Effect of Clay Soil from Mbiama on the Mechanical and Moisture Damage Properties of Asphaltic Concrete

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Abstract

Many studies have shown the damaging effect of moisture on conventional asphalt concrete when submerged in water for a time period under the application of traffic load. This study is aimed at determining the effect of partially replacing the mineral filler portion of the total mix with 2-14% clay, sourced from Mbiama on asphaltic concrete. The Marshall Stability Design Method was used to determine the optimum bitumen content of 5% and to evaluate asphalt concrete properties after soaking durations of 2, 4, and 7 days. The clay used for the study underwent Atterberg Limit Test for classification. The results show that the clay adhered to OL and A-3 in both the USC and AASTHO soil classification systems. The Marshall Stability value for the control sample increased from 8.4 kN to 16.54 kN at 4% clay addition, given a 49% increase in stability over the control sample. Soaked clay modified asphalt concrete samples maintained a significant retained stability across all soaking duration with superior moisture resistance capabilities.

Keywords: Marshall, stability, flow, Mbiama, clay, flood, modified, asphalt, concrete

1.0 INTRODUCTION

Bitumen, a vital binder for aggregates in asphalt concrete production, plays a key role in constructing durable road surfaces that can endure heavy traffic over long periods. The quality and performance of asphalt surfacing continue to decline below expectations, posing challenges for road users, impacting the economy, and resulting in high maintenance and reconstruction costs (Jaacob et al., 2016). A major concern is the degradation of traditional asphalt concrete when subjected to moisture and traffic loads (Omar et al., 2020). Moisture damage is as a result of stripping, a phenomenon due to loss of bonding strength between the bitumen and aggregates in asphalt concrete. As a result, highway engineers continually seek modifiers for asphalt concrete to reduce the impact of moisture damage.

In the past decade, researches have been investigating the effect of clay addition as modifier in the manufacture of hot mix bituminous asphalt concrete for enhanced properties (Boateng et al., 2022; Ismael & Ismael 2019). Clay possesses a large surface area, a distinctive characteristic that significantly influences the rheological and anti-aging properties of modified asphalt concrete (Kumari and Mohan 2021; Cheraghian 2017). Additionally, it enhances the bond strength at the aggregate-bitumen interface (Kleiziene´ et al., 2019).

A study conducted by Hainin et al. 2019, using Kaolin clay at a dosage of 3%, 6% and 9% replacement of binder improved the performance of the modified asphalt concrete properties, specifically, the addition of 6% and 9% kaoline clay resulted in good stability of the mixture. Ahmad and Farhan 2022 carried out a study to determine the effect of adding five different percentages of Organophilic Nano Clay (ONC) on two different grades of bitumen using four laboratory test check on moisture damage, such as Static Immersion Test, Total Water Immersion Test (TWIT), Boiling Water and Rolling Bottle Test. The result shows that at 4.5% ONC on both binder types, there was a significant decrease in moisture damage and gave the best resistance to moisture attack.

This study focuses on the effect of clay sourced from Mbiama as modifier for the partial replacement of mineral filler of the total mix on the Marshall properties of asphaltic concrete mixture and its resistance to moisture damage that has not been studied before.

2.0 MATERIAL AND METHOD

The binder used for this study (bitumen) was obtained from Ringardas Nigeria Limited, Rivers State. Coarse aggregates from crushed granites were sourced from the Oil Mill Granite Dump site in Port Harcourt, Rivers State, carefully selected for angularity and roughness to prepare asphalt sample mixtures. Naturally occurring river sharp sand from Eleme in Rivers State was used as fine aggregates, while Dangote Portland Limestone cement, conforming to ASTM C595/C595M - 21, served as the mineral filler for the Marshall sample mixes. Additionally, clay soil was collected one foot below the ground surface in the freshwater zone of Mbiama town, Rivers State, and subjected to the Atterberg limit test on a soil fraction passing the No. 40 sieve, in accordance with ASTM D4318-17, to determine its identity and suitability as a filler material.

2.1 Sample Preparation

The procedure used to determine the optimum bitumen content followed the Marshall Mix Design Method in accordance with ASTM D1559-89/ASTM D2726-21 and was used to prepare all Marshall samples for this study.

The aggregates were washed to eliminate any deleterious materials, dried and sieved in accordance with ASTM D 3515-01 specification. Oven dried Mbiama clay (modifier) was used to partially replace the mineral filler component of the total mix at 2%, 4%, 6%, 8%, 10%, 12%, and 14%. The mixture of clay, coarse and fine aggregates are preheated in accordance with specified proportions at 175°C. Marshall molds are also preheated and kept at temperatures between 100°C to 145°C to avoid sudden loss in temperature.

Bitumen is heated at 138°C and added to the clay-aggregates mixture and thoroughly mixed until a uniform consistency is achieved at 160°C.

The mixture is placed into Marshall molds and compacted using a standard Marshall hammer, with 75 blows on each face of the cylindrical specimen. Each sample was carefully prepared to ensure accuracy and reliability in the results. Three Marshall specimen are required to evaluate Stability and Flow using the optimum bitumen content (OBC). Afterwards the Marshall samples are allowed to cool down and are extracted from the molds using an asphalt sample extractor.

Marshall samples are submerged in water bath as conditioned samples for different duration of 2 days, 4 days and 7 days. Marshall stability tests were then conducted on the Marshall samples after immersing them in water bath at a temperature of 60 ± 1°C for 30 minutes. Subsequently, Marshall samples are placed in the Marshall stability testing machine and subjected to a constant deformation rate of 5 mm per minute until failure. The measured stability values are adjusted for nonstandard specimen height using stability correlation ratios in accordance with ASTM D-1559-89. The flow, defined as the deformation at maximum load, is recorded in 0.25 mm increments.

3.0 RESULTS AND DISCUSSIONS

3.1 Clay Properties

Referring to Table 1, the soil at Mbiama in Rivers State has a 93% particle size distribution, with liquid limit (LL) of 32% and a 24% plasticity limit (PL). It is classified as OL (organic silty clay of low plasticity) in the AASHTO system's A-3 group, demonstrating the consistency and reliability of soil characterization across various classification methodologies. Figure 1 show moisture variation due to number of blows.

Table 1: Classification of Soil

Site	Plasticity Index	Atterberg Limit		USC System	AASTHTO Classification
	PI	LL	PL		
Mbiama	7	32	25	OL	A-3

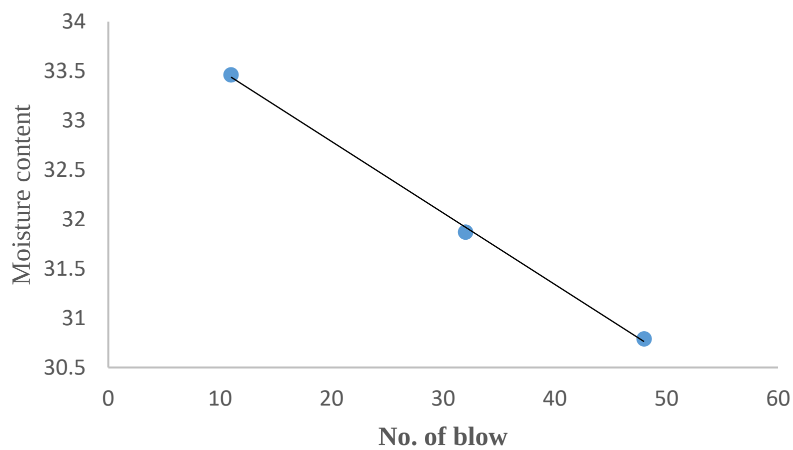

Figure 1: Moisture Content versus Number of Blows for Mbiama Soil

Mechanical and Volumetric Properties of Asphalt Concrete Modified with Clay

The results presented in Table 2 and Figures 2 to 4 provide valuable insights into the mechanical and volumetric properties of asphalt modified with clay sourced from Mbiama, Rivers State, Nigeria.

3.2 Marshall Stability

It can be observed that the addition of clay increased the Marshall Stability, reaching a maximum value of 16.54 kN, at 4% clay content - a 49% increase in Marshall Stability value. The reason for this increase in stability is due to the stiffening effect of the clay particles, which act as reinforcing agents within the asphalt matrix (Muniandy et al., 2013).

Table 2: Mechanical and Volumetric Properties of Asphalt Modified with Clay Sourced from Mbiama with 5% Bitumen Content– Un-soaked

% Clay	Marshall Stability kN	Marshall Flow mm	Unit Weight	% VTM	% VMA	% VFB
0	8.4	2.2	2.400	5.2	17	70
2	14.92	2.17	2.426	1.42	13.23	89.25
4	16.54	2.10	2.446	0.57	12.51	95.45
6	15.62	2.50	2.435	1.02	12.91	92.13
8	14.30	2.07	2.373	3.50	15.12	76.87
10	14.29	2.04	2.418	1.67	13.51	87.66
12	13.45	2.20	2.351	4.59	15.91	71.17
14	13.02	2.17	2.416	1.71	13.58	87.42

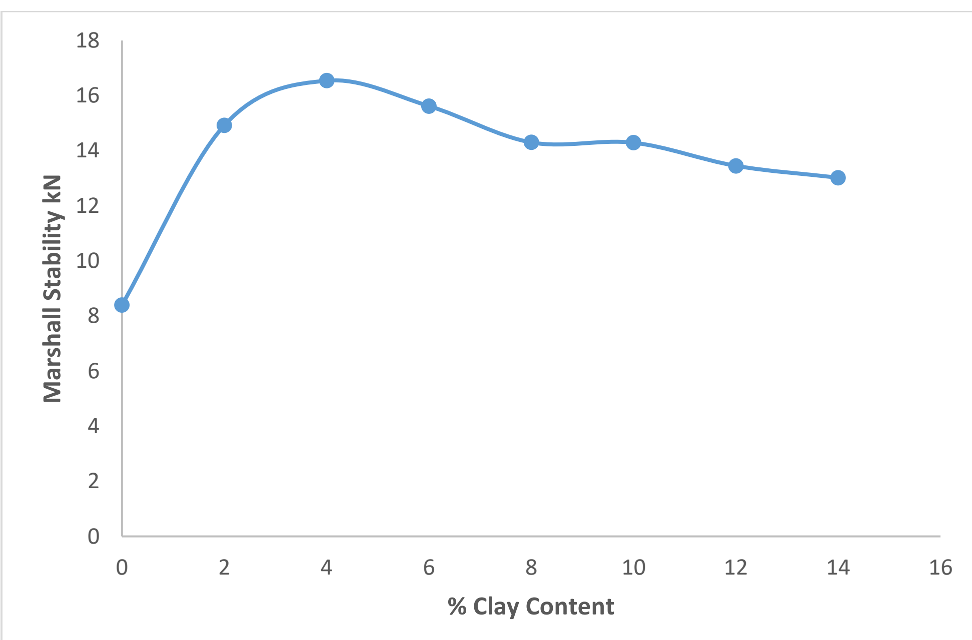

Figure 2: Stability versus Percent Clay Content

However, beyond 4% clay content, the stability values started decreasing due to the potential reduction in asphalt film thickness, leading to inadequate binding of the aggregate particles (Alkofahi & Khedaywi. 2019). This trend is evident in Figure 2, which depicts the variation of stability with increasing clay content. The presence of an optimal clay content suggests that there is a balance to be achieved between the stiffening effect of the clay and the necessary asphalt film thickness for effective aggregate-binder bonding.

3.3 Marshall Flow

From Table 2, it's evident that the Marshall Flow values fell within the acceptable range of 2-4 mm as recommended by the FMWH 1997 specification.
The variation of Marshall flow with clay content, as shown in Figure 3, exhibits a non-linear trend, with values fluctuating around a mean of approximately 2.18 mm. This suggests that the addition of clay, sourced from Mbiama does not significantly alter the plastic behavior of the asphalt mixture within the investigated clay content range. However, it is essential to consider the Marshall flow in conjunction with the Marshall Stability to ensure an optimal balance between stiffness and flexibility.

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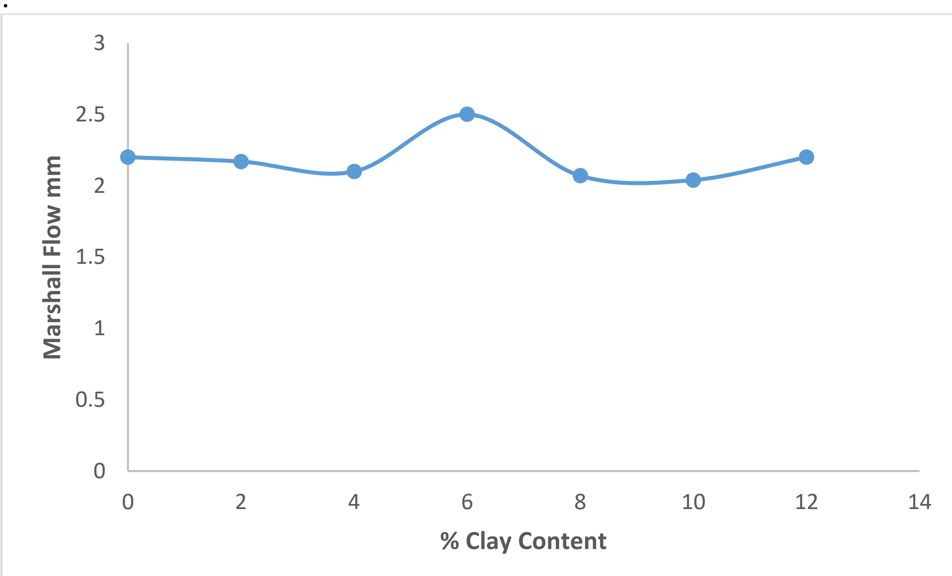

Figure 3: Flow versus Percent Clay Content

3.4 Percentage Voids in Total Mix (% VTM)

From Table 2, it can be observed that the VTM values range from 0.57% to 4.59%, with two values falling within the recommended range of 3% to 5% for dense-graded asphalt mixtures (FMWH 1997).

The variation of VTM with clay content, as shown in Figure 4, exhibits a non-linear trend, with values fluctuating around a mean of approximately 2.5%. This observation suggests that the addition of clay does not significantly impact the air void content

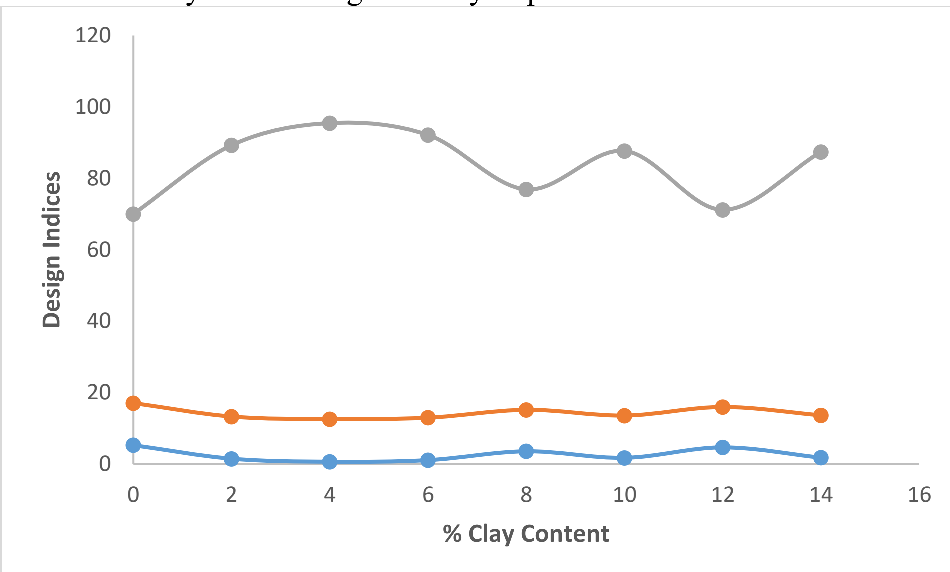

Figure 4: Design Indices versus Percent Clay Content

within the investigated clay content range, which is desirable for achieving adequate durability and resistance to moisture damage (FMWH 1997).

3.5 Percentage Voids in Mineral Aggregate (%VMA)

It can be observed from table 2 that the VMA values range from 12.51% to 15.91%, which falls within the recommended range of 13% to 16% for dense-graded asphalt mixtures.

The variation of VMA with clay content, as shown in Figure 4, exhibits a non-linear trend, with values fluctuating around a mean of approximately 13.5%. This observation suggests that the addition of clay sourced from Mbiama does not significantly impact the empty space between the aggregate particles within the investigated clay content range, which is essential for ensuring adequate asphalt film thickness and durability.

3.6 Percentage Voids Filled with Bitumen (% VFB)

From table 2, it can be observed that the VFB values range from 71.17% to 95.45%, with two values falling within the recommended range of 65% to 75% for dense-graded asphalt mixtures (FMWH 1997).

The variation of VFB with clay content, as shown in Figure 4, exhibits a non-linear trend, with values fluctuating around a mean of approximately 85%. This observation suggests that the addition of clay does not significantly impact the fraction of bitumen filled spaces within the investigated clay content range, which is ideal for reaching the necessary levels of durability and moisture damage resistance.

3.7 Results for Soaked Asphalt Samples

The data presented in Table 3 and Figure 5 provide insights into the behaviour of clay-modified asphalt concrete mixtures under different soaking durations (2, 4, and 7 days). The soaking process simulates the exposure of the asphalt mixture to water, which can potentially lead to moisture damage and a reduction in stability due to the stripping of the asphalt binder from the aggregate surface.

Table 3: Variation of Marshall Stability Due to Percentage Replacement of Mineral Filler with Clay

Mbiama Clay (%)	Un-soaked	Soaked for 2 days	Soaked for 4 days	Soaked for 7 days
0	8.4	5.35	5.10	4.73
2	14.92	14.90	14.71	14.66
4	16.54	16.52	16.52	16.34
6	15.62	15.51	15.50	15.22
8	14.30	14.28	13.92	13.12
10	14.29	13.96	13.41	13.30
12	13.45	13.45	13.44	13.43
14	13.02	13.03	13.03	13.00

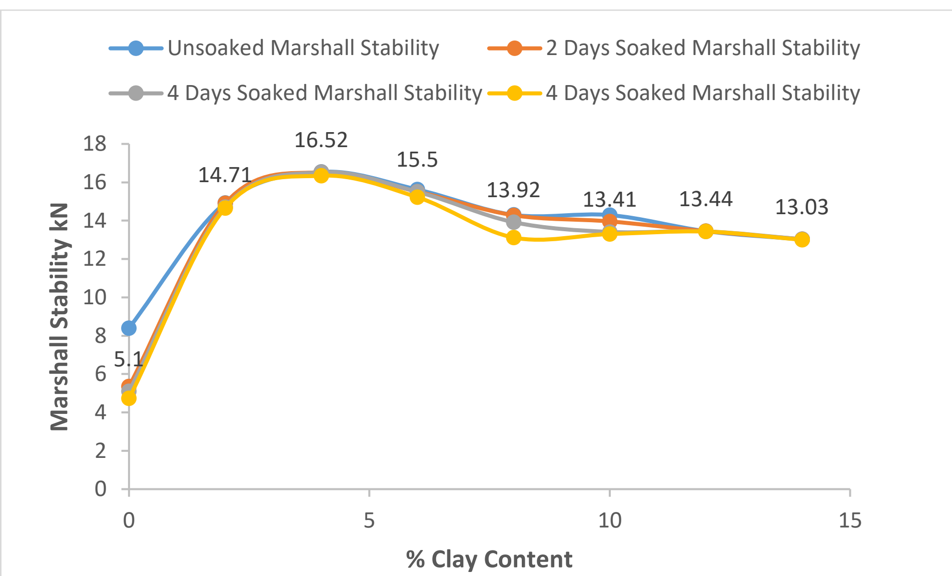

Figure 5: Variation of Stability due to Percent Clay Content and Soaked for 2 days, 4 days, and 7 days

The data clearly demonstrates that the Marshall Stability values of the clay-modified asphalt mixtures show insignificant variation when exposed to different soaking durations. However, with prolonged soaking durations of more than 7 days, the stability values are likely to further decrease as the trend shows a gradual decrease in Marshall stability values as soaking duration increases from 2 to 7 days, suggesting potential moisture damage and loss of integrity within the asphalt mixture.

The aforementioned pattern can be ascribed to the complex interactions between the clay particles, asphalt binder, and water molecules. Initially, the clay particles may act as a barrier, preventing the ingress of water into the asphalt-aggregate interface (Shenoy et al., 2022). However, prolonged exposure to water can lead to the swelling and dispersion of the clay particles, weakening the asphalt-clay composite and causing degradation of the asphalt-aggregate bond (Noor et al., 2017; Sahoo & Rout, 2020).

It is noteworthy that the stability values exhibit a non-linear trend with varying clay content and soaking durations. This behaviour can be attributed to the heterogeneous nature of the asphalt-clay composite and the complex interactions between the different components (Cheraghian & Wistuba. 2020). Additionally, various factors, including the specific type and composition of the clay, the characteristics of the asphalt binder, and the gradation of the aggregate, can significantly influence both the moisture susceptibility and the overall stability of the asphalt mixture (Mallick et al., 2020; Pan et al., 2018).

3.8 Results of Marshall Flow

The data presented in Table 4, Figure 6 provide valuable insights into the variation of Marshall Flow for asphalt mixtures modified with Mbiama clay subjected to different soaking durations.

3.9 Un-soaked Condition

From Table 4, it can be observed that the Marshall flow values for the un-soaked asphalt mixture without clay addition (0% clay) is relatively high at 2.2 mm. This baseline value serves as a reference point for evaluating the effects of clay modification on the plastic behavior of the asphalt mixture.

Table 4: Variation of Marshall Flow Due to Percentage Replacement of Mineral Filler with Clay - Soaked

Clay (%)	Marshall Flow (mm)			
	Un-soaked	Soaked for 2 days	Soaked for 4 days	Soaked for 7 days
0	2.2	2.48	2.55	2.75
2	2.17	2.18	2.56	2.63
4	2.10	2.30	2.36	2.60
6	2.50	2.52	2.56	2.63
8	2.07	2.21	2.28	2.44
10	2.04	2.29	2.30	2.36
12	2.20	2.44	2.47	2.96

14	2.17	2.19	2.28	2.48

With the addition of clay from Mbiama, the Marshall flow values generally exhibit a decreasing trend, ranging from 2.04 mm to 2.50 mm, with all values falling within the recommended range of 2 to 4 mm, as per the FMWH 1997 specifications. This decrease in Marshall flow can be linked to the stiffening effect of the clay particles, which act as reinforcing agents within the asphalt matrix, resulting in a more rigid and less plastic material (Muniandy et al., 2013; Tarefder & Ahmed, 2014). The decrease in Marshall flow observed with clay addition can be elucidated by the physicochemical interactions between the clay particles and the asphalt binder

3,10Soaked Condition

The data presented in Table 4 and Figure 6 provide insights into the behavior of clay-modified asphalt mixtures under different soaking durations (2, 4, and 7 days).

The results clearly show that when the clay-modified asphalt mixtures are soaked for varying amounts of time, their Marshall Flow values tend to increase slightly. For instance, at 2% clay content, the flow value slightly increased from 2.17 mm (un-soaked) to 2.18 mm after 2 days of soaking, indicating an initial increase in plastic deformation. Subsequently, with prolonged soaking durations of 4 and 7 days, the flow values increase to 2.56 mm and 2.63 mm, respectively, suggesting potential moisture damage and an increase in plastic deformation.

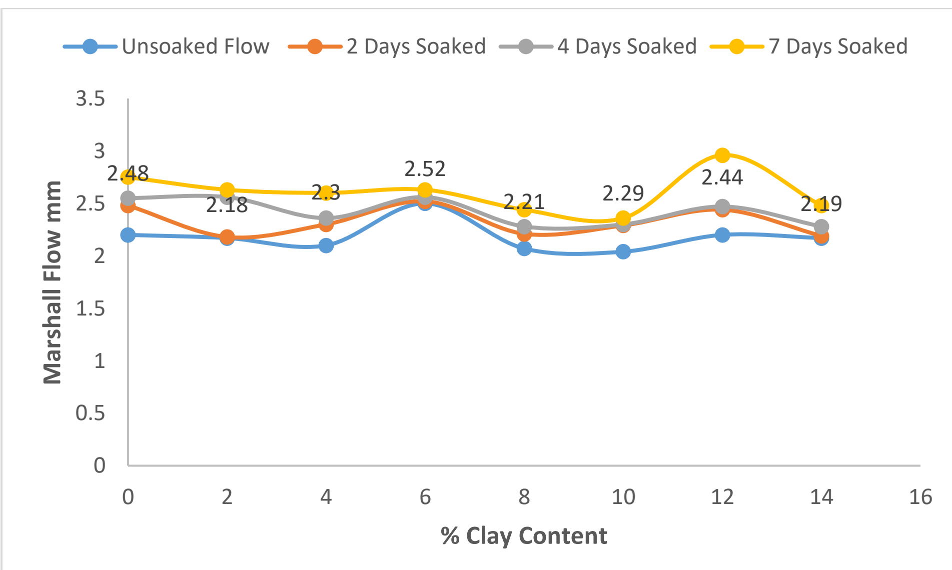

Figure 6: Variation of Flow due to Percent Mbiama Clay Content and Soaked for 2-days, 4-days, and 7-days

This observed trend is due to the complex interactions between the clay particles, asphalt binder, and water molecules. Initially, the clay particles may act as a barrier, preventing the ingress of water into the asphalt-aggregate interface (Shenoy et al., 2022). However, prolonged exposure to water can lead to the swelling and dispersion of the clay particles, weakening the asphalt-clay composite and reducing its stiffness, resulting in increased plastic deformation (Noor et al., 2017; Sahoo & Rout, 2020).

It is noteworthy that the flow values exhibit a non-linear trend with varying clay content and soaking durations. This behavior can be attributed to the heterogeneous nature of the asphalt-clay composite and the complex interactions between the different components (Cheraghian & Wistuba (2020). Additionally, factors such as the type and composition of the clay, the properties of the asphalt binder, and the aggregate gradation can influence the moisture susceptibility and plastic behavior of the asphalt mixture (Mallick et al., 2020; Pan et al., 2018).

4.0 CONCLUSION

This study evaluated the effect of partially replacing the mineral filler portion of the total mix of asphalt concrete mix with clay sourced from Mbiama as modifier on the strength properties and moisture damage of bituminous hot mix asphalt concrete. The following conclusion can be drawn from the laboratory experimentation:

i. The control bituminous asphalt concrete mix had a Marshall Stability value of 8.4 kN and a Marshall Flow of 2.2 mm;
ii. The addition of clay sourced from Mbiama increased the stability value from 8.4 kN at 4% clay content (49% increase over the control sample) and started decreasing on addition of more clay;
iii. The VTM, VMA and VFB all exhibited a non-linear trend, with values fluctuating around a mean of approximately 2.5%, 13.5% and 85%, respectively and are within the FMWH 1997 specifications. This observation suggests that the addition of clay sourced from Mbiama does not significantly impact on the asphalt concrete volumetrics, which is ideal for reaching the necessary levels of durability and moisture damage resistance;
iv. Soaked clay modified asphalt concrete samples maintained relatively significant retained stability across all soaking duration of 2, 4 and 7 days with superior moisture resistance;
v. Marshall Flow values for soaked asphalt concrete across all soaking duration showed appreciable resistance to plastic deformation, indicating the stiffening effect of clay from Mbiama. However, there is a gradual increase in flow values indicating the tendency for moisture damage after prolong soaking.

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