FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 6, June, 2025, pp 1 – 9
DOI: https://doi.org/10.33003/fjs-2025-0906-2979

DEVELOPMENT OF FILLER FROM LOKOJA BENTONITE CLAY FOR APPLICATION IN THE PRODUCTION OF PLASTER OF PARIS (POP)

***Uthman, H. and Dirisu Abraham Danjuma**

Department of Chemical Engineering, Federal University of Technology, P.M.B. 065, Gidan-Kwano Campus, Minna, Nigeria.

*Corresponding authors' email: habibumuhammad@gmail.com; habibuuthman@futminna.edu.ng
ORCID iD: https://orcid.org/0000-0002-7409-8431

ABSTRACT

This research aimed at enhancing the production of plaster of Paris (POP). Compressive strength, flexural strength, water absorption, density and setting time tests were carried out on these samples. The Bentonite clay collected from the Lokoja mining site were processed and characterized with the sample on the average having compressive strength of up to 0.000148 N/mm^2, 0.000284 N/mm^2 and 0.000385 N/mm^2, flexural strength of 0.7 N/mm^2, water absorption of 0.46–0.60%, 1.00–1.43% and 1.43–2.08% setting time of 15 minutes and 58 seconds. The compressive strength test results reveal a positive progression in strength over the curing period, with developed plaster of Paris (DPOP) consistently outperformed commercial plaster of Paris (CPOP). The flexural test demonstrates DPOP superior resistance to bending stresses, providing insights into its potential applications in construction industries. The water absorption test, conducted at varying calcination temperatures and times, elucidates the material's porosity/absorbency characteristics, offering valuable information for applications where resistance to moisture is critical. The setting time test results provide crucial data on the workability and usability of the plaster, indicating that DPOP exhibits a slightly longer final setting time compared to CPOP. Properties obtained from the characterized DPOP revealed that sample collected from the Lokoja mining site and well processed can replace CPOP in the market because of their outstanding properties which exceeded CPOP. This approach utilized in the development of POP from locally sourced bentonite clay emphasizes its potential for various applications.

Keywords: Bentonite clay, Plaster of Paris, Compressive strength, Flexural strength, Water absorption, Setting time

INTRODUCTION

In the design of any structure, the ceiling stands out as a crucial architectural component demanding primary attention. As the need for thermal comfort within buildings rises, there is a subsequent escalation in energy consumption (Souci and Houat, 2018). Ceiling plays a vital role in shielding the occupant from direct heat absorbed from an external environment by the building roof. Stating in another way, ceiling is a finished surface that conceals the underside of a building roof to impart aesthetic appeal and also prevent thermal influx to the room, thereby promoting comfort as well as safety of individuals. Based on the used materials, various types of ceiling include asbestos ceiling, gypsum ceiling, polyvinylchloride (PVC) ceiling and POP ceiling, among others (Robert *et al*., 2020; Shiyo, 2020; Ngaaje, 2021).

The dihydrate of calcium sulphate ($CaSO_4.2H_2O$), gypsum is one of the most widely used minerals for improving the strength of materials (Akinnifesi and Ogunbodede, 2012; Akinade *et al*., 2015; Yahaya *et al*., 2017). When ¾ of its water of crystallization has been driven off, it becomes what is called plaster of Paris or simply POP ($CaSO_4.½H_2O$). This plaster is used especially in construction materials, in the cement industry to control setting time, as paint fillers, as moulds and extensively in dentistry for recording dental impressions of jaws (Anderson, 1976; Williams *et al*., 2017; Anderson and Williams, 2023; Smith *et al*., 2023; Smith and Johnson., 2023a; Smith and Johnson, 2023b).

The amount of POP used in dentistry is quite substantial, although the main source of procurement is however by importation (Anderson, 1976; Akinnifesi and Ogunbodede, 2012; Duan *et al*., 2019), alternative sourcing of the material deserves to be explored and exploited (Akinnifesi and Ogunbodede, 2012).

It was reported that even at low concentration, asbestos has a significant health risk (Luus, 2007). The findings made by (Palieeti *et al*., 2016; Garcia *et al*., 2018) also supported such report. Hence, taking into account the susceptibility of gypsum ceilings to water damage from roof leaks and the lack of heat resistance in PVC ceilings, the choice leans towards POP ceilings. Typically available as a dry powder, POP can be transformed into a paste by blending it with water, which is subsequently applied to create the ceiling. During the mixing process, crystallization generates heat, leading to the solidification of the hydrated POP within a few minutes after being cast into moulds (Robert *et al*., 2020).

Where the raw material is scarce, unabundant or unavailable, POP can be obtained by synthetic production and calcination of gypsum. The pure dihydrate is white or colourless and has oxide compositions by weight: CaO, 32.5%, SO_3, 46.6% and H_2O 20.9% (Akinnifesi and Ogunbodede, 2012; Robert *et al*., 2020). Mineral gypsum usually contains varying amounts of clay, slate, anhydrite chalk, dolomite, silica, iron and water (IS 1290, 1973; Robert *et al*., 2020).

Plaster is formed through the calcination process of gypsum ($CaSO_4\ 2H_2O$), leading to a partial dehydration that produces hemi-hydrate ($CaSO_4\ ½H_2O$). While POP is extensively utilized in modern times, its historical roots extend back 9,000 years to discoveries in Anatolia and Syria. Indeed, historical evidence confirms that approximately 5000 years in the past, ancient Egyptians engaged in the practice of subjecting gypsum to open-air fire, subsequently pulverizing it into a fine powder, and ultimately combining it with water. This resulting mixture served as a binding substance for assembling the blocks of monuments. Additionally, they adopted a plastering technique inspired by the human body's form and structure (Abou-Patterson *et al*., 1983; Jamo *et al*.,

2014; El-Sherbini *et al*., 2017; Lima *et al*., 2017; Williams *et al*., 2017).

The emergence of POP occurred during the 1700s, a period when Paris had already established itself as the foremost hub for plaster usage ("Plaster of Paris"), due to the prevalent practice of covering the walls of wooden houses with plaster as a safeguard against fires (Sullivan, 2019; Ngaaje, 2021).

The vicinity of Paris had abundant gypsum deposits, which have been exploited for a significant duration to produce the renowned "Plaster of Paris." (Brown, 2019; Sullivan, 2019; Ngaaje, 2021; Smith *et al*., 2023b).

A pivotal element within Nigeria's oil and gas sector pertains to the process of drilling. This operation is indispensable for confirming the presence of oil and gas reserves beneath the Earth's surface. An integral component facilitating this operation is the drilling fluid, often referred to as drilling mud. The use of the term "drilling fluid" is favoured over the more general "drilling mud" because it denotes that the properties, attributes and characteristics are deliberately incorporated into a fluid system. This is distinct from the naturally occurring attributes found in subsurface formations through the interaction of water and formation of clays. Furthermore, the term "drilling fluids" encompasses fluids of varying compositions, while "drilling muds" merely indicates a mixture of water and clay. Notably, drilling mud constitutes a substantial portion of the yearly consumption of oil field chemicals (Odom *et al*.,1984; Srasra *et al*., 1989; Tranger *et al*., 1994; Christidis *et al*., 1997; Benson and Daniel., 2000; Taylor and Anderson., 2007; Ahohen *et al*., 2008; James *et al*., 2008; Tijen *et al*., 2010; Apugo-Nwosu, 2011; Holtzer *et al*., 2011; Ahmed *et al*., 2012; Washburn *et al*., 2015; Hassanpour *et al*., 2017; Kooli and Kentache., 2019; Cieschi *et al*., 2020).

Before the implementation of the Nigerian Federal Government's local content development strategy, research conducted over the past few years has highlighted that drilling activities undertaken by both domestic and foreign oil companies in Nigeria have necessitated the importation of either the necessary components for formulating the fluids or pre-made drilling fluids customized to match the specific needs of the geological formations in the Niger Delta region (Olatunde *et al*., 2012; Omole *et al*., 2013; Akinade and Afolabi, 2015).

The expense linked with importing these substances for drilling activities is projected to reach millions of dollars annually, posing a detrimental impact on the economy. Additionally, as the exploration for oil and gas deposits transitions from land-based locations to offshore and deep offshore zones, the overall expenses of drilling operations follow suit. The financial outlay of drilling operations is also shaped by the effectiveness of the drilling fluid. Consequently, this emphasizes the significance of designing, creating, and sustaining drilling fluids (Afolabi *et al*., 2017).

Nigeria possesses abundant reserves of bentonite, a valuable resource that, when effectively utilized, has the potential to diminish the need for importing ingredients for drilling fluids and specialized drilling compounds. Reports indicate that significant deposits of bentonite clays are present in all regions across Nigeria. The confirmed reserve of bentonite within Nigeria has been conservatively approximated to exceed 700 million metric tons (Aigbedion and Iyayi, 2007; James *et al*., 2008; Omole *et al*., 2013; Bilal *et al*., 2015).

With the bulk of it lying in Afuze, Edo State, Mid-Western Nigeria which holds about 70–80 million metric tons of bentonite clay (Nweke *et al*., 2015; Nweke, 2015). In view of these vast deposits of local bentonite within the Nigerian soil, the Federal Government in 2003 restricted the importation of foreign bentonite clays with a view to tapping into these vast deposits (Oriji *et al*., 2014).

Despite this act, the oil and gas industry are yet to place full confidence in the use of locally sourced bentonite clays for drilling application, as there is little or no reported case of the use of local bentonite clays for drilling operations. Most of the foreign bentonites being used are often smuggled into the country by the multinational companies (Oriji *et al*., 2014).

This singular act has brought about increased research into the use of local clays for drilling mud application in the oil and gas industry. Previous works on the use of strictly Nigerian bentonite in producing drilling fluids have shown that such drilling fluids exhibit high fluid loss. This may be due to the poor quality of bentonite sourced in Nigeria. These clays in its raw form exhibit poor rheological and fluid loss properties hence the need for beneficiation (Olatunde *et al*., 2012). This research therefore seeks to develop a new filler from Bentonite clay obtained from Kogi State; Nigeria applicable in the production of plaster of Paris.

MATERIALS AND METHODS

Chemicals Used

The solvent and materials used in this research work include: sodium bentonite, gypsum and water.

Sample Collection and Preparation

The materials used in this study include: water, sodium bentonite clay that was collected from Lokoja, Kogi State, Nigeria. The bentonite clay was ground into powder form and then sieved into fine powder (50 µm) form to remove impurities or larger particles. The powdered form was then stored in a container and kept in a cool dry place. Gypsum rock powder was collected from Kalambaina plant Sokoto State, Nigeria.

Equipment Used

The equipment used for this study include: Electric blast drying oven (Type 10–1A, Beijing Luda Waiye Technology) for calcination (at civil engineering Lab, FUT, Minna, Nigeria), digital weighing scale (model, Szegedi, OmhEng Type), electric hydraulic pressure testing machine (Huaxi, DYE-2000 type) to determine compressive strength, shovel, pulley, torch light, hand gloves, Vernier calliper, sieve (model, Bosch-112219), crucible for loading sample, stirrer for mixing gypsum, bentonite clay and water.

Methods

This work adopted the method of calcination used by Maiva *et al*. (2024). This included collection of gypsum samples, selection and cleaning, washing and drying, crushing, screening/sieving, calcination, storing, porosity, density and compressive strength were determined. The experimentation was carried out at the civil engineering department laboratory, Federal University of Technology, Minna, Niger State, Nigeria. The chemical analysis was done at Spectral Laboratory Services, Tudun Wada, Kaduna, Kaduna State, Nigeria.

Preparation of Bentonite Clay

Sodium bentonite clay was collected from Lokoja, Kogi State, Nigeria, the clay was ground into powder form and then sieved into fine powder (50 µm) form to remove impurities or larger particles. The powdered form was then stored in a container and kept in a cool dry place.

Preparation of the gypsum samples

Gypsum was obtained from underground mines by digging. Different samples were collected. Good samples of gypsum were obtained by further processing; impurities were thoroughly and meticulously removed from the samples. This was done by picking out and removing the larger clay and sand particles from the samples and washing it. Gypsum was soaked for about 1hour to allow easy removal of the clay on the samples. It was thoroughly washed to ensure that it is free from impurities like sand and clay that got stuck to it. After proper washing, it was then allowed to dry under normal room temperature. A grinder was used to crush the samples to powdered form. A sieve of 300 mm was used for sieving the powder in order to obtain a fine powder.

Procedure of producing POP

Preparation of POP was performed according to the methods and procedures described by (Maiva *et al*., 2024). To produce 100 grams of POP, Bentonite clay and gypsum were obtained and ground into a fine powder. 40g, 50g and 10g of bentonite clay, gypsum and water respectively were measured. Firstly, 20g bentonite clay was placed inside a mixing container. Water was gradually added while stirring to create a bentonite slurry. The slurry was uniform and free of lumps. Then, 70g gypsum was added to the mixture and was stirred thoroughly to ensure even distribution. The mixture was allowed to hydrate for a specific period of 25 minutes (this is when the gypsum and bentonite clay absorbed water and swell, creating a homogenous mixture. The hydrated mixture was oven dried at 120−140^{o}C until it reached a moisture content of 5% by weight. After the drying the solidified material was ground into fine powdery form at this stage the POP is made. These steps were repeated until a desire proportion was achieved. Figure 1 presents flow diagram of developing filler from Lokoja bentonite clay.

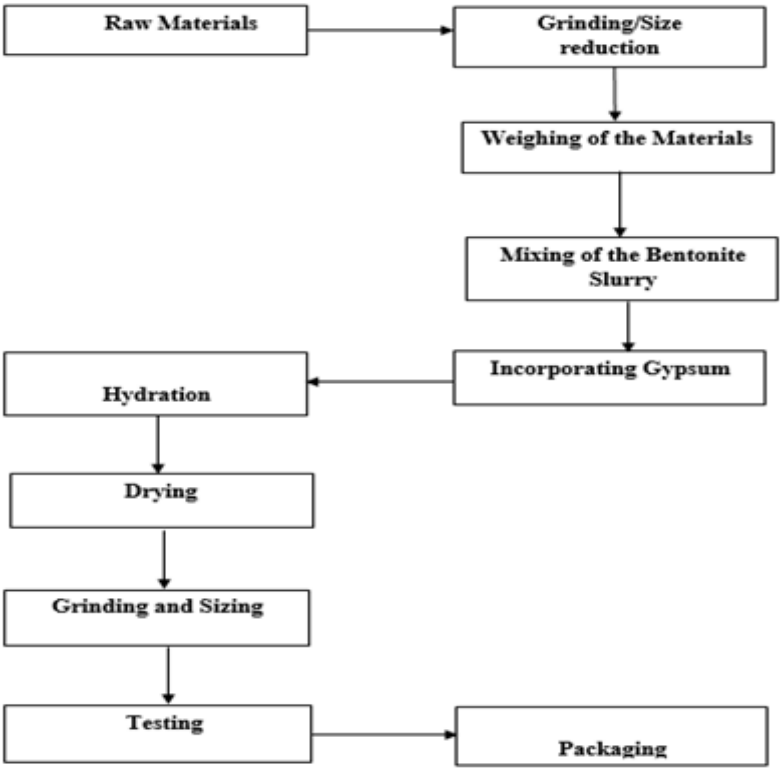

Figure 1: Block flow diagram of developing filler from Lokoja bentonite clay

Moulding Procedure

Moulding is done to confirm the effectiveness of using bentonite clay in the production POP. There are two types of moulding in POP which are pushing and casting.

Procedure for Casting

Using the produced POP made up of bentonite clay as filler. The POP was mixed with water in the ratio of 2:1. The mixture was put in the require mould and filler fibres were spread all over the mixture. The mixture was added all over the filler fibres until the mould is filled up. It was allowed to set for 5 minutes before removing it from the mould.

Procedure for Pushing

Using the produced POP made up of bentonite clay as filler, a mixture was made in the ratio of 1.5:1. Grease was applied all over the working area to prevent the POP from sticking to the working area. Filler fibres were immersed in the mixture and spread in the working area. A mixture of POP was made in the ratio of 2:1 and added on the immersed fibres. Blade was used to shape it by pushing it across the mixture until a desired shape was obtained. Hack saw was used to cut the casting to the required size.

Characterization of the POP

The samples were subjected to various tests (characterization) to determine the water absorption/porosity/absorbency, strength, flexural strength, compressive strength and setting time.

Strength test

Strength test was carried out to ascertained quality assurance, material suitability and process optimization. Samples of bentonite clay with a consistent dimension (diameter and

height) were used. The samples were allowed to cure for 24 hours. The diameter and height of each cured samples was measured using calipers and readings were recoded. Thereby ensuring proper alignment and calibration on the testing machine. The sample was placed in the testing machine. Compressive axial load was applied to the sample at a constant rate until failure occurs. The load and deformation were monitored throughout the test.

Determination of Compressive Strength (ASTM standards: C11, C39 and C617)

This test was performed using universal testing machine. The machine is equipped with indenter, hardness number indicator, load shifter and hand wheel. The sample whose hardness was to be determined was place on a vertical beam attached to the hand wheel. The wheel was screwed up to a particular level marked on the machine. The load shifter was released so that the indenter moves down to hit the sample. The impact with which it hits the sample was recorded on the meter. Sample was tested for 3, 7 and 29 days after mixing.

Determination of Flexural Strength (ASTM standards: C1161)

The flexural strength (3-point flexural test) is a property of material which define the maximum stress in the material just before it yields to a bending test. To carry out the flexural test of the POP the sample was cut into a rectangular shape. The two ends of the rectangular sample were well fixed onto a rigid support. A known or standard load or force is then applied to the middle section of the sample until the materials bends. The total force or load applied on the sample is noted.

Porosity/Water absorption Test/Absorbency (The ASTM C20 standard)

Porosity/Absorbency is a measure of the void spaces in a material. High porosities result in micro-cracks forming in regions where stress concentration is high thereby affecting the strength of the POP (Maiva *et al*., 2024). The porosity/water absorption/absorbency test was carried out at the civil engineering department, Federal University of Technology, Minna, Niger State, Nigeria. The samples were dried in the oven for 24 hours at a temperature of 45^{o}C and cooled before the porosity/water absorption test was performed. The weight of the dried samples was measured. The samples were then soaked in water for a period of 1−3 hours to ensure optimum saturation (Maiva *et al*., 2024). Water absorption test was carried out in the sample to determine the water adsorption capacity of the produced POP. To carry out this test, part of the POP bar was cut off and weighed to know the initial weight. It was then completely immersed in water for 7 days. Therefore, the sample was removed from the water and re-weighed. This was repeated for the different POP sample produced from POP calcined at different temperature and time.

Setting time (The ASTM C266-03 standard)

To determine the setting time, 2g of each calcined POP was thoroughly mixed with water in a plastic container to ensure even setting. The setting time was determined using vacate needle apparatus and stops watch. A needle, which is a sort of pentameters was used to ascertain complete setting by insertion of the needle in to the mortar, penetrating its surface as far as 1mm. The sample is placed at the base of the apparatus. An adjusting screw which is used to control the movement of the needle was used to screw down the needle to penetrate the sample. The time it takes for which the needle can no longer penetrate the sample beyond 1mm is the setting time.

Figure 2 shows Lokoja Sodium Bentonite clay and Figure 3 depicts Kalambaina plant Gypsum powder. Figure 4 presents Plaster of Paris powder (Bentonite clay + Gypsum + H_2O) and Figure 5 illustrates moulded plaster of Paris produced using casting and pushing methods respectively.

Figure 2: Lokoja Sodium Bentonite clay

Figure 3: Kalambaina plant Gypsum powder

Figure 4: Plaster of Paris powder (Bentonite clay + Gypsum + H_2O)

Figure 5: Moulded plaster of Paris produced using casting and pushing methods

RESULTS AND DISCUSSION

Compressive strength test

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. Among physical properties of POP, compressive strength is the most important property. When POP is use for important structures, this test is always carried out to ascertain quality of cement. Formula for compressive strength is compressive force over area. Table 1 shows compressive test results obtained for 3 days. Table 2 presents compressive test results obtained for 7 days and Table 3 depicts compressive test results obtained for 28 days respectively.

Table 1: Compressive strength test result for 3 days

S/N	Length (mm)	Breadth (mm)	DPOP Load (N)	CPOP Load (N)	DPOP compressive strength (N/mm²)	CPOP compressive strength (N/mm²)
1	150	150	3.10	2.96	0.000138	0.000132
2	150	150	3.46	3.47	0.000154	0.000154
3	150	150	3.45	3.38	0.000153	0.000150

Average: DPOP = 0.000148; CPOP = 0.000145

Table 2: Compressive strength test result for 7 days

S/N	Length (mm)	Breadth (mm)	DPOP Load (N)	CPOP Load (N)	DPOP compressive strength (N/mm²)	CPOP compressive strength (N/mm²)
1	150	150	6.50	5.92	0.000289	0.000263
2	150	150	6.30	6.12	0.000280	0.000272
3	150	150	6.39	6.23	0.000284	0.000277

Average: DPOP = 0.000284 CPOP = 0.000271

Table 3: Compressive strength test result for 28 days

S/N	Length (mm)	Breadth (mm)	DPOP Load (N)	CPOP Load (N)	DPOP compressive strength (N/mm²)	CPOP compressive strength (N/mm²)
1	150	150	8.40	7.56	0.000373	0.000336
2	150	150	8.82	7.65	0.000392	0.000340
3	150	150	8.79	8.20	0.000390	0.000364

Average: DPOP = 0.000385 CPOP = 0.000347

The compressive strength test result for a POP presents a clear progression in strength over the curing period of 28 days. At day 3, DPOP exhibits a compressive strength of 0.000148, while CPOP is slightly lower at 0.000145. Although the absolute values are relatively small, they serve as a baseline for comparison as the plaster undergoes further curing. Moving to day 7, both samples display a substantial increase in compressive strength with DPOP reaches 0.000284 and CPOP follows closely at 0.000271. This notable enhancement over the initial measurement suggests that the POP undergoes significant structural development during the early stages of curing. By day 28, the compressive strength of both samples continues to rise. With DPOP records a value of 0.000385, indicating a consistent upward trend in strength. CPOP also shows improvement, reaching 0.000347. it's essential to note that the difference in strength between the two samples persists, with DPOP consistently outperforming CPOP throughout the testing period.

The increasing compressive strength over time is expected in cementitious materials like POP as hydration reaction continue, leading to the formation of a more robust and interconnected structure. The observed disparity between DPOP and CPOP is as a result of variations in material composition, filler, mixing and environmental conditions during the curing process.

Flexural Strength Test

The flexural strength test results for POP, with average values of 0.7 for DPOP and 0.4 for CPOP, reveal distinct difference in the material's ability to withstand bending stresses. Table 4 illustrates Flexural test results obtained for POP.

Table 4: Flexural strength test results for plaster of Paris

S/N	length (mm)	Breadth (mm)	Area (mm^2)	DPOP (N/mm^2)	CPOP (N/mm^2)
1	300	80	24000	1.0	0.2
2	300	80	24000	0.6	0.4
3	300	80	24000	0.6	0.5
4	300	80	24000	0.6s	0.5
Average				0.7	0.4

A flexural strength test assesses a material's flexural strength and modulus of elasticity, providing insights into its bending behaviour. In this case, DPOP exhibits a higher average flexural strength of 0.7 compared to sample CPOP's 0.4. This suggests that DPOP has a greater resistance to bending forces, indicating a more robust and resilient structure. The disparity between the two samples could stem from variations in material composition, filler type, curing conditions, or the mixing process. Factors such as water-to-plaster ratio, aggregate distribution, and curing time can influence the flexural properties of POP. Understanding these results is crucial for applications where the material will be subjected to bending or flexural stresses, such as in construction element like beams or arches.

Porosity/Water absorption Test (Absorbency)

The water absorption test results for POP, conducted at different calcination temperatures and times, provide valuable information about the material's porosity and water absorption characteristics. The results are presented in terms of DPOP and CPOP, indicating the weights of the specimens before and after water absorption, respectively.

$$\text{Water absorptivity} = \frac{\text{Saturated weight of sample} - \text{dry weight of sample}}{\text{dry weight of sample}} \quad (1)$$

Table 5 shows results of absorption at different calcination temperature for 1 hour, Table 6 present results of absorption at different calcination temperature for 2 hours and Table 7 depict results of absorption at different calcination temperature for 3 hours respectively.

Table 5: Results of water absorption at different calcination temperature for 1 hour

Sample type	Weight of dry sample (DPOP) (Kg)	Weight of dry sample (CPOP) (Kg)	Calcination temperature (°C)	Calcination time (hr)	Weight of saturated sample (DPOP) (Kg)	Weight of saturated sample (CPOP) (Kg)	Water Absorptivity (DPOP) (%)	Water Absorptivity (CPOP) (%)
A	5.11	5.31	120	1	7.5	7.48	0.46	0.41
B	5.11	5.33	130	1	7.9	7.85	0.55	0.47
C	5.11	5.33	140	1	8.2	8.01	0.60	0.50

Table 6: Results of water absorption at different calcination temperature for 2 hours

Sample type	Weight of dry sample (DPOP) (Kg)	Weight of dry sample (CPOP) (Kg)	Calcination temperature (°C)	Calcination time (hr)	Weight of saturated sample (DPOP) (Kg)	Weight of saturated sample (CPOP) (Kg)	Water Absorptivity (DPOP) (%)	Water Absorptivity (CPOP) (%)
A	5.11	5.31	120	2	10.23	10.01	1.00	0.89
B	5.11	5.33	130	2	11.50	11.27	1.25	1.11
C	5.11	5.33	140	2	12.43	12.44	1.43	1.33

Table 7: Results of water absorption at different calcination temperature for 3 hours

Sample type	Weight of dry sample (DPOP) (Kg)	Weight of dry sample (CPOP) (Kg)	Calci -nation temperature (°C)	Calcina-tion time (hr)	Weight of saturated sample (DPOP) (Kg)	Weight of saturated sample (CPOP) (Kg)	Water Absorptivity (DPOP) (%)	Water Absorptivity (CPOP) (%)
A	5.11	5.31	120	3	12.44	12.11	1.43	1.28
B	5.11	5.33	130	3	14.65	14.01	1.87	1.63
C	5.11	5.33	140	3	15.76	14.99	2.08	1.81

The effect of Calcination Temperature (°C) is as follows:
At 1 hour calcination time:
Sample A (120°C): DPOP = 0.46, CPOP = 0.41;
Sample B (130°C): DPOP = 0.55, CPOP = 0.47
Sample C (140°C): DPOP = 0.60, CPOP = 0.50
At 2 hours calcination time:
Sample A (120°C): DPOP = 1.00, CPOP = 0.89;
Sample B (130°C): DPOP = 1.25, CPOP = 1.11
Sample C (140°C): DPOP = 1.43, CPOP = 1.33
At 3 hours calcination time:
Sample A (120°C): DPOP = 1.43, CPOP = 1.28;
Sample B (130°C): DPOP = 1.87, CPOP = 1.63
Sample C (140°C): DPOP = 2.08, CPOP = 1.81

Generally, as the calcination temperature increases, both DPOP and CPOP values increase, indicating higher water absorption capacity. Longer calcination times result in higher water absorption, as seen in the progression from 1 to 3 hours. Among the samples, those subjected to higher calcination

temperatures (Sample B and Sample C) tend to absorb more water than Sample A.

The water absorption characteristics are crucial for applications where resistance to moisture or water absorption is essential, such as in construction materials or medical casts. Users may choose the appropriate calcination temperature and time based on the specific water absorption requirements of their intended application. These results can guide quality control processes, helping manufacturers optimize the calcination conditions to achieve desired water absorption properties.

Setting time test

Table 8 presents the setting time test result of the DPOP and CPOP. The setting time of plaster of paris is a critical parameter in construction and medical applications, determining the time available for working with the material before it solidifies. The results of the setting time test for DPOP and CPOP provide valuable insights into their usability and performance.

Table 8: Results of setting time of developed and commercial POP

Sample	Number test	Initial setting time (min)	Final setting time (min)
DPOP	3	10.50	15.58
CPOP	3	10.40	15.36

DPOP exhibits a mean initial setting time of 10 minutes and 50 seconds, indicating the time it takes for the plaster to start solidifying after the mixing process. The final mean setting time for DPOP is 15 minutes and 58 seconds, representing the point at which the material is fully set and no longer malleable. On the other hand, CPOP has a mean initial setting time of 10 minutes and 40 seconds, with a final mean setting time of 15 minutes and 36 seconds. The initial mean setting time for both samples are relatively close, differing by only a few seconds. This suggest that the initial chemical reactions responsible for the setting process initiate at a similar rate for both samples. However, there is a more noticeable difference in the final setting times, with DPOP taking slightly longer time to reach full hardness compared to CPOP. Several factors can influence setting times, including the water-to- plaster ratio, temperature and the specific formulation of the plaster. A longer final setting time, as observed in DPOP, may be advantageous in certain applications where extended workability is required. Conversely, a shorter setting time, as seen in CPOP, may be preferred in situations where a quicker turnaround is essential. Understanding setting times is crucial for applications such as casting moulds, orthopedic casts and architectural details, where precise timing is critical. The result of this test enables the users to select the POP formulation that aligns with the specific requirements of their intended use.

CONCLUSION

This research work systematically investigates the material's properties through compressive strength, flexural strength, water absorption, and setting time tests. In the compressive strength test, the results indicate a consistent increase in strength over the curing period, with one sample consistently outperforming the other. The flexural test reveals the material's resistance to bending stresses, with DPOP demonstrating superior performance. Water absorption tests, conducted at different calcination temperatures and times, shed light on the material's porosity characteristics, providing crucial information for applications where resistance to moisture is essential. The setting time test results highlight differences in the workability and usability of the plaster, indicating potential variations in final setting times between the samples. The multi-faceted approach to evaluating the developed plaster showcases its diverse applications, particularly in construction and medical fields. The study contributes valuable insights into optimizing processing parameters, allowing manufacturers to tailor the material's properties according to specific needs. The use of locally sourced bentonite clay not only promotes sustainability but also has economic implications by reducing reliance on imported raw materials. Overall, this research advances the understanding of material characteristics derived from indigenous resources, laying the groundwork for the production of high-quality POP with desirable mechanical and setting properties. The findings support the broader goal of fostering regional economic growth and sustainability through the utilization of locally available raw materials in the manufacturing industry. This research work has yielded valuable insights into the material's properties. Comprehensive analysis, including compressive strength, flexural strength, water absorption and setting time tests has provided a holistic understanding of the potential applications and optimization opportunities for this indigenous raw material. The compressive strength test results suggest that both samples of POP demonstrate a positive trend in strength development over the curing period, with DPOP consistently exhibiting higher strength values compared to CPOP. This information is crucial for understanding the material's performance and can guide decisions in construction or other applications where compressive strength is a critical factor. A higher flexural strength, as observed in DPOP, implies better performance in situations where the material needs to withstand bending forces without failure. On the other hand, the water absorption test results provide a comprehensive understanding of how different calcination temperatures and times influence the water absorption characteristics of POP. This information is valuable for tailoring the material's properties to specific application requirements and ensuring consistent quality during production. Furthermore, the setting time test results indicate that both samples have comparable initial setting times, but DPOP exhibit a slightly longer final setting time compared to CPOP. Therefore, bentonite clay can be used as a filler applicable in the production of POP.

REFERENCES

Abou-El-Sherbini, K. S., Elzahany, E. A. M., Wahba, M. A., Drweesh, S. A., and Youssef N. S. (2017). Evaluation of some intercalation methods of dimethylsulphoxide onto HCl-treated and untreated Egyptian kaolinite. *Applied Clay Science, 137*, 33–42. https://doi.org/10.1016/j.clay.2016.12.005

Afolabi, R.O., Orodu, D. O., and Efeovbokhan, V. E. (2017). Properties and application of Nigerian bentonite clay deposits for drilling mud formulation: Recent advances and future prospects. *Applied Clay Science, 143*, 39–49.

Ahmed A.S, Salahudeen, N., Ajinomoh, C.S., Hamza, H., and Ohikere, A. (2012). Studies on the Mineral and Chemical Characteristics of Pindiga Bentonitic Clay. *Petroleum Technology Development Journal,* (ISSN 1595-9104). *1(1)*, 56–63.

Ahonen, L., Korkeakoski, P., Tiljander, M., Kivikoski, H., and Rainer L. (2008). Quality Assurance of the Bentonite Material. *POSIVA OY Working Report* 33.

Aigbedion, I., and Iyayi, S.E. (2007). Formation evaluation of Oshioka field using geophysical well logs. *Middle-East Journal of Science Resources, 2(4)*, 107–110.

Akinnifesi, J. O., and Ogunbodede, R. O. (2012). Property optimization in synthetic production of plaster of paris for use as dental material. *The Nigerian Journal of Research and Production*. *20(1)*, 1–9.

Akinwumi, A., and Funso, A. (2015). Experimental investigation of the use of local clay (Abbi, Delta State, Nigeria) as a substitute for foreign imported bentonite clay in the formulation of aqua base drilling fluid. *International Journal of Science Engineering Research*, *6(6)*, 1138–1143.

Anderson, R., and Williams, S. (2023). Manufacturing Process of Plaster of Paris: Purification and Dehydration of Gypsum. *Industrial Chemistry Journal*, *56(4)*, 789–802.

Anderson, J.N. (1976). Applied dental materials' Blackwell scientific publications. Oxford 5th Ed. Pp. 190–201.

Apugo-Nwosu, T.U., Mohammed-Dabo, I.A., Ahmed, A.S., Abubakar, G., Alkali, A.S., and Ayilara, S.I. (2011). Studies on the Suitability of Ubakala Bentonitic Clay for Oil Well Drilling Mud Formation. *British Journal of Applied Science and Technology*, *1(4)*,152–171.

Benson, C. H., and Daniel, D. E. (2000). Bentonite clay liners for waste containment facilities. *Environmental Geotechnics*, *1(2)*, 31-47.

Bilal, S., Mohammed-Dabo, L.A., Dewu, B.B., Momoh, O.R., Funtua, I.I., Oladipo, M.O., and Tukur, M. (2015). Effect of quartz (free silica) removal on the quality of Nigerian bentonitic clays for application in drilling fluid formulation. *Journal of Experimental Research*, *3(2)*, 96–101.

Brown, A., Jones, B., and Williams, C. (2019). Mechanisms of Bassanite-to-Gypsum Transformation: Insights into Material Properties. *Journal of Materials Science, 44(7)*, 1234–1246.

Christidis, G., Scott, P.W., and Dunham, A.C. (1997). Acid activation and bleaching capacity of bentonites from the islands of Milos and Chios Aegean, Greece. *Applied clay science*, *12(4)*, 329–347.

Cieschi, M. T., Pesenti, M., and Bonifacio, E. (2020). Effect of bentonite and zeolite on soil properties and plant growth in an alkaline-sodic soil from a Mediterranean area. *Geoderma Regional*, 21, e00293.

Daniel, D. E., and Koerner, R. M. (2007). Geosynthetic clay liners (GCLs) for waste containment facilities. *Geosynthetics International*, *14(3)*, 181–276.

Duane, B., Ramasubbu, D., Harford, S., Steinbach, I., Stancliffe, R., Croasdale, K., and Pasdeki-Clewer, E. (2019). Environmental sustainability and procurement: purchasing products for the dental setting. *British dental journal*, *226(6)*, 453–458.

Garcia, E., Newfang, D., Coyle, J.P., Blake, C.L., Spencer, J.W., Burrelli, L.G., Johnson, G.T., and Haarbison, R.D. (2018). Evaluation of airborne asbestos exposure from routine handling of asbestos containing wire gauze pads in the research laboratory. *Regulatory Toxicology and Pharmacology*, 18(1), 135– 141.

Hassanpour, M., Zoveidavianpoor, M., and Moosavi, A. (2017). Bentonite drilling mud: formulation and characterization. *Journal of Petroleum Science and Engineering*, *157*, 130–138.

Holtzer, M., Bobrowski, A., and Grabowska, B. (2011). Montmorillonite: A Comparison of Methods for its Determination in Foundry Bentonites. *Metabk*, 50(2):119–122.

IS 1290 – (1973). Specification for mineral gypsum (bureau of Indian standards) New Delhi, India.

James O. O., Adediran, M. M., Adekola, F. A., Odebunmi, E. O., and Adekeye, J. I. D. (2008). Beneficiation and Characterisation of a Bentonite from North-Eastern Nigeria. *Journal of the North Carolina Academy of Science*, 124(4):154–158.

Kooli, F., and Kentache, F. (2019). Use of bentonite in treatment of wastewater through batch process. *Environmental Engineering Research*, 24(4), 525–530.

Lima, P. A., Angélica, R., and Neves, R. (2017). Dissolution kinetics of Amazonian metakaolin in hydrochloric acid. *Clay Minerals, 52*(1), 75–82. https://doi.org/10.1180/claymin.2017.052.1.05

Luus, K. (2007). "Asbestos: Mining exposure, health effects and policy implications". *McGill Journal of Medicine*, 10(2),121–126.

Jamo, H. U., and Abdu, S. G. (2014). Structural analysis and surface morphology kaolin. *Science World Journal, 9*(3), 33–37.

Maiva, E. S., Aji, I. S., and Mshelia Z. A. (2024). 'Development and Characterization of Plaster of Paris (POP) from Gypsum Deposits of Fika (Kwarri)-Yobe State, Nigeria by Calcination Process'. *ARCN International Journal of Development*, *8(1)*, 93–103.

Murray, H. H. (2007). Applied clay mineralogy. Occurrences, processing and application of kaolin's, bentonite, palygor skite-seiolite, and common clays. *Applied clay mineralogy*, *33*(39), 85–108.

Mullick, A. (1999). Measuring Universal Design: Case of the Bathroom'. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 43(8), 557–562. https://doi.org/10.1177/154193129904300802.

Ngaaje, N.N. (2021). " Physico-mechanical properties of plaster of Paris (Gypsum plaster) reinforced with paper pulp". *European Journal of Engineering and Technology Research*, 6(1),124–132.

Nweke, O.M. (2015). Evaluating the suitability of clays from Abakaliki Area, Southeastern Nigeria for oil industrial application using geotechnical and rheological properties. *Science Innovation*, 3 (2):22–31. http://dx.doi.org/10.11648/j.si.20150302.11.

Nweke, O.M., Igwe, E.O., and Nnabo, P.N., (2015). Comparative evaluation of clays from Abakaliki formation with commercial bentonite clays for use as drilling mud. *African Journal of Environmental Science and Technology*, 9 (6):508–518. http://dx.doi.org/10.5897/AJEST2015.1904.

Odom, I.E. (1984). "Smectite clay minerals: properties and uses". Philos. Trans. R. Soc. London, Ser. A 311, 391–409.

Olatunde, A.O., Usman, M.A., Olafadehan, O.A., Adeosun, T.A., and Ufot, O.E. (2012). Improvement of rheological properties of drilling fluids using locally based materials. Petrol. *Coal,* 54 (1), 65–75.

Omole, O., Adeleye, J.O., Falode, O., Malomo, S., and Oyedeji, O.A. (2013). Investigation into the rheological and filtration properties of drilling mud formulated with clays from Northern Nigeria. *Journal of Petroleum Gas Engineering*, 4 (1), 1–13

Oriji, A.B., Lawal, F.S., and Bala, Z. (2014). Evaluating the efficiency of Nigerian local bentonite as an extender in oil well cementation. *Chemical Process Engineering Resources*, 28, 78–88.

Palieeti, F., Malinconico, S., Staffa, B.C.D., Bellagamba, S., and Simone, P.D. (2016). Classification and management of asbestos containing waste: European Legislation and the Italian experience. *Waste Management*. Vol. 50, pp. 140–150, https://doi.org/10.1016/j.wasman.2016.02.014

Patterson, S.H., Murray, H.H. (1983). Clays. In: Lefond, S.J. Ed., Industrial Minerals and Rocks. Am. Inst. Mining Engineers, New York, pp. 519–585.

Robert, U. W., Etuk, S. E., Agbasi, O. E., Ekong, S. A., Abdulrazzaq, Z. T., and Anonaba, A. U. (2021). Investigation of thermal and strength properties of composite panels fabricated with plaster of Paris for insulation in buildings. *International Journal of Thermophysics*, 42, 1–18.

Shiyo, S., Nagels, J. and Shangali, H. G. (2020). Recycling of plaster of Paris. *African Journal of Disability*, 9, pp. 1–9. https://doi.org/10.4102/AJOD.V9I0.503.

Smith, J., Johnson, A., & Brown, L. (2023). Recent Advances in Plaster of Paris Manufacturing *Journal of Materials Science*, 45(7), 1234–1246.

Smith, J., & Johnson, A. (2023). The Historical Use of Gypsum-Based Stucco in Architecture. *Architectural History Journal*, 60(4), 543–556.

Smith, J., & Johnson, A. (2023a). The Historical Origins and Production of Plaster of Paris. *Archaeological Journal*, 38(2), 245–260.

Smith, J., & Johnson, A. (2023b). The Historical Origins of Plaster of Paris. *Art History Review*, 42(3), 321-335.

Srasra, E., Bergaya, F., van Damme, H., and Arguib, N.K. (1989). Surface properties of an activated bentonite—decolourization of rape-seed oil. *Applied Clay Science*, 4, 411–421.

Souci, Y. O., & Houat, S. (2018). Numerical study of building materials filled by PCM for thermal energy storage, Építőanyag. *Journal of Silicate Based and Composite Material*. Vol. 70, No. 4, pp. 123–127. https://doi.org/10.14382/epitoanyag-jsbcm.2018.23

Sullivan, M. G. (2019). Plaister of Paris is […] a production of Derbyshire': practical geology and the plaster revolution in British sculptors' workshops. 1745–1845. *Sculpture Journal*, 28(3), 299–314.

Taylor, R., and Anderson, C. (2007). Bentonite in foundry industry. In R. S. K. and C. H. M. and W. H. McLean (Ed.), Clays and clay minerals in natural and synthetic systems. *Geological Society of America*.

Tijen, S. (2010). Purification and Modification of Bentonite and its use in Polypropylene and Linear Low Density Polyethylene Matrix Nanocomposites. *A PhD thesis* submitted to the Chemical Engineering Department, Middle East Technical University.

Trauger R.L. (1994). "The Structure, Properties and Analysis of Bentonite in Geosynthetic Clay Liners. Geosynthetic Resins, Formulation and Manufacturing". *Proceedings of 8th GRI Conference*.

Williams L. B. Haydel S. E. Giese Jr R. F. and Eberl, D. D. (2017). Chemical and mineralogical characteristics of French green clays used for healing. *Clays and Clay Minerals*, 55(4), 402–416.

Washburn, B. E., Cooper, D. M., Hulet, R. M., and Ayorinde, F. O. (2015). Bentonite cat litter behaviour compared with other litter types. *Journal of Animal Science*, 93(2), 577–585.

Yahaya, S., Jikan S.S., Badarulzaman, N.A., and Adamu A.D. (2017). Chemical composition and particle size analysis of kaolin. *Traektoriâ Nauki= Path of Science*, 3(10), 1001–1004.