison of the results at the temperature when the plates are changed shows that the measurement has good reproducibility. The obtainable results indicated that for the unaltered binders, a lower penetration grade (harder bitumen) displays higher penetration and indicate the softer of the bitumen in the entire investigated temperature range.

Table 6.0:The result of Asphalt softening point testing

Specimen	Specimen	softening point Value°C	Code Specification	Status
MBA-0	Asphalt + 0 % Sasobit+ Wetfix	64.4	≥ 54	Fulfilled
MBA-10	Asphalt + 0.5% Sasobit+ Wetfix	51.7	≥ 54	Not Fulfilled
MBA-20	Asphalt +1.0% Sasobit+ Wetfix	53.2	≥ 54	Not Fulfilled
MBA-30	Asphalt + 1.5% Sasobit+ Wetfix	55	≥ 54	Full filed
MBA-40	Asphalt + 2.0% Sasobit+ Wetfix	57	≥ 54	Fulfilled

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MBA-50	Asphalt + 2.5% Sasobit+ Wetfix	60	≥ 54	Fulfilled
MBA-60	Asphalt + 3.0% Sasobit+ Wetfix	62	≥ 54	Fulfilled

3.4 Prediction of Penetration Value (PV)

Table 8.0: Prediction of Penetration Value (PV)at the Training Phase

Model	Topology	MSE	MAE	R	R^2
1	5-8-1	0.5	0.5	0.9977	0.9954
2	5-3-1-1	0.8750	0.6250	0.9952	0.9905
3	5-3-1	1.8125	1.0625	0.9918	0.9836

Table 9.0: Prediction of Penetration Value (PV) at Validation Phase

Model	Topology	MSE	MAE	R	R^2
1	**5-8-1**	**0.8**	**0.8**	**0.9979**	**0.9957**
2	5-3-1-1	1.4	1.0	0.9841	0.9684
3	5-3-1	2.6	1.4	0.9676	0.9363

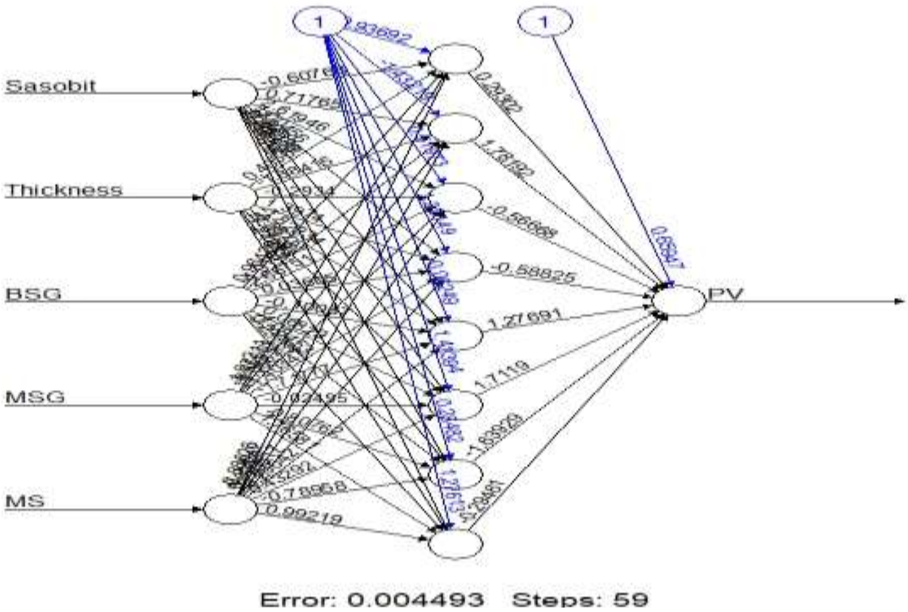

Figure 1.0: ANN topology with 5-8-1 for predicting Penetration Value (PV)

3.5 Prediction of Softening Point (SP)

Table 10.0: Prediction of Softening Point (SP) at the Training Phase

Model	Topology	MSE	MAE	R	R^2
1	5-8-1	0.4375	0.4375	0.9937	0.9874
2	5-3-1-1	0.5	0.75	0.9917	0.9835

3	5-3-1	0.8125	0.5625	0.9880	0.9761

Table 11.0: Prediction of Softening Point (SP) at Validation Phase

Model	Topology	MSE	MAE	R	R^2
1	5-8-1	1.0	1.0	0.9604	0.9224
2	**5-3-1-1**	**1.2**	**0.8**	**0.9830**	**0.9663**
3	5-3-1	1.6	1.2	0.9321	0.8688

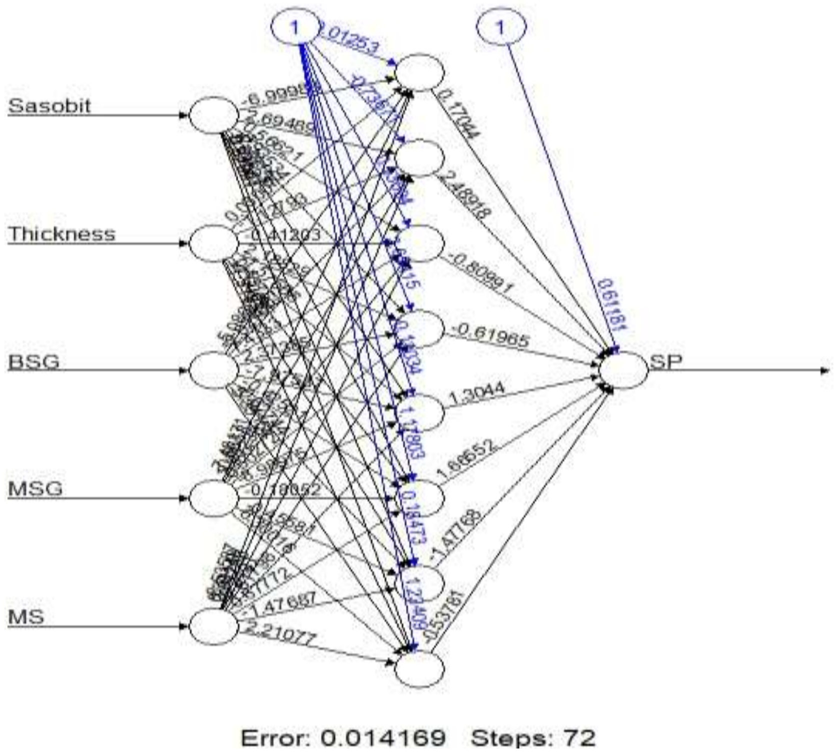

Figure 2.0: ANN topology for 5-8-1 for predicting Softening Point (SP)

IV. CONCLUSIONS

Based on the results of the various tests and analysis carried out on constituent materials, Sasobit+ Wetfix B.E and samples of modified asphalt, the following conclusions are drawn:

1. With the addition of Sasobit+ Wetfix B.E level, the modified asphalt's softening point value tends to increase. When 0.5% and 1.0% Sasobit+ Wetfix B.E are added, the softening point values, which are both 51.7°C and 53.2°C, do not match the requirement. The penetration value of the modified asphalt decreases with an increase in the addition of Sasobit+ Wetfix B.E level and substitution levels of waste ceramic aggregates. The penetration value with the additions of 2.5% and 3.0% Sasobit+ Wetfix B.E failed to meet the requirements with each value of 38 and 34 and this does not fulfill the minimum value of 40.
2. The ANN analysis was able to predict more than 95% of the variation of penetration value and softening point value. ANN with 5-8-1 (5 nodes at input layer, 8 nodes at hidden (middle) layer, and 1 node at output layer) Topology performed best in predicting Penetration Value (PV), While ANN with 5-3-1-1 (5 nodes at input layer, 3 nodes at 1st hidden and 1 node at the 2nd hidden (middle) layers, and 1 node at output layer) Topology

performed best in predicting Softening Point (SP).

CONFLICT of Interest
On behalf of all authors, the corresponding author states that there is no conflict of interest.

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