



Relating Soil Moisture Content to Adhesive and Visual Characteristics of Clay for Painting and Three-Dimensional Artwork

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Abstract

The research work explicated moisture variation in clay soil as it affects its adhesive and visual colour characterization for painting and three-dimensional artwork. It involved subjecting clayey soil to particle size analysis thereby obtaining the actual clay soil content. The clay was taken to laboratory, conditioned and determined its moisture content variations at every time interval until no visual variation was observed. A mixture Gmelina (*Gmelina arborea*) seed extract and Teak (*Tectona grandis*) leaves extract was used as solvent to make a paint solution with the clay sample at each observed time interval at ratio 1:5 (clay to solvent) by weight. It was discovered that as the cumulative moisture variation increases, instant moisture variation decreases until a constant value in every measurement was obtained. Colour variation in the clay under observation was also noticed to have stopped when other measurements attained their constant values of 0% and 5.7% for moisture variation and cumulative moisture variation respectively. In the same vein, adhesion test was conducted using cross-cut test procedure. The study showed that the actual colour of any three-dimensional artwork and painting done out of clay could only be precise until all forms of water other than hygroscopic water are fully dissipated and this is achievable after 10th hour of drying process at temperature of 105 °C. A stable moisture variation was attained at moisture content of 23% moisture loss and 10th hr of the drying process. Evaluation of colour uniformity showed that the optimum

moisture content for a uniform colour in clay soil is obtainable at 25%. In addition, adhesion strength (based on ISO/IJS classification) of clay was carried out at every drying time interval. Adhesive test was carried out on the coated surface using QFH Cross Cutter Adhesion Tester at 2 mm gauge showed that 0-5hr drying time (6-17.6% mc) gave high adhesive score of 5 (poor adhesion) while 8hr and above drying time (23% mc) gave a lower score of 2 (high adhesion) which suggested better resistance to environmental stresses. The result showed that clay has better resistance to abrasion as it gets dryer.

Keywords: clay, paint, three-dimensional artwork, moisture variation, hygroscopic water, time, colour uniformity.

Introduction

Clay soil is a very important tool in three-dimensional work of art due to its malleable nature that enhance easy shaping of a molded object created out of it (Forgione, 2021)^a. In addition, its two-phase textures found in its wet and dry state respectively gives its higher advantage of fluidity and solidity over other soil materials in sculptural artwork (Zhang, *et al.*, 2023; Stuart, *et al.*, 2019)^b. Traditional ornamental works are largely dependent on clay for its activity. This is the reason why clay formed the basis of cultural art work in places like ancient museums (Forgione, 2021)^b. Clay soils are found typically in dark or reddish colour largely due to the presence of iron oxide but other variation in colour such as yellowish, orange, kaki, blueish green or greyish white (Wang, 2023; Stuart, *et al.*, 2019)^a. These colour variations are largely due to mineral content of the parent material deposited as a result of weathering, organic matters and minerals accumulation and even contact with water and exposure to oxygen (Li *et al.*, 2024; Firoozi, *et al.*, 2016). Uniformity in colour variation at a specified moisture content is very important when it is been considered as an integral part of paint production (Ishikawa, *et al.*, 2026)^b. The

uniformity can be measured using spectrophotometer readings, visual comparison panels, and ΔE (Delta E) colour difference calculations. These instruments measured how consistent the colour appears across the surface. In addition, it evaluated Patchiness, shade consistency, streaking, coverage consistency and pigment distribution (Ishikawa, *et al.*, 2026^b, Adekunle *et al.*, 2023.)

During modeling in three-dimensional artwork, the major factor that can make clay particles to slide and reorganize is water. Hardness and rigidity in structure increase as moisture evaporates. However, deformation and shrinkage cracks may occur if the moisture loss is rapid (Kim *et al.*, 2023; Janas *et al.*, 2022^a). Soil-water retention theories revealed that behavior clay is greatly influenced by pore distribution, particle size, and capillary action (Ishikawa, *et al.*, 2026^a; Hassan *et al.*, 2024). Textured grounds and clay-based pigments in painting rely on balanced water content surface stability and proper adhesion (Bury & Bratasz, 2024^b; Silva *et al.*, 2014; Li *et al.*, 2022^b). Too much moisture and excessive dryness always result in flaking and weakens paint layers

respectively (Nguyen *et al.*, 2023). Bury and Bratasz (2024)^a reviewed that to prevent deterioration of clay-containing artworks, it is very important to regulate humidity. Investigation as carried out by Li *et al.* (2022)^a showed that clay-rich soils exhibited stronger adhesion at moderate moisture levels. The study concluded that adhesive performance is a joint function of moisture and clay content. Research further revealed that moisture fluctuations can generate stress and dimensional changes in clay-based artworks (Ahmed *et al.*, 2022; Janas *et al.*, 2022^b). Stuart *et al.* (2019)^a explored the properties of modeling clays used in artworks and found that durability and physical stability of clay objects is greatly affected by environmental moisture. These studies collectively demonstrate that moisture content is a critical factor affecting both adhesive and visual characteristics of clay in artistic applications.

Clay Soil is characterized with fine particles smaller than 0.002 mm. They are classified as the finest soil in all soil categories (Goraczko & Topolinski, 2020). Its distribution in the soil are in lesser quantity compare to other types of soil (Malewski, 2017; Elfaki, *et al.*, 2016^b). When using electro-mechanical sieving method, they are not easily separated from silt but nonetheless, its small pore spaces enable it to be able to retain more water and therefore having poor drainage properties making it to have high cohesive characteristics and thereby suitable for molding work (Zhao *et al.*, 2024; Awoniyi, *et al.*, 2023). Most times, clay soil could distinctly be determined using hydrometer sedimentation method. This would clearly separate it from silt particles (Awoniyi, *et al.*, 2023^b; Goraczko, *et al.*, 2020; Elfaki, *et al.*, 2016^a; Kramarenko *et al.*, 2016.).

Soil water are basically three form: gravitational water, capillary water and hygroscopic water. Gravitational water excess water from precipitation or irrigation that are largely stored in the large pore spaces of soil and could be quickly drain away within the shortest possible time for the draining process depending on the soil types and other intrinsic characteristics of the soil (Adeniran & Awoniyi, 2017). They are mostly loss due to deep percolation, seepages and leaching thereby not available to crops (Brady & Weil, 2016). Capillary water is the water located within the root zone of crop and depend on the type of crop otherwise, they join gravitational water and drain out. They are available for evapotranspiration (Awoniyi *et al.*, 2020). Hygroscopic water exists in the soil as a thin layer of vapour held tightly to soil particles by surface tension and are not available for plant growth (Hassan *et al.*, 2024)

Clay soil as a natural resource in Nigeria has been experimented to be a good additive in paint formulation due to its natural cohesion and consistency but it has varying cohesive power and visual appearances at different moisture content (Aderemi & Ajayi, 2019)^b. However, this might drastically affect the quality of paint if used as the primary additive (Aderemi & Ajayi, 2019)^a. This research therefore looked into adhesive and visual characterization of clay in relation to its moisture content. It gave insight to the moisture content in clay which would give a better resistance to environmental stresses for paint coat and three-dimension artwork. Likewise, the research shed more light on actual form of clay soil water responsible for attaining colour uniformity when used as paint base, and three-dimensional artwork.

Methodology

This research was carried out at Federal Polytechnic, Bida, Niger State, Nigeria. The institution is sited in the Southern part of Bida, Doko, Lavun Local Government Area, Niger state, Nigeria which lies on the latitude $9^{\circ}08'1''\text{N}$ and longitude $6^{\circ}01'1''\text{E}$ at an elevation of about 118 m above the sea level. Bida is in Northern Guinea Savannah Ecological Zone of Nigeria with an annual rainfall of about 900 mm (Awoniyi, *et al.*, (2023)^a. The research involved taking clayey soil sample from field, oven dried and subjected it to sieve analysis to actualize the clay content in the soil particle size distribution. 1000 g of the soil passing through 0.075 mm was over saturated and left to drain for 24 hrs, the sample was weighed, recorded and put in an oven at a temperature of 105°C . The weights of the soil were taken at every 1 hr time intervals while the moisture variations at each time were determined using equation (1). Changes in moisture variations and cumulative moisture variations were obtained using equation (2) and equation (3) respectively while the moisture content on dry basis was obtained using equation (4). Visual variations in terms of colour were noted at every time interval while the uniformity in colour was determined using spectrophotometer readings. Cross-Cut-Test was achieved by taking 100 g of drying clay at every 1 hr time interval added to 500 g mixture of gmelina (*Gmelina arborea*) and Teak (*Tectona grandis*) leaves extracts. Each resulted mix was used to coat a surface measured 5 cm by 5 cm and left for at least 3 hours to enable it to dry. 2 mm blade from Cross-Cut Adhesion Test kit was used to carry out 2 series of crossed cuts at right angle to obtain series of lattices (grids). Every cut was ensured it penetrated through the paint layer down to the coated surface. An adhesive tape (Scotch transparent tape) was firmly applied on each obtained lattice and then quickly removed at a consistent angle. The left-over pattern on the grid was viewed using hand held lens. The image obtained was evaluated and classified (based on the amount of coat removed by the tape) with reference to standard scale (ISO 4624:2023).

$$\text{moisture variation, } m_v(\%) = \left| \frac{w_1 - w_2}{w_1} \right| \times 100 \quad (1)$$

$$\Delta m_v = \left| m_{v_{t_2}} - m_{v_{t_1}} \right| \quad (2)$$

$$\left| \sum \Delta m_v \right|_0^t = m_{v_1} + \dots + m_{v_t} \quad (3)$$

$$\text{Moisture content, } mc(\%) = \left| \frac{w_0 - w_t}{w_t} \right| \times 100 \quad (4)$$

where w_1 and w_2 are the initial weight and final weight of soil respectively at time, t ; Δm_v is the change in moisture variation, $m_{v_{t_1}}$ and $m_{v_{t_2}}$ are initial and final moisture variation with respect to time; $\left| \sum \Delta m_v \right|_0^t$ is the cumulative moisture variation from initial drying time to an instant drying time while mc is the moisture content, w_0 and w_t are moisture content of the clay at time zero and time, t respectively.

Result and Discussion

Table 1 shows the results obtained from the conducted experiment at each time interval. It was observed that the weight of the soil and moisture variation decreases as its undergoing drying

process while the cumulative moisture variation increases. A constant value of measurements was noticed after the 10th hour of drying process. Visual colour variations were also noticed in the soil as the drying time progresses with constant colour observed when other measurements remain constant. Table 1 shows the particle size distribution in the clayey soil while Table 2 shows moisture variation in relation to colour change and soil water present. Uniformity of colour variation as measured by spectrophotometer is given in Table 3. The particle size distribution shows highest percentage passing (55.1 %) in 0.075 mm aperture of sieve. This confirmed that the experimental soil to be clayed soil. At 10th drying hour in Table 2, zero moisture variation was recorded while the cumulative moisture variation recorded highest of 5.7% from which it became constant with no colour change observed in the clay. The no visual colour change was also confirmed by moisture content of 23% which remained constant from the 10th drying hour of the experiment. From the result as indicated in Table 3, colour uniformity was found to increase from 4 (5% moisture content) to a peak of 9 (25% moisture content) and then started to declined. This shows that the optimum level of colour uniformity is obtainable at 25% moisture content. Figures 1 and 2 show graphical illustration of moisture variation and change in moisture variation respectively with respect to time. Meanwhile, Figure 3 shows the colour uniformity cure at varying moisture content in clay soil.

Adhesion test carried out on the coating characteristics in line with ISO 4624:2023 showed that at 0-5 hr drying time (6-17.6% mc), 5-7 hr drying time (19.7-21.1% mc), 7-8 hr (22.1% mc) drying time and 8 hr and above drying time fell into class 5, 4, 3 and 2 respectively. Class 5 classification indicates poor adhesion property while class 2 indicates good adhesion property. The test affirmed best adhesion property at no moisture variation (moisture content of 23%) in drying clay. Higher class numbers in the adhesion characteristics indicate lower grade adhesive property which means that the coat is poorly adhered to the surface and has lower resistance to environmental stresses while lower class numbers indicate better adhesive characteristic and higher resistance to environmental abrasion. Table 4 shows adhesion classification based on ISO 4624:2023.

Table 1: Particle size distribution of a clayey soil

Sieve Size	weight retain (g)	% retained	% passing
0.3	619	31.0	69.1
0.15	66	3.3	65.8
0.075	210	10.5	55.3
< 0.075	1105	55.3	0.0

(Source: Authors' research work, 2026)

Table 2: Moisture Variation in Clay Soil

Time (Hour)	w ₁ (g)	w ₂ (g)	% moisture variation	Δm_v (%)	$ \sum \Delta m_v _0^t$	mc (%)	Colour Change	Adhesive Characteristic Class
0-1	1223	1153	5.7	-	-	6.0	-	5

Time (Hour)	w ₁ (g)	w ₂ (g)	% moisture variation	Δm_v (%)	$\left \sum \Delta m_v \right _0^t$	mc (%)	Colour Change	Adhesive Characteristic Class
1-2	1153	1102	4.4	1.3	1.3	11.0	yes	5
3-4	1102	1066	3.3	1.2	2.5	14.7	yes	5
4-5	1066	1040	2.4	0.8	3.3	17.6	yes	5
5-6	1040	1022	1.7	0.7	4.0	19.7	yes	4
6-7	1022	1010	1.2	0.6	4.5	21.1	yes	4
7-8	1010	1002	0.8	0.4	4.9	22.1	yes	3
8-9	1002	997	0.5	0.3	5.2	22.7	yes	2
9-10	997	994	0.3	0.2	5.4	23.0	yes	2
10-11	994	994	0.0	0.3	5.7	23.0	No	2
11-24	994	994	0.0	0.0	5.7	23.0	No	2
24-25	994	994	0.0	0.0	5.7	23.0	No	2
25-26	994	994	0.0	0.0	5.7	23.0	No	2

(Source: Authors' research work, 2026)

Table 3: Colour Uniformity

Soil Water Content (%)	Colour Uniformity
5	4
10	5
15	6
20	8
25	9
30	8
35	6
40	4

(Source: Authors' research work, 2026)

Table 4: Adhesion Characteristics Description

Adhesive Characteristics Class		Description
ISO/JIS	ASTM	
0	5B	No coat removal (Excellent adhesion)
1	4B	A cross cut area not significantly greater than 5% is affected
2	3B	A cross cut area significantly greater than 5% but not significantly greater than 15% is affected
3	2B	A cross cut area significantly greater than 15% but not significantly greater than 35% is affected
4	1B	A cross cut area significantly greater than 35% but not significantly greater than 65% is affected.
5	0B	A cross cut area significantly greater than 65%

Adapted from ISO 4624:2023

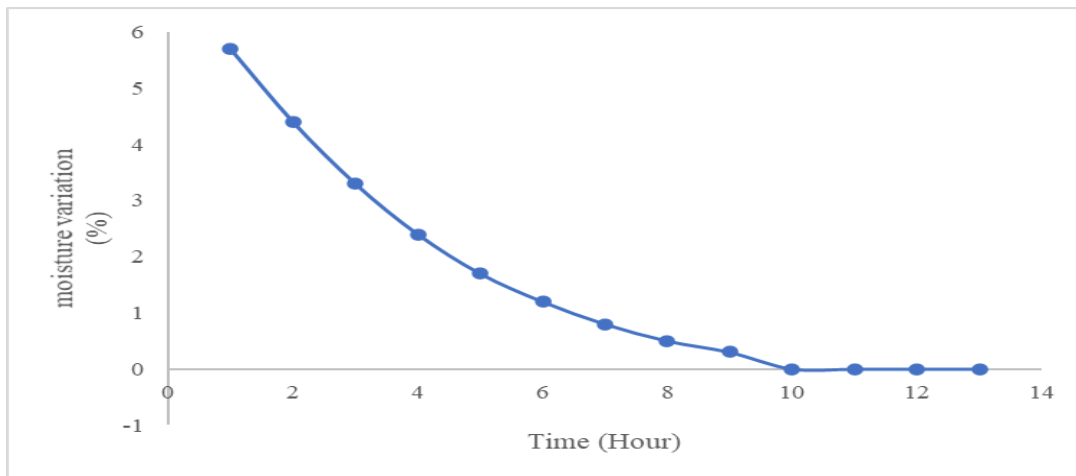


Figure 1: Moisture variation with Drying Time

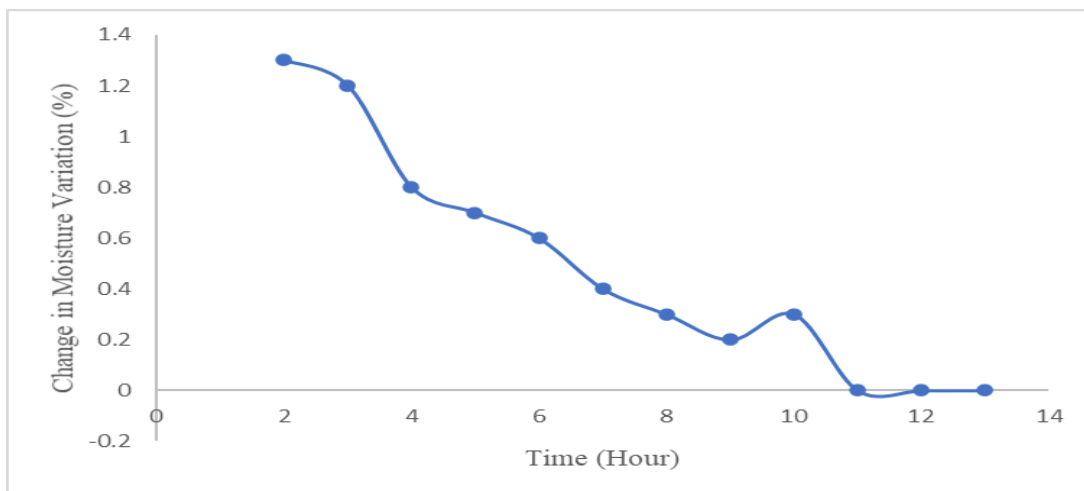


Figure 2: Change in Moisture Variation with Drying Time

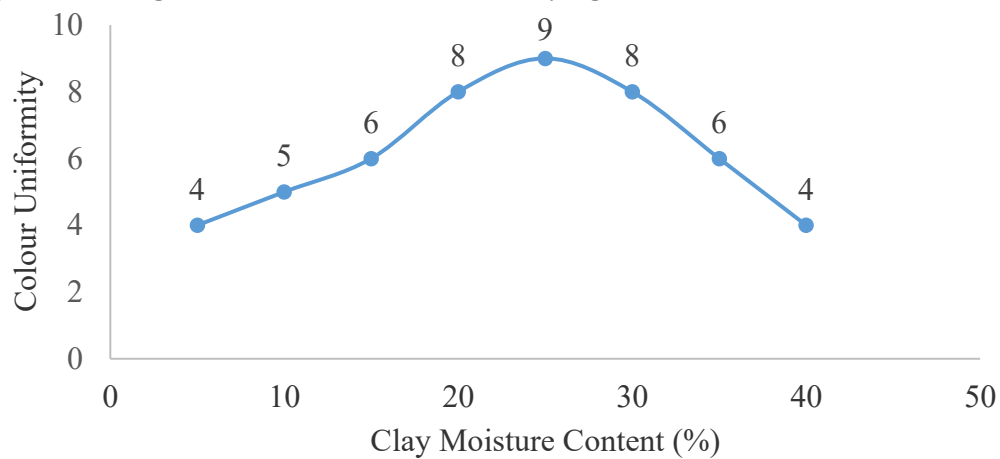


Figure 3: Colour Uniformity in Clay Relative to Moisture Contents

Validation of Results

The results were validated by relating cumulative change in moisture variation with drying time as shown in Figure 4. The graph is a relatively uniform curve which affirmed the increase in cumulative moisture variation with drying time but at slower pace as the time increases. This affirmed the moisture variation reduction down the slope as shown in Figure 2.

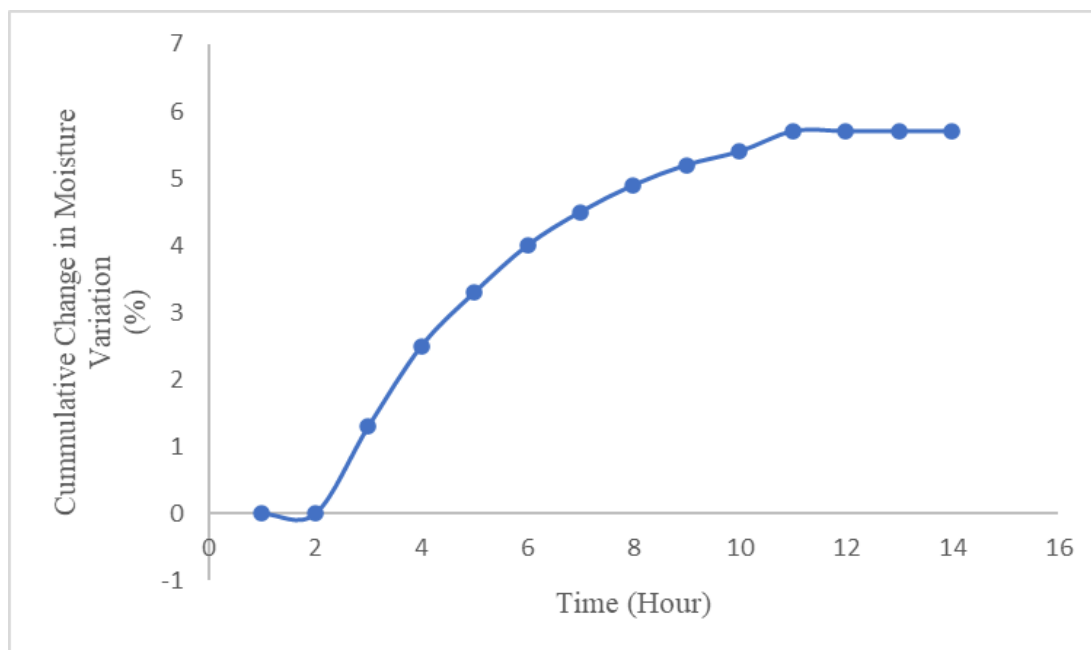


Figure 4: Cumulative Change in Moisture Variation with Drying Time

Conclusion and Recommendation

The visual variation in clay soil characteristics to dryness changes as the soil moisture variation aggregate increases. It should be noted that the soil moisture aggregate is a representation of instant sum of loss soil moisture due to evapotranspiration at time, t . On the other hand, changes in the soil moisture variation reduces with the drying time at constant temperature while colour variation keeps changing as the cumulative moisture variation increases until constant value which simulate full dissipation of gravitational and capillary water. Higher uniformity in clay colour indicated better pigment dispersion propensity, proper application thickness and consistent mixing. A constant colour is obtainable in clay soil when only hygroscopic water remained in it. Storage moisture content of any clay base three-dimensional artwork is therefore generalized to be 23% prior to further moisture reduction. Furthermore, the result from the adhesion test carried out in this research based on International Organization for Standard (ISO) affirmed that clay has better resistance to environmental stresses such as abrasion as moisture content therein reduces. Higher adhesion property in clay is attainable at higher moisture loss and as drying process progresses. Further researches on colour characteristic variations on other forms of clay soils suitable for three-dimensional artwork are hereby encouraged.

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