



DEVELOPMENT OF PLASTER OF PARIS (POP) FROM GYPSUM DEPOSITS OF FUNE - YOBE STATE, NIGERIA BY CALCINATION PROCESS

E. S. Maiva^{1*}, I. S. Aji² and Z. A. Mshelia²

^{1,2}Marini Asphalt Plant, Ministry of Works and Housing Maiduguri, Borno State-Nigeria

²Department of Mechanical Engineering, Faculty of Engineering, University of Maiduguri, Maiduguri, Borno State-Nigeria

*Corresponding author's e-mail address: esmaiva@gmail.com

ARTICLE INFORMATION

Submitted 18 August, 2024
Revised 11 September, 2024
Accepted 15 September, 2024

Keywords:

Gypsum
Plaster of Paris
Calcination
Density
Porosity
Compressive strength

ABSTRACT

Gypsum is a common sulfate mineral which has significant commercial value mostly made up of hydrated calcium sulphate. over dependence on foreign/imported POP into the country is in the high rise, local economy is affected and local miners are not patronized. Thus, the study produced and characterized POP from Fune Local Government Area of Yobe State- Nigeria (Alangefe deposit site). The Gypsum sample was collected at three layers of 0.5m each after excavating the top soil. The samples were beneficiated and calcined at the Civil Engineering Laboratory of Eighteenth Engineering Company at 170°C. Porosity, shrinkage, compressive strength and density tests were carried out on these samples. The gypsum collected were processed and characterized with the sample having porosity of 53.37% on the average, 0% shrinkage, compressive strength of up to 23.03N/mm² and 21.04N/mm², density of 0.91g/cm³ and 1.01g/cm³. Water:POP ratio of 80-100:100 gave the best results. The properties of the characterized POP from Fune (Alangefe) mining site had excellent properties as compared with the POP obtained in the market. Thus, the produced POP can replace the ones being sold in the market in terms of availability and its properties.

© 2024 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

1.0 Introduction

Gypsum is a common sulfate mineral which has significant commercial value mostly made up of hydrated calcium sulphate (CaSO₄·2H₂O). It is a white mineral of calcium sulphate in the earth crust (Mohammed, 2015). It is a common mineral that occurs in combination with sedimentary rocks and has thick, broad evaporation beds. Gypsum can be found in nature as translucent, cleavable masses termed selenite and as flattened, frequently twinned crystal (Mohammed, 2015). It has been used as a bonding material in building walls and the finishing works of walls. The most common reason for its widespread use is availability, efficiency, and low cost (Salman *et al.*, 2023). Gypsum is an essential material used for numerous construction purposes ranging from building and several others due to its aesthetics and insulative properties (Kerstin *et al.*, 2023). According to the Federal Ministry of Science and Technology, (Raw Materials Research and Development Council: RMRDC, 2010), gypsum has been in existence in Nigeria since 1921 with grades from the various deposits in the country (at about one billion tonnes spread across the deposit sites) satisfying the specifications required by the cement industry: identified deposits in North Eastern Nigeria are found in Adamawa, Taraba, Yobe, Borno, Bauchi and Gombe States respectively. Locations like Yobe, Sokoto, Adamawa, Gombe, Benue state and others have gypsum deposits in substantial quantities. Plaster of Paris is a quick-setting gypsum plaster consisting of a fine white powder (calcium sulphate hemihydrate), which hardens when moistened and allowed to dry and it is known since ancient times as plaster of Paris, so called because of its preparation from the abundant gypsum found near Paris (Britannica, 2021). Calcination is the process of heating gypsum to evaporate the crystalline water in order to dehydrate it into plaster or stucco. This can be done in a batch or continuous manner. Free water is usually removed at 45°C steps in the initial process, while crystalline bound water is removed in 120–180°C steps in the second process. Many systems additionally include options for grinding capacity before, during and after calcination, depending on the product intended to be produced.

The present study assessed Fune (Alangefe) deposit site in Yobe State, Nigeria for the production of Plaster of Paris (POP) and compared their properties with POP currently available in the market (POPm). This study explored the use of gypsum from our readily available deposit sites which will improve industrialization, create more job opportunities for local miners and boost the local economy through industrialization. Soyinka (2015), in their research on the comparative analyses of Wurno, Dange and Weppa gypsums in Nigeria for plaster and ceramic production, it was deduced that the constant importation of plaster of Paris constitutes a drain on national economy and an added cost on ceramic mass production. Various tests were carried out; results showed that the ratio mix of 75-85 of the plaster to water ratio mix were suitable for ceramic slip casting process. 65 and 70 plaster:water ratio mix were better used for casting models and press moulding process. The gypsum obtained from the three locations can be used for ceramic application. Bukar *et al.* (2011), in their research on, Geology and Geochemistry of Gypsum Deposits in Fika and Fune Local Government Area of Yobe State, Nigeria: Implication to Industrial Applications, It was concluded in the study that the gypsum of the study areas fall within the Cretaceous sequence and the gypsum occur as seams, vein let and lenses and based on these geochemical values the gypsum of the two areas is good quality for cement, plaster of Paris, solid wallboard, ceramic and ammonium sulphate fertilizers. Further, Oyedele *et al.* (2018), in their research on processing a locally sourced gypsum material for medical and industrial applications, results of property tests showed that the products will have long service life. It was concluded in this study that that Ibese gypsum, when properly treated, can be used in both industrial and medical settings. In order to prevent unanticipated failure in service, processing should involve a multistage de-gritting operation with the final gypsum slip carefully dewatered and converted to gypsum plaster at about 200°C. The use of any quality enhancer that tends to affect the hardness or softness of the plaster products should be carefully controlled based on the specific application. Also, Ngaaje (2021) in the study on the physic-mechanical properties of plaster of Paris (Gypsum plaster) reinforced with paper pulp in order to improve the weight of plaster paste and to obtain materials of lighter weight that solve problems such as poor flexural strength, and crack propagation. It was determined at the end of the study that the incorporation of small amounts of paper pulp (2 kg samples) into the plaster paste improves its flexural properties. The presence of paper pulp in the plaster of POP paste increases the time of hardening of the plaster cement from one proportion to another, reduces the workability of the mixed paste, significantly solves the problem of removal, the apparent density drops when waste paper paste is increased in the mixed plaster. Because of its light weight, low density, its acceptable mechanical properties, these new materials are recommended for exploitation in the manufacturing of popular lightweight construction finishing like panels for ceiling or walls, staff works and other applications. Similarly, Pirman *et al.* (2022) in their research on enhanced mechanical properties plaster of paris with addition of rice husk fibers, the incorporation of additives materials into gypsum alters water absorption and mechanical properties of the final products. The density, water absorption, porosity, and mechanical properties prior to compressive strength were examined. The density, water absorption, porosity, and mechanical properties of plaster lies in the range of 1.521 – 1.673 g/cm³, 25.107 – 33.989 %, 40.196 – 53.295 %, and 2.666 – 9.438 MPa, respectively. The incorporation of moderate size rice husk fibers in the range of 63 µm and 250 µm enhanced the compressive strength due to the contribution of rice husk fibers as reinforcement agent in the gypsum network.

This work used gypsum deposit at three different layers to explore its properties and characterized the POP formed. Properties obtained were then compared with the POP available in the open market.

2. Materials and Methods

2.1 Materials

The materials used in this study include water and Gypsum rock from Fune (Alangefe) (Latitude 11.306947°, Longitude 11.38767°) deposit mining site in Yobe State. Figure 1 shows Yobe State Map with all the Local Government Areas.

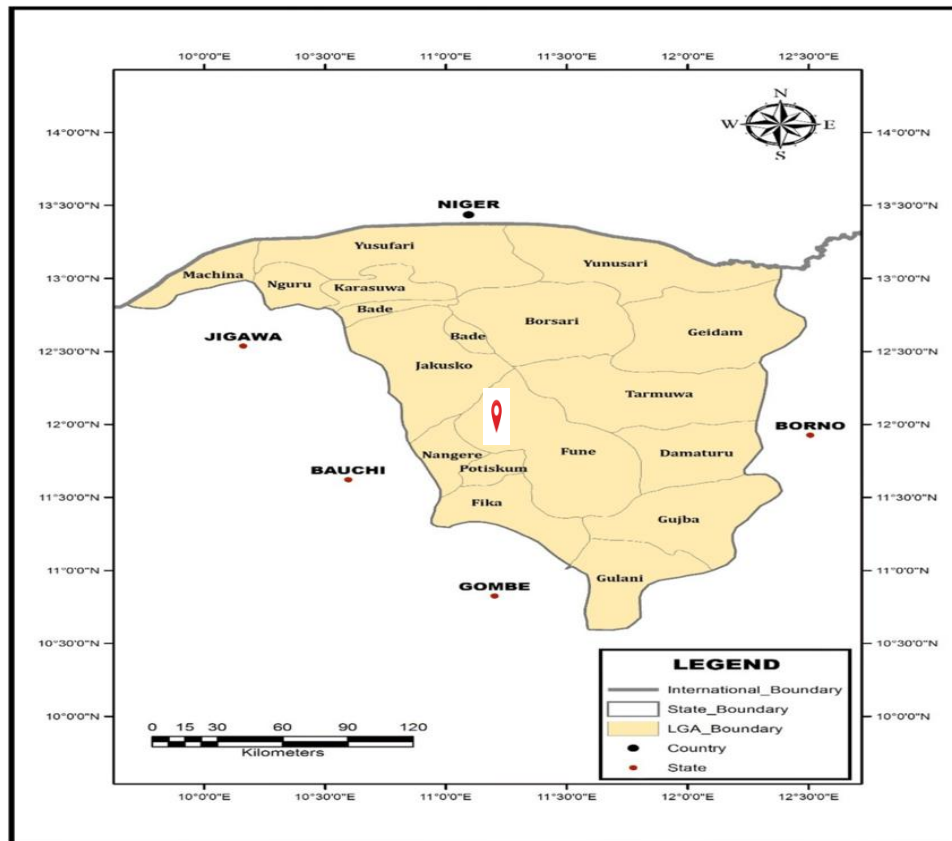


Figure 1: Map Showing Yobe State LGAs (Geospatial Analysis Mapping and Environmental Research Solutions (GAMERS), 2018)

The equipment used for this study include; Electric blast drying oven (Type 10 -IA, Beijing Luda Waiye Technology) for calcination (at EEC Laboratory), digital weighing scale (model, Szegedi, OmhEng Type), electric hydraulic pressure testing machine (Huaxi, DYE-2000 type; EEC Lab) to determine compressive strength, shovel, pulley, torch light, hand gloves, Vernier caliper, sieve (model, Bosch-112219), crucible for loading sample, stirrer for mixing gypsum and water.

2.2 Method

This work adopted the method of calcination used by Hamdan *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 was determined. The experimentation was done at the Eighteenth Engineering Company (EEC) Laboratory, Molai, Maiduguri, Borno State. Also, the chemical analysis was done at Spectral Laboratory Services, Tudun Wada, Kaduna, Kaduna State.

2.2.1 Preparation of the Gypsum Samples

The mineral was produced from underground mines which is below water level by excavation (digging). Three separate samples each at 0.5m, 1m and 1.5m respectively from each location after removal of the top soil were collected. The topsoil was removed at 1.8m. It was then collected, stored in a bag and transported to the workshop where it was processed. Figure 2 shows the samples collected from the mining site.



Figure 2: Gypsum samples from deposit site

To produce good samples of gypsum that would be further processed, impurities were thoroughly cleared and cleaned from the samples. This was done by picking out and removing the larger clay and sand particles from the samples and washing it. Also, Gypsum was soaked for about 1 hour to allow easy removal of the clay on the samples. It was then washed thoroughly to ensure it was 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 conditions. A grinder was used to first reduce the size of the dried gypsum rocks to smaller pellets, then it was taken to another grinder which crushed the samples to powdered form. In addition, A manual sieve of 300 μ m (ASTM E11) was used for sieving the crushed powder in order to remove the large grains which were not properly crushed so as to obtain a fine powder.

2.2.2 The Calcination Process

The process of calcination to form plaster of Paris was one involving heating of the cleaned, dried, and crushed gypsum to a certain temperature ranging from 120°C to 180°C to drive off a portion of the water of crystallization (Tesfaye, 2015). The gypsum powder after preparation was poured into a crucible and loaded into the electric blast drying oven for calcinations (Figure 3) shows the electric blast drying oven). Crucible was used in the kiln for calcinations of gypsum because POP produced from a crucible is denser and stronger. Thereafter, sample was heated to a temperature of 170°C, to ensure that the combined water was released from the samples. After heating it to the required temperature, the oven was turned off and the powder allowed to cool down inside the oven for a period of 18 hours before it was opened.



Figure 3: Electric blast drying oven

After calcination, the powder was kept dry and enclosed in a polythene bag to stop moisture intrusion/infiltration.

2.2.3 Characterization of the POP

The samples were subjected to various tests (characterization) to determine the porosity/absorbency, density, shrinkage and compressive strength.

a. Porosity

Porosity 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 material (POP) as reported by

Mahendra (2018). The porosity test was carried out at the Eighteenth Engineering Company (EEC) Civil Engineering Laboratory at Molai, Maiduguri.

The samples were dried in the oven for 24 hours at a temperature of 45°C and cooled before the porosity/water absorption test was performed. The weights of the dried samples were measured. The samples were then soaked in water for a period of two hours to ensure optimum saturation as similarly reported by Hamdan *et al.* (2024). Thereafter, the POP was further subjected to porosity test with a ratio mix of POP/water at about 80ml to 150ml. Figures 4 and 5 show how the porosity test were carried out. Samples were moulded (Figure 5) according to the mix ratio of water: POP as presented in Table I as recommended by Hamdan *et al.* (2024).

The porosity was determined using Equation 1.

$$\text{Percentage of Water Absorption} = \frac{W_s - W_d}{W_d} \times 100 \quad (1)$$

where; W_s = Saturated Weight (g) and W_d = Dry Weight (g).



Figure 4: Samples weighed for Porosity



Figure 5: Samples being Soaked

b. Density

The mass of the samples was measured using the electric weighing scale and the volume was calculated using Equations 2 and 3;

$$\text{Volume of Cylinder} = \pi r^2 h \text{ (cm}^3\text{)} \quad (2)$$

$$\text{Dry Density} = \frac{\text{Mass}}{\text{Volume}} \text{ (g/cm}^3\text{)} \quad (3)$$

c. Shrinkage

Shrinkage is reduction in single dimension of a sample when moisture is reduced as reported by Hamdan *et al.* (2024). The samples were placed in a mould and allowed to solidify. After it was dried completely, it was observed that there was zero reduction in their sizes.

d. Compressive Strength

Compressive strength of a material is the uniaxial compressive stress reached when the material fails completely. Compressive strength test was carried out on POP because it falls into the category of earthen materials which lacks the ability to withstand tensile stress (Stress due to pull as in metallic materials) (Soyinka, 2015). The compressive strength was obtained by experimental means using the Electro-hydraulic pressure testing machine. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied as shown in Figure 6. The specimen (usually cylindrical) is shortened as well as spread laterally (Tesfaye 2015). The compressive strength of the POP was determined using the ratio mix of 80ml to 130ml to 100g of water: POP. The test was carried out at the Eighteenth Engineering Company (EEC) civil laboratory situated at Molai, Maiduguri, using the Electric Hydraulic Pressure Testing Machine. The compressive strength and cross-sectional area were calculated using Equation 4 and 5 respectively.

$$\text{Compressive Strength} = \frac{\text{Applied Force}}{\text{Cross - Sectional Area}} \text{ (N/mm}^2\text{)} \quad (4)$$

$$\text{where: Cross - Sectional Area of Cylinder} = 2\pi r h + 2\pi r^2 h \text{ (mm}^2\text{)} \quad (5)$$



Figure 6: Sample loaded to the press jaws

3. Results and Discussion

3.1 Porosity

Figure 7 shows a comparison between the POP obtained in the market (POPm) and that of the samples obtained from Fune (Alangefe) deposit site at 0.5m, 1.0m and 1.5m depth respectively.

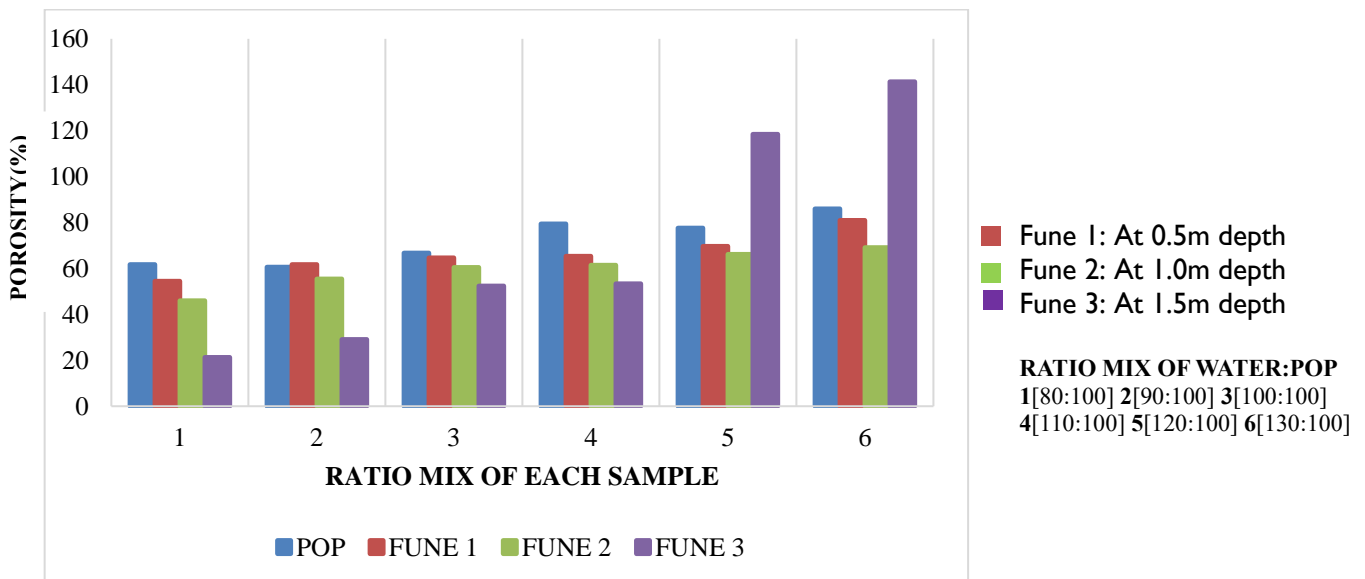


Figure 7: Comparison between Porosities of POPm and Fune (Alangefe) POP

From Figure 7, percentage in porosity increases as the volume of water increases. The POPm had its highest porosity of 85.92% at 100:130 ratio mix of POP to water and the lowest percentage porosity at 61.65% at 100:80. For Fune (Alangefe) at 0.5m, the highest percentage porosity was 81.00% of POP to water mix ratio at 100:130 and the lowest to be 54.52% at 100:80. For Fune (Alangefe) at 1.0m, a similar steady increase in porosity was observed as the volume of water increased. At 100:80 ratio mixes of POP to water, the porosity was 46.01% and the highest was at 100:130 which was 69.10%. For Fune (Alangefe) at 1.5m, the lowest porosity was 21.34% at 100:80 POP to water ratio mix and the highest was 141.37%. The third layer at 1.5m had the highest porosity among all the samples tested. The increase in porosity was as a result of the increase in the volume of water added to the POP. These results are in agreement with Hamdan *et al.* (2024), which stated that porosity or absorption in POP increases with increase in the proportion of water added to it. The results from this sample also agreed to their work which also had increase in porosity upto 80% for 100:130 ratio mix of POP to water. The porosity of POPm was higher in percentage when compared to Fune (Alangefe) which indicates that the produced POP has better porosity and it could replace the POPm in terms of porosity.

3.3 Shrinkage

The shrinkage percentage of POPm compared to Fune (Alangefe) samples at 0.5m, 1.0m and 1.5m is presented in Table I.

Table I: Shrinkage Test Result for POPm with Fune (Alangefe) sample at 0.5m, 1.0m and 1.5m Depths

Parameters	Samples					
	1	2	3	4	5	6
Plaster(g)	100	100	100	100	100	100
Water	80	90	100	110	120	130
Shrinkage(%)(POPm)	0	0	0	0	0	0
Shrinkage (%) (Fune, Alangefe)	0	0	0	0	0	0

Table I shows the shrinkage percentage for Fune (Alangefe) samples for first, second and third layers. It can be noticed that the percentage in shrinkage is at 0% for all the water:pop mix ratio. This result agrees with that of Hamdan *et al.* (2024) and Soyinka (2015) who had in their research 0% shrinkage of the cast sample used.

3.4 Compressive Strength

From Figure 8, the compressive strength of POPm was 12.88N/mm² at 100:80 and the lowest 4.16N/mm² at 100:100 ratio mix of POP to water respectively. When compared to POP from Fune (Alangefe), at 0.5m a compressive strength of 23.03N/mm² as the highest at 100:80 and the least as 3.80N/mm² at 100:110 ratio mix of POP to water. At 1.0m layer of the sample, the highest was 11.47N/mm² at 100:80 and the least 3.60N/mm² at 100:100 ratio mix of POP to water. The 1.5m layer however had compressive strength of 10.12N/mm² as the highest and the lowest 5.59N/mm² at 100:120 and 100:100 ratio mix of POP to water respectively. It was observed that the compressive strength of POPm and the three depths that the stress decreases with increase in the water volume. Also, the compressive strength of the produced POP was higher than that of the POPm which indicates that Fune POP had better compressive strength and can replace the POPm. The highest compressive strength of the 1.5m depth sample was similar to the finding of Hamdan *et al.* (2024).

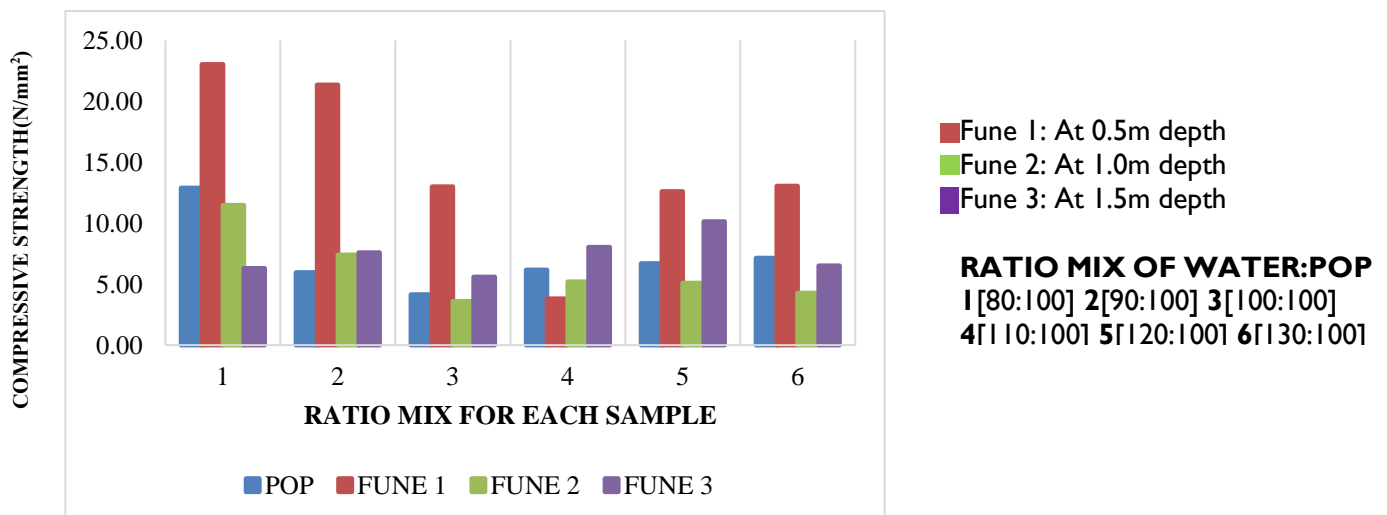


Figure 8: Comparison between Compressive Strengths of POPm and Fune (Alangefe) POP

3.5 Density

Density test was carried out and the results are presented in Figure 9 which compares POPm density to that of Fune (Alangefe) Samples at 0.5m, 1.0m and 1.5m depth.

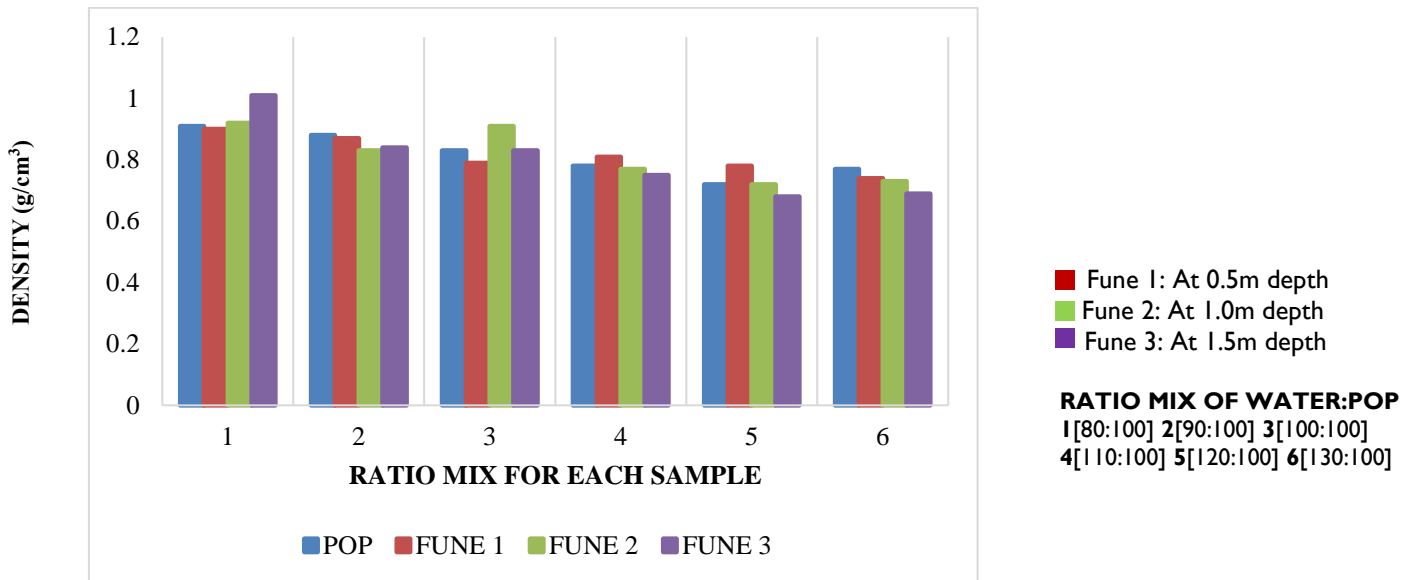


Figure 9: Density of POPm Compared to Fune (Alangefe) POP

POPm had its density highest which was 0.91g/cm^3 and lowest at 0.72g/cm^3 at 100:80 and 100:120 ratio mix of POP to water. For Fune (Alangefe) sample at 0.5m depth, the highest density was 0.90g/cm^3 and lowest 0.74g/cm^3 at 100:80 and 100:130 ratio mix of POP to water respectively. The values at 1.0m depth was 0.92g/cm^3 and 0.72g/cm^3 highest and lowest at 100:80 and 100:120 ratio mix of POP to water respectively. At 1.5m depth, the highest was 1.01g/cm^3 and lowest 0.68g/cm^3 at 100:80 and 100:130 ratio mix of POP to water respectively. It can be observed that the decrease in density as the volume of water increases per sample as stated by Hamdan *et al.* (2024) which had a similar result in density for Nafada sample in their research. The density of POPm and that of Fune (Alangefe) were similar which indicates that the produced POP could replace the POPm in terms of density.

4. Conclusion

Based on the results obtained from this study, the following conclusions were drawn.

- i. Qualitative Gypsum is readily available in deposit sites and can be mined at different layers after excavating the topsoil in Fune Local Government area of Yobe State.
- ii. The characterized POP in all the samples showed excellent properties with;
 - a. porosity of 53.37 at the average for all samples,
 - b. Zero percent shrinkage for all samples,
 - c. compressive strength of 23.03N/mm^2 at 0.5m depth,
 - d. density of 0.91g/cm^3 and 1.01g/cm^3 .
- iii. The properties obtained from the characterized POP revealed that in all the samples, as the depth of collection increases, the POP has differing properties in terms of its porosity/absorbency, density, shrinkage and compressive strength. However, the POP when processed, can replace the one obtainable in the market, due to the excellent characterized properties which surpassed the ones being used.
- iv. POP at the three depths of mining possessed properties which could replace the ones obtainable in the market and the most viable is at 0.5m depth.

References

- Abidoeye, LK. and Bello, RA. 2010. Restoration of Compressive Strength of Recycled Gypsum Board Powder. The Pacific Journal of Science and Technology, 11(2): 42-50.
- Anthony, JW., Bideaux, RA., Bladh, KW. and Nichols, MC. 2003. "Gypsum". Handbook of Mineralogy (PDF). V (Borates, Carbonates, Sulfates). Chantilly, VA, US: Mineralogical Society of America.
- American Standard of Testing Materials (ASTM) – E11, 2024 updated on 23rd June 2024.
- Broadhurst, JL., Petrie, JG. and VonBlottnitz, H. 2007. Understanding element distribution during primary metal production, 116(1): 1-16.

- Bukar, F., Baba, S., Shettima, B. and Kyari, AM. 2011. Geology and Geochemistry of Gypsum Deposits in Fika and Fune Local Government Area of Yobe State, Nigeria: Implication to Industrial Applications. *Borno Journal of Geology* 8(1): 57-66.
- Ciullo, PA. 2006. *Industrial Minerals and their uses handbook and formulary*, Westwood New Jersey, 1(1): 35-36.
- Hamdan, AF., Hassan, OH. and Awang, NN. 2024. Characteristics of recycled plaster of Paris at several different temperatures between 150°C-190°C during recycling process. *International Journal of Art and Design (IJAD)*, 8(2): 31-37.
- Henkels, PJ. and Gynor, JC. 1996. Characterizing synthetic gypsum for wallboard manufacture. *Preprints of Papers, American Chemical Society, Division of Fuel Chemistry*, 41(2): 569-574.
- Kerstin, E., Pedro, B. and Miguel, B. 2023 Influence of calcination on hydration behavior, strength and weathering resistance of traditional gypsum. *Plaster, Construction and Building Materials Journal*, 367(1): 130361
- Mahendra, G. and Arjun, SS. 2018. Effect of Porosities on strength of Plaster of Paris. *International Conference paper on Advances in Construction Materials and structure held at IIT Rookee, Uttarakhand, India on March 7th - 8th 2018*, 1(1):1-10
- Mohammed, IY. 2015. Suitability of Nafada Gypsum for the Production of Jute Fibre Reinforced Plasterboards. *ATBU Journal of Environmental Technology*, 8(2): 79-92.
- Oyedele, EA. and Omolara, O. 2018. Processing a Locally Sourced Gypsum Material for Medical and Industrial Applications. *FUOYE Journal of Engineering and Technology*, 3(2):118-124
- RMRDC. 2010. *Non-metallic mineral endowments in Nigeria*. Federal Ministry of Science and Technology, Abuja, 1(1): 1-16.
- Sidney, D. 2008. Gypsum. *Encyclopaedia of Earth* Eds. Cutler J. Cleveland, Washington D.C. Environmental Information Coalition, national Council for Science and the Environment. <http://www.eoearth.org/article/Gypsum>> (accessed on 21st November 2021)
- Soyinka, GK. 2015. Comparative Analysis of Wurno, Dange and Weppa Gypsums in Nigeria for Plaster and Ceramic Production. A Dissertation submitted to the School of Post Graduate studies, Ahmadu Bello University, Zaria, Nigeria.
- Tesfaye, AB. 2015. Recycling Plaster of Paris from Discarded Gypsum moulds for Tabor Ceramics Products Manufacturing Share Company, Department of Chemical and Bio Engineering, Addis Ababa University School of Graduate Studies, Addis Ababa Institute of Technology, Addis Ababa.