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Moisture Effect on the Strength Properties of Patani-Clay Modified Asphalt Concrete

Toscanini D. S. And Nelson A.
Niger Delta University, Wilberforce Island Bayelsa State, Nigeria
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Abstract
Traditional asphalt concrete is an important road surfacing material and tends to fail when submerged in water for a period under traffic load. The study is aimed at investigating the effect of clay, sourced from Patani, as modifier of asphalt concrete on Marshall mechanical properties and its resistance to moisture damage under soaking duration of 2, 4 and 7 days. Clay was used to partially replace the mineral filler at dosage rates ranging from 0% - 14% by weight of the mineral filler component in the total mix. The Marshall Mix Design Method was adopted to determine the optimum bitumen content of 5% and also used to prepare clay-modified asphalt concrete samples. Atterberg Limit Test was conducted on the soil sample for identification. The results show that the clay used is classified as inorganic, high plasticity clay in the AASHTO system's A-6 group. The control mix with no clay content addition had the lowest Marshall stability value of 8.4 kN and increased to 18.73 kN when clay sourced from Patani was incorporated at 4%, representing an increase of 123% over the control mix. Marshall stability values were substantially retained under soaking duration up to 7 days and maximizing anti-stripping properties of asphalt concrete mix.

Keywords: *Patani, clay, flood, modified, asphalt, concrete, Marshall, stability*

1.0 INTRODUCTION

Asphalt concrete is a major component in flexible pavement roads, providing durability and strength. Bitumen, a crucial binder for aggregates in the manufacture of asphalt concrete, plays an essential role in creating road surfaces capable of withstanding heavy traffic loads and harsh environmental conditions over extended periods. Unfortunately, bitumen losses the ability to bond with mineral aggregates (stripping) due to the infiltration of moisture when subjected to flooding under traffic load. The detrimental effect is huge and well documented (Omar et al., 2020). Consequently, addressing the impact of climate change on asphalt concrete is becoming an increasingly important concern in road construction and maintenance. In view of this, international experts and researchers in highway engineering have embraced innovative processes and advanced materials in road construction to tackle these challenges effectively by integrating specialized admixtures or modifiers to enhance durability, optimize performance, and substantially extend the lifespan of asphalt pavement (Sun et al., 2017; Ozen 2011).

Moisture-related damage in asphalt concrete pavement infrastructure results in millions of dollars in annual maintenance, repairs and rehabilitation costs (Abuawad et al., 2015; Ismael et al., 2015). The primary cause of the problem is the separation of aggregates from the binder in asphalt concrete (Ashish et al., 2016). The continuous soaking of asphalt concrete in water under traffic load gradually weakens the mechanical properties of the asphalt concrete mix, ultimately compromising the structural integrity of the pavement and making it unsafe for vehicular and pedestrian use (Ismael et al., 2019).

Progressive stripping or raveling can quickly cause the asphalt concrete wearing surface to deteriorate, potentially leading to pothole formation. Moisture damage in asphalt concrete typically occurs in two main ways: loss of adhesion between the binder and aggregate, and loss of cohesion within the binder itself (Das et al., 2015).

Road pavement failures in the Niger Delta area in Nigeria after annual floods have resulted in numerous fatalities, economic setbacks, and extensive property damage due to road crashes. Studies by Otto et al. 2020; Otto & Awarri 2021 have demonstrated the detrimental effect of moisture on traditional asphalt concrete

Use of several clays as modifiers in the manufacture of hot-mix asphalt concrete has had promising results in improving the properties of traditional asphalt concrete (Mohd Satar et al., 2018; Muniandy et al., 2013). Clay readily adheres to binder, coating aggregates and creates a denser network with less air voids in mixtures. However, adequate workability should be ensured with high clay contents above 12% (Das et al., 2020).

Ahmad et al., (2022) carried out a study on the moisture susceptibility of Organophilic Nano Clay (ONC) modified asphalt mixture using different percentages of ONC on two different grades of bitumen and experimenting with Static Immersion Test, Total Water Immersion Test, Boiling Water Test and Rolling Bottle Test. The result shows that by incorporating 4.5% ONC to both binder types decreased the moisture damage by improving the affinity between binder and aggregates in the asphalt concrete mixture.

Baker et al. (2018) examined the effect of replacing filler with 5%-30% bentonite clay in asphalt mix. Samples underwent Marshall stability, bulk density, flow, indirect tensile strength, and hydraulic conductivity tests. Results showed stability and density peaked at 15% bentonite clay. Stability increased by 11.57 kN, compared to 9.17 kN for the control, showing improvement. However, a 23% stability loss occurred after 24-hour water soaking. The modified mixture showed higher flow and indirect tensile strength, with reduced hydraulic conductivity versus the control, indicating enhanced performance despite water exposure effects.

Tarefder & Ahmed (2014) determined the optimal clay content in hot mix asphalt to be between 7% and 12% by weight of the aggregates. Mixtures with 8% to 10% clay exhibited notably higher stiffness modulus and indirect tensile strength, along with enhanced resistance to moisture damage.

Additionally, the incorporation of 10% clay improved rutting resistance and extended the fatigue life compared to unmodified mixes.

Mandal et al. (2023) reported 30% higher stiffness modulus and 50% decrease in rut depth meeting AASHTO T 340-10 (2018) criteria for mixes with 15% kaolin clay validating improved performance for mixes containing 12% kaolin clay.

This study aims to examine the impact of moisture on the Marshall stability and flow properties of asphalt concrete by partially replacing the mineral filler component with Patani clay, using both conditioned and unconditioned Marshall samples.

2.0 MATERIAL AND METHOD

2.1. Asphalt cement

Asphalt cement (bitumen) was obtained from Ringardas Nigeria Limited, Rivers State and used in this study.

2.2. Aggregates

Crushed granite with angular particles and rough surface texture, obtained from Yenagoa crushed stone dump site was used as coarse aggregate and utilized in preparing asphalt mixtures. Natural sand obtained from fresh water river in Amassoma, Bayelsa State is used as fine aggregates. The mineral filler used is Dangote Portland Limestone cement in accordance with ASTM C595/C595M-21.

2.3. Clay

Clay soil for this study was sourced from the fresh water zone of Patani in Delta State of Nigeria and used as a modifier as partial replacement of mineral filler in the production of hot mix bituminous asphalt concrete. Atterberg Limit Test was performed on a soil fraction passing the 0.450mm (No. 40) sieve in accordance with ASTM D4318-17e1 to identify the type of clay and its suitability as a filler material.

2.4. Mix Preparation

The optimum bitumen content was determined in accordance with the Marshall Mix Design Procedure ASTM D2726M-21 and used to prepare Marshall samples for this study.

Prior to batching, the aggregates were washed, dried, and sieved in accordance with ASTM D 3515-01. Oven-dried clay from Patani was used as a partial replacement for the mineral filler in asphalt mixtures at varying percentages (0%, 2%, 4%, 6%, 8%, 10%, 12%, and 14%). The clay, along with the coarse and fine aggregates, was preheated to 175°C and mixed according to the specified proportions. The Marshall molds were also preheated and maintained at a temperature range of 100°C to 145°C.

Preheated bitumen at 138°C is added to the aggregate mixture and thoroughly mixed until a uniform consistency is achieved at 160°C. The mixture is then carefully placed into a Marshall mold and compacted using a standard Marshall hammer, applying 75 blows on each side of the cylindrical specimen. To evaluate stability and flow measurements, three (3) Marshall specimens are prepared using the optimum bitumen content. After a short cooling period, the samples are extracted from the molds using an asphalt sample extractor.

Each sample was carefully prepared to ensure accuracy and reliability in the results. The conditioned specimens were submerged in a water bath for different durations - 2, 4, and 7 days. The Marshall stability test was then conducted on each specimen after being immersed in a water bath at a temperature of 60 ± 1°C for 30 minutes. Subsequently, the specimens were loaded into the Marshall stability testing machine at a constant deformation rate of 5 mm per minute until failure. Stability values were then corrected for nonstandard specimen height using stability correlation ratios as per ASTM D-1559-89. The flow - deformation at maximum loading is recorded in increments of 0.25 mm.

3.0 RESULTS AND DISCUSSION

3.1 Clay Properties

Table 1 shows that the primary soil type collected from Patani site in Delta State adhered to CL and A-6 outlined by both the Unified Soil Classification (USC) and American Association of State Highway and Transportation Officials (AASTHO) systems, demonstrating the consistency and reliability of soil characterization across various classification methodologies.

Referring to Table 1, the soil has a 90% particle size distribution, while Atterberg limits are 41% Liquid Limit and 29% Plastic Limit. It is classified as CL (inorganic, high plasticity clay) in the AASHTO system's A-6 group. Figure 1 shows the moisture variation due to number of blows.

Table 1: Classification of Soil

Test No	Plasticity Index	Atterberg Limit		USC System	AASTHTO Classification
	PI	LL	PL		
Patani 1	12	41	29	CL	A-6

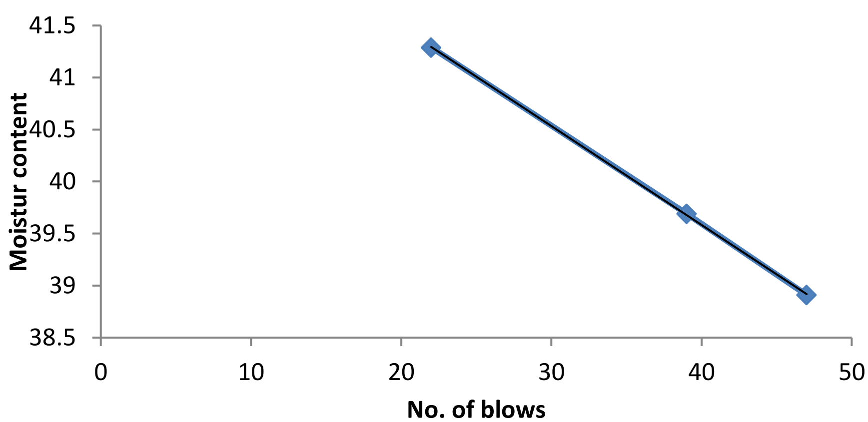

Figure 1: Moisture Content Versus Number of Blows Graph for Patani Soil

Tests conducted on the bitumen at the Civil Engineering Highway Laboratory, Niger Delta University, indicate a penetration grade of 60/70. This conforms to the Nigeria General

Specifications for Roads and Bridges (NGS 1997). The bitumen has a softening point ranging from 46°C to 54°C, a flash point between 230°C and 300°C, and a specific gravity at 25°C of 1.01 to 1.06. Additionally, its solubility exceeds 99% by weight, its ductility at 25°C is greater than 100 cm, and the optimum bitumen content is 5%. The results are within the prescribed ranges defined by relevant codes. These results suggest that the selected bitumen is appropriate for use in asphalt concrete applications.

The physical properties of the aggregates used in this study conforms to AASHTO T 27-14, meeting the required standards for use in asphalt. The gradation of the aggregates shows that the fine aggregate and coarse aggregate were uniformly graded, having Cu value of 2.3 for fine aggregate and 2.1 for coarse aggregate.

3.2 Marshall Mechanical and Volumetric Properties

Table 2 shows the Marshall stability values for asphalt concrete mixes modified with different percentages of clay, sourced from Patani under un-soaked (dry) conditions. The control mix containing no clay addition had the lowest stability of 8.4 kN. Stability initially increased with rising clay content, reaching a maximum value of 18.73 kN at 4% clay content. This represents an increase of 123% over the control mix without clay. Further increases in clay content led to a gradual decrease in stability.

Table 2: Mechanical and Volumetric Properties of Asphalt Modified with Patani Clay – Un-soaked

% Patani Clay	Unit Weight	Marshall Stability kN	Marshall Flow mm	% VTM	% VMA	% VFB
0	2.28	8.4	2.2	2.2	16	72
2	2.304	17.57	2.42	6.38	17.59	63.73
4	2.32	18.73	2.45	7.72	18.81	58.96
6	2.341	17.11	2.46	7.24	18.41	60.67
8	2.38	15.86	2.47	9.80	20.67	52.59
10	2.392	15.77	2.74	2.69	14.44	81.37
12	2.384	16.42	2.45	3.01	14.73	79.57
14	2.413	16.23	2.4	1.79	13.69	86.92

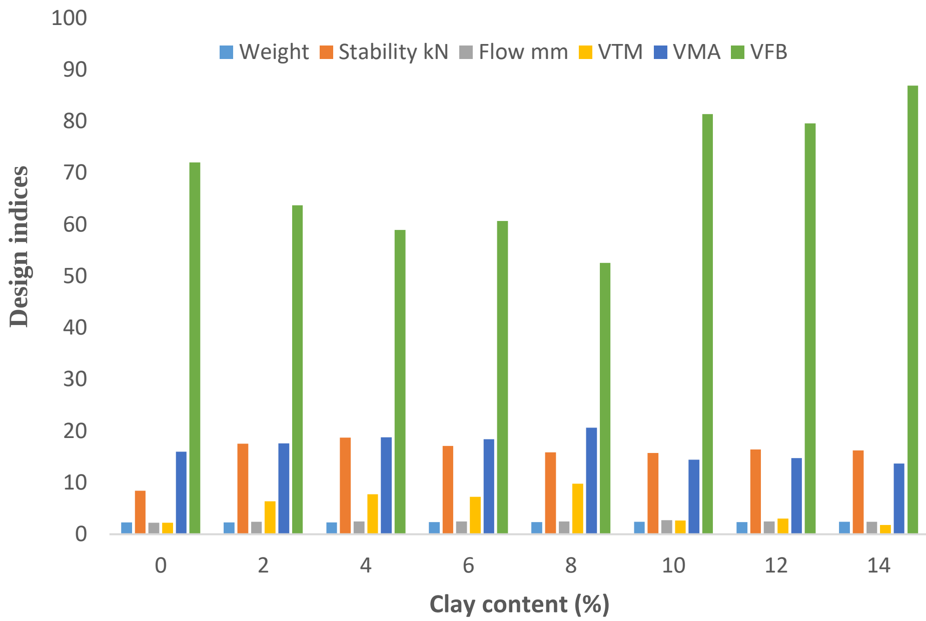

Figure 2: Variation of Design Indices due to Clay Content

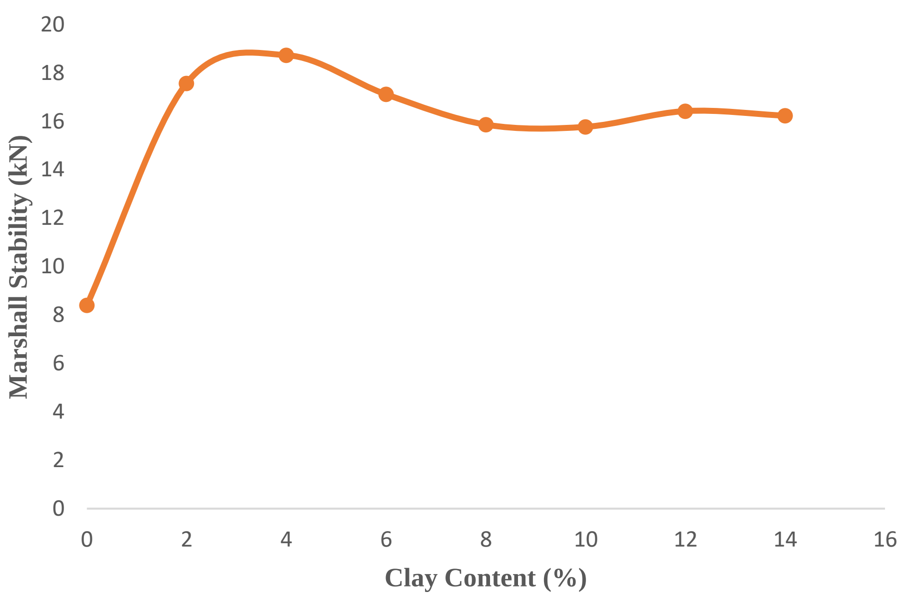

Figure 3: Marshall Stability versus Percent Clay Content

The initial rise in stability can be due to the filler effect of finer clay particles, which improves cohesion within the bitumen mastic (Lakshminarayanan et al., 2016). Finer clay particles also enhance aggregate-binder adhesion by filling voids between the aggregate skeleton (Cabral et al., 2013). However, excess clay above the optimum limit hinders coating of aggregates due to over-densification, thereby reducing stability (Awotunde et al., 2022). The observed optimum of 4% clay modification agrees with recommendations in the literature to balance enhancement in properties without significant change in workability (Pandit & Patel. 2021).

3.3 Analysis of Marshall Flow Results

Table 2 also presents the Marshall flow values, which characterize the mix workability and compaction. Flow initially increased from the control value of 2.2 mm, reaching a maximum of 2.74 mm at 10% clay content (Figure 4).

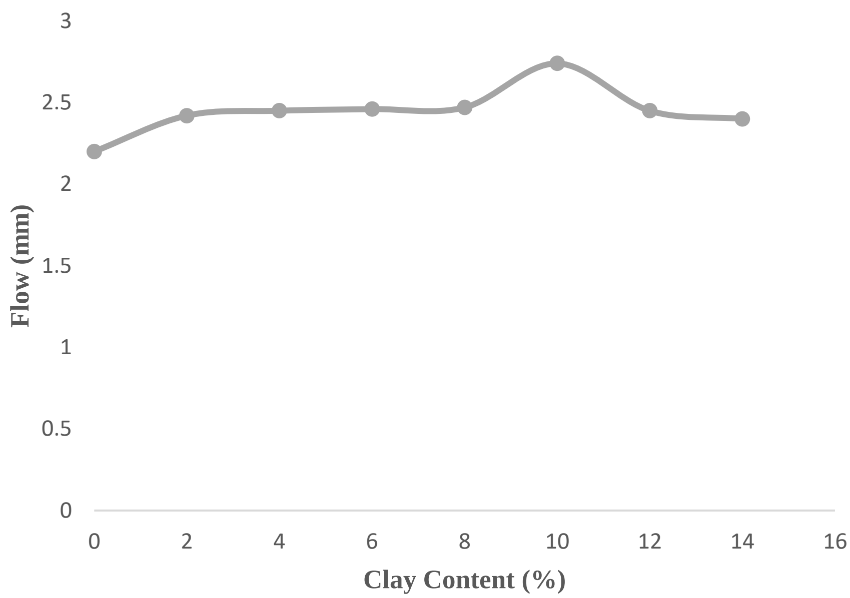

Figure 4: Marshall Flow versus Percent Clay Content

Clay enhances mix workability and compaction by facilitating better distribution of the binding agent (Sahoo & Rout, 2020). However, excessively high clay triggers early stiffening that hinders compaction (Lakshminarayanan et al., 2016). The marginal increase in optimum clay content for flow (10%) compared to stability (4%) corroborates findings that an optimally balanced combination of workability and strength can be achieved between these dosage limits (Sahoo & Rout. 2020; Lakshminarayanan et al., 2016).

3.4 Analysis of Volumetric Properties

The impact of clay incorporation on volumetric properties including VTM, VMA, and VFB are shown in Table 2 and Figure 5. VTM, which measures mix density, initially increased up to a value of 7.72% at 4% clay content. This validates past research attributing higher density to the filler effect of finer clay particles that aid compaction. However, VTM rose further with clay content above 4%, likely due to over-densification hampering the compaction process.

VMA, which represents the total void space between aggregate particles, increased constantly with rising clay content levels as expected. Maximum VMA of 20.67% occurred at 8% Patani clay addition. Simultaneously, VFB declined above 6% clay dosage.

These correlated VMA and VFB trends corroborate findings that excess non-absorbent clay beyond optimum limits dilutes the binding agent (Awotunde et al., 2022).

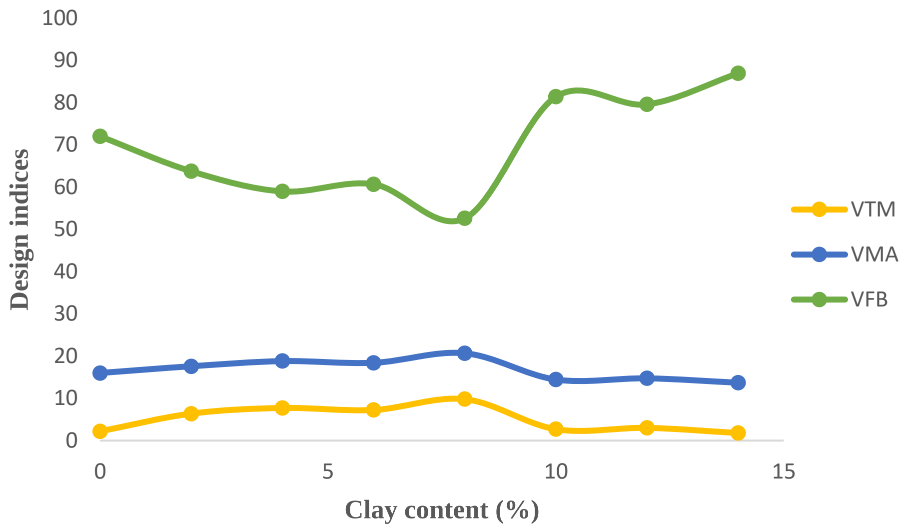

Figure 5: Variation of Volumetric Properties due to Percent Clay Content

Overall, the volumetric properties were optimized between 4-6% clay modification meeting mix design specifications.

3.5 Results of Soaked Mechanical Properties of Asphalt Modified with Patani Clay

Table 3 gives effect of soaking asphalt specimens containing different clay percentages for 2, 4, and 7 days and analyzed for its mechanical properties.

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

Patani 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	17.57	17.15	17.13	17.00
4	17.73	17.72	17.70	17.69
6	17.11	17.09	17.09	17.07
8	15.86	15.15	15.05	15.05
10	15.77	15.25	15.22	15.15
12	14.42	14.32	14.31	14.30

14	14.23	14.22	14.22	14.19

Overall, this comprehensive analysis serves to substantiate the technical efficacy of utilizing natural clays like Patani clay to modify asphalt concrete mixtures and improve sustainability and performance.

3. 6 Marshall Stability Variations

A critical indicator of the mechanical strength and expected field performance of asphalt mixtures is the Marshall stability (Iloeje, et al., 2019). As seen in Table 3 and Figure 6, the control specimen without any clay addition exhibited the lowest un-soaked stability value of 8.4 kN, as expected. At first, the stability rose with the addition of Patani clay, reaching a maximum value of 17.73 kN at 4% clay content. A rising trend in stability with clay dosage up to an optimum limit has been well-documented in numerous past studies (Tarefder & Ahmed. 2014). At filler contents below 4%, the finer clay particles act to enhance cohesion within the asphalt mastic by filling voids in the aggregate skeleton (Lakshminarayanan et al., 2016). The improved aggregate-binder adhesion and densification led to higher load bearing capacity (Cabral et al., 2013).

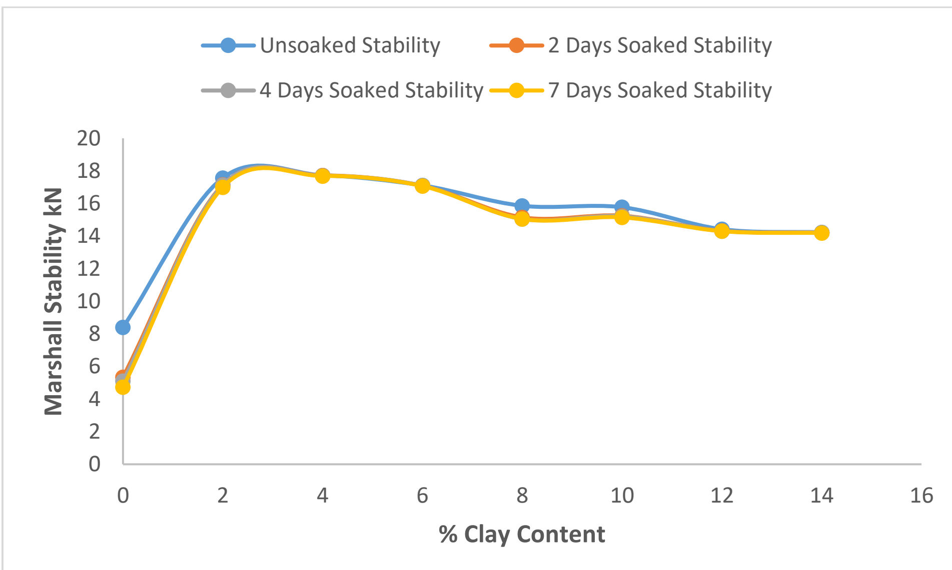

Figure 6: Trend in Variation of Stability due to Percent Clay Content for Un-soaked and Soaked Samples

In the present study, stability began decreasing beyond the 4% clay optimum limit, which agrees with previous observations that excessive clay can coat and over-densify aggregates, thereby reducing mix strength. The findings also align with common recommendations to incorporate natural clay modifiers like kaolin within the range of 4-8% to achieve balanced enhancement in mechanical properties without compromising workability (Tarefder & Ahmed. 2014).

Along with un-soaked stability, Figures 6 shows the influence of soaking duration on Marshall stability values at different clay percentages. As expected, the control mix without any clay addition experienced the lowest retained stability after soaking for all periods due to its inherent susceptibility to moisture damage (Shen et al., 2018). The trends observed for Marshall stability agree very well with past evidence regarding the filler and stiffening impact of clay addition up to an optimum limit, as well as its ability to enhance moisture resistance. The stability response effectively demonstrates the significant potential of clay sourced from Patani to enhance the mechanical strength and durability characteristics of asphalt concrete mixtures.

3.7 Marshall Flow Variations

Table 4 shows the measured Marshall flow values, which initially increased from the control mix with maximum value of 2.74 mm at 10% clay content. A marginal rise in optimum clay content for flow relative to stability has been linked in past research to balancing compaction and strength requirements (Sahoo & Rout. 2020; Lakshminarayanan et al., 2016). The finer clay particles enhance binder distribution and mixture workability during compaction at lower filler dosages before premature stiffening sets in (Sahoo & Rout. 2020).

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

Patani 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	2.42	2.42	2.55	2.80
4	2.45	2.51	3.15	3.69
6	2.46	2.48	2.48	2.48
8	2.47	2.50	3.06	3.16
10	2.74	2.74	2.74	2.80
12	2.45	2.48	2.51	2.51
14	2.4	2.43	2.50	2.50

Figure 7 depict largely consistent flow values amongst the soaked specimens. The restricted plastic deformation even under moisture conditions indicates enhanced resistance to rutting attributable to clay's stiffening characteristics (Tarefder & Ahmed 2014). Prior studies have also reported 6-10% clay as an optimal range minimizing permeability and susceptibility to moisture damage in asphalt mixes (Sahoo & Rout. 2020; Awotunde et al., 2022).

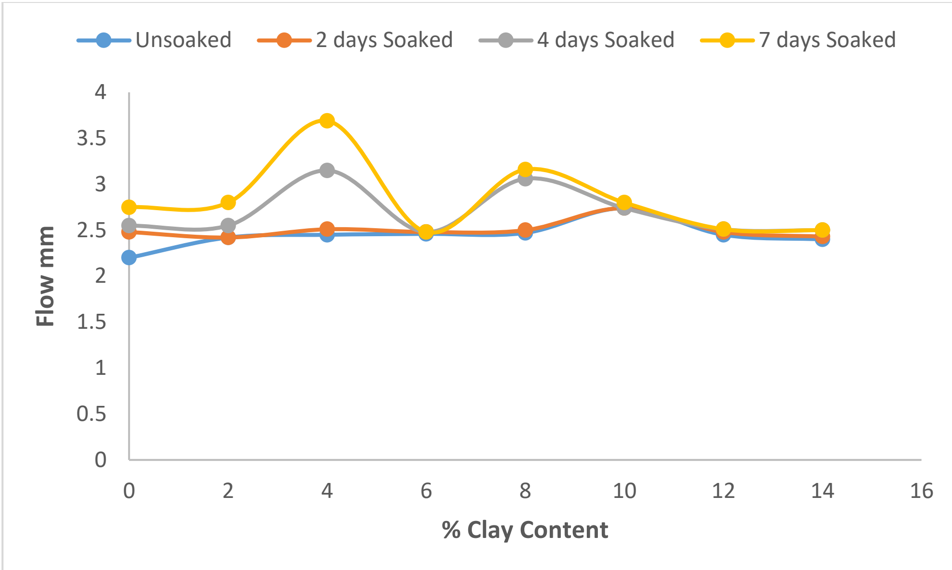

Figure 7: Trend in Variation of Flow due to Percent Patani Clay Content and Soaked for 2 days, 4 days and 7 days

In summary, the marginal optimum clay increase seen for flow versus stability and the uniform flow response of soaked samples incorporating 6-8% Patani clay agrees well with reported filler and anti-stripping behavior in literature. These trends substantiate improved workability and durability due to clay modification meeting design specifications.

4.0 CONCLUSION

Clay sourced from Patani was partially used to replace the mineral filler component of the total mix as a modifier in mix preparation of hot mix asphalt mixture to determine its mechanical strength and resistance to moisture damage. Based on the laboratory test results, the following conclusions can be drawn:

i. The control asphalt concrete mix had a Marshall stability value of 8.4 kN and a flow value of 2.2 mm without addition of clay;
ii. The Marshall stability value of clay modified asphalt mixture increased with rising clay content up to 18.73 kN maximum at 4% clay content – an increase of 123% over the control mix and started decreasing with an increase in clay content. This validates literature of improved mechanical properties of clay modified asphalt concrete;
iii. The volumetric properties of the clay modified asphalt concrete were optimized between 4 – 6% clay modification, meeting mix design specifications;
iv. The Marshall stability values of asphalt mixtures for all soaking duration shows a near constant trend of retained stability, which shows the moisture resistivity of clay modified asphalt concrete;

v. The flow values across all soaking duration shows the restricted plastic deformation even under moisture conditions indicating enhanced resistance to rutting attributable to clay's stiffening characteristics.

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