

A study of casting characteristics of some Nigerian clay slips for industrial production

¹ Edoziuno FO, ² Iloghalu FI, ³ Akaeze MC, ⁴ Umeohia NO, ⁵ Nwaeju CC, ⁶ Anene FA

¹ Department of Metallurgical Engineering, Delta State Polytechnic, Ogwashi-Uku, Nigeria.

^{2, 3, 4, 5, 6} Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Nigeria.

Abstract

Laboratory Clay castability test has been conducted on three Nigerian clay samples: kankara clay, Barkimladi clay and Nsu clay; to determine their slip casting characteristics. Four specimens labeled K (kankara clay slip), B (Barkimladi clay slip), K + N (kankara clay blended with Nsu clay slip) and B + N (Barkimladi clay blended with Nsu clay slip) were prepared, mixed with water and deflocculated with Na₂SiO₃ to form casting slips. Plaster of Paris (P.O.P.) moulds were used to absorb the clay slips during slip casting, and the volume of the casting slip sucked-up was determined for each specimen at time intervals ranging from 0 to 35mins. The results obtained indicate that the volume of slip absorbed by the P.O.P. mould is proportional to the time of absorption. Graphs of volume of slip sucked-up against time were plotted and parabolic curves typical of clay casting were obtained. When volume of slip sucked-up were plotted against square root of time, linear curves were obtained, the gradient of which showed the rate of casting. Analysis of the experiment revealed that a better casting tendency of 9.3ml/min was obtained for specimen B closely followed by specimen K + N at 10.7ml/min. By contrast specimens K and B + N did not cast well and appropriate suggestions were given in order to improve their properties for use as casting slips.

Keywords: Slip casting, Clay Castability, Deflocculation, Clay slips

1. Introduction

Clay is a naturally occurring hydrous aluminosilicate compound formed by gradual weathering of silicate bearing rock by low concentrations of carbonic acid and other diluted solvents. In addition to the weathering process, some clay minerals are formed by hydrothermal activity. It is one of the widely used ceramic materials found naturally in great abundance. Nigeria is richly blessed with various clay deposits in different parts of the country which have been variously characterized and classified for suitable industrial applications by some researchers [1, 2, 3, 4, 5]. One reason for the popularity of clay lies in the ease with which clay products may be formed; when mixed in the proper proportions, clay and water form a plastic mass that is perfectly pliable as long as it stays fairly moist. Optimal casting rate requires that the slurry have minimal water content, e.g., 30% or below [6]. When dried clay becomes firm and when fired in a kiln, permanent physical and chemical reactions occur which among other changes, cause the clay to be converted into a ceramic product [7].

The characteristics common to all clays derive from their chemical compositions, layered structure (shape) and particle size [8]. Individual mineral grains of clay are microscopic in size and shaped like flakes. This makes their aggregates surface area much greater than their thickness and allows them to take up large amounts of water by adhesion, giving them plasticity and causing some variety to swell [9]. When an electrolyte is added to wet clay, the chemical affinity between particles is diminished forming casting slips. Thus it can be used industrially for the mass production of ceramics products by slip casting operations. When the clay slip is poured into a porous mould, commonly made of P.O.P, water from the slip is absorbed into the mould, leaving behind a solid layer or shell

on the mould wall, the thickness of which depends upon time [10].

Clay is used in many industrial processes such as paper and paint making, cement production and chemical filtering. Clay is used by the metallurgical industries due to its refractoriness in construction of kilns, furnaces, power generation and transmission and other high temperature operations. Structural clay products like building bricks, tiles, drainage pipe, sanitary, wares etc., have been used much more in building industries because they display essential properties as load-bearing strength, resistance to wear and chemical attack, attractive appearance and ability to take decorative finish [11]. Recently clays have become important for various aspects of environmental science and remediation. As research continues, clay minerals are playing an increasing role in solving modern environmental problems and meeting other needs of man.

2. Materials and Method

2.1 Materials

Three (3) different Nigerian clay samples were used in this research, namely; Kankara clay sourced from Katsina State, Barkimladi clay sourced from Barkimladi in Plateau State and Nsu clay sourced from Imo State. Chemicals/Reagents used were Na₂SiO₃ (deflocculant), Plaster of Paris Powder (P.O.P), CaSO₄ · ½ H₂O. Clean water, and sizing medium.

2.2 Methods

Each of the clay samples was crushed and ground properly with mortar and pestle. Sieving operation was carried out to obtain fine grains in accordance with sieve aperture of 0.001mm (ASTM).

Mixing of the clay with water to form clay water mixture is as shown below.

Table 1: Amount of clay constituents and water of plasticity in each specimen.

Specimen	Composition in Kg			
	Kankara clay	Barkimladi clay	Nsu clay	Water of Plasticity
K	3.00			1.11
B		3.00		1.11
K + N	1.50		1.50	1.11
B + N		1.50	1.50	1.11

Note: K = Kankara clay, B = Barkimladi clay, K + N = blend of Kankara and Nsu clays and B + N = blend of Barkimladi and Nsu clays

Deflocculation

Each specimen (K, B, K + N and B + N) was deflocculated with Na₂SiO₃ to form casting slips having low viscosity and a high solid content. The quantity of deflocculant in each specimen was approximately 0.5% of the total weight of that particular specimen. Understanding the process of deflocculation and how to measure specific gravity and viscosity, and how to adjust the slip densities are the key to controlling a slip casting process [12, 6, 13,].

Clay Castability Test

The various slip densities of the four clay slip specimens were determined using a hydrometer and result presented below.

Table 2: Slip densities of the specimen

Specimen	Clay Slip Densities (g/ml)
K	1.55
B	1.60
K + N	1.62
B + N	1.64

The clay slip was poured into the experimental set-up made up of a 100ml calibrated glass cylinder connected to a 100ml glass beaker with a hose and control tap and suction were made by the P.O.P test tiles (mould) fitted to the opening of the beaker and made air-tight with rubber strip and seal. A total of seven (7) casts were made from each clay slip specimen and the time of each cast was varied by 5 minutes interval.

3. Results and Discussion

The results of the experiment are presented in table 3 and the analysis of the numerical data showing their casting tendencies were presented graphically in Figures 1 - 8.

Table 3: Clay slip casting Result

S. No.	Time (Mins)	T ^{1/2} (Mins)	Volume of slip absorbed (ml)			
			K	B	K + N	B + N
1	0.0	0.0	0.0	0.0	0.0	0.0
2	5.0	2.2	30.0	20.0	23.0	6.0
3	10.0	3.2	43.0	29.5	34.7	14.0
4	15.0	3.9	52.5	36.0	41.0	26.0
5	20.0	4.5	60.0	41.5	47.6	31.0
6	25.0	5.0	66.5	46.0	57.1	33.0
7	30.0	5.5	67.0	48.0	58.0	36.5
8	35.0	5.9	67.5	48.5	59.0	37.0

Note: T^{1/2} = Square root of time of cast.

The results of clay slip casting (Table 3) revealed that the volume of clay slip absorbed by the mould increases with increase in time of absorption. The plot of volume of slip absorbed by the P.O.P mould against the time intervals gave a parabolic curve typical of clay casting. But the plot of the same

volume of slip absorbed against the square root of time gave a straight line, the slope of which is the rate of casting. This also means that the sucked up volume is proportional to the square root of time, (T^{1/2}). Thus the thickness of the cast layer (L) will be proportional to volume of slip sucked-up [14].

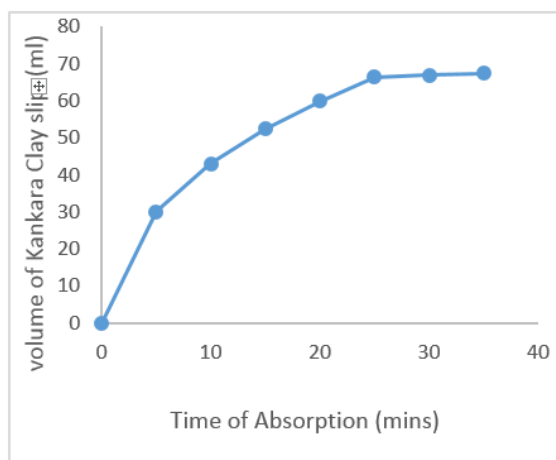


Fig 1: Volume of Kankara clay slip against time of absorption.

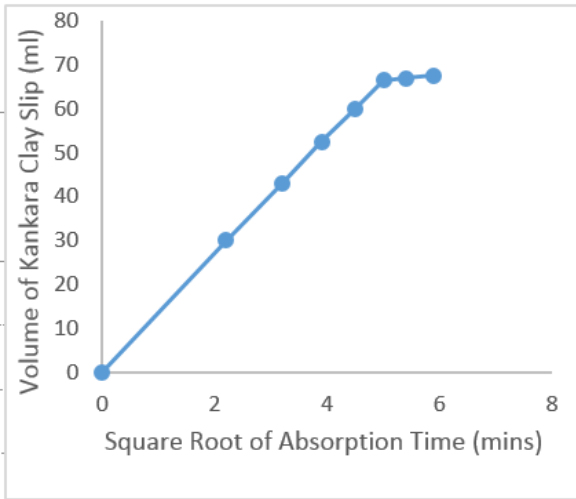


Fig 2: Volume of Kankara clay slip against square root of time of absorption

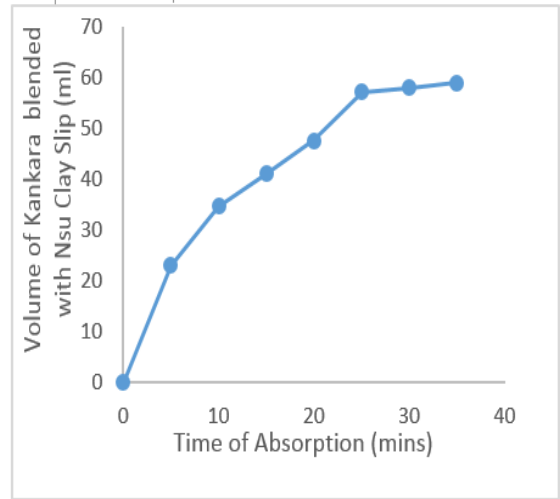


Fig 5: Volume of Kankara blended with Nsu clay slip against time of absorption.

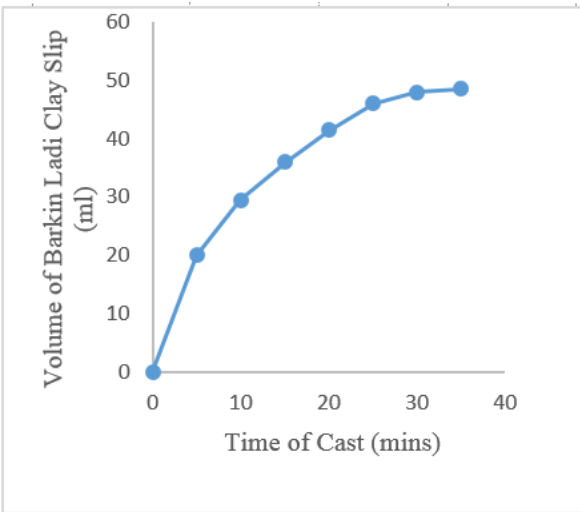


Fig 3: Volume of Barkinladi clay slip (ml) against Time of cast (mins)

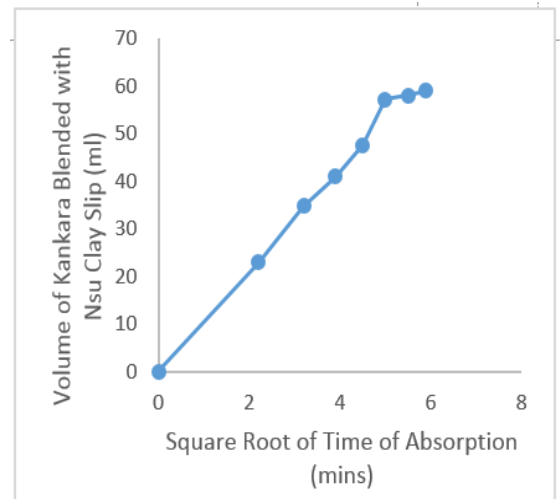


Fig 6: Volume of Kankara blended with Nsu clay slip against square root of time of absorption.

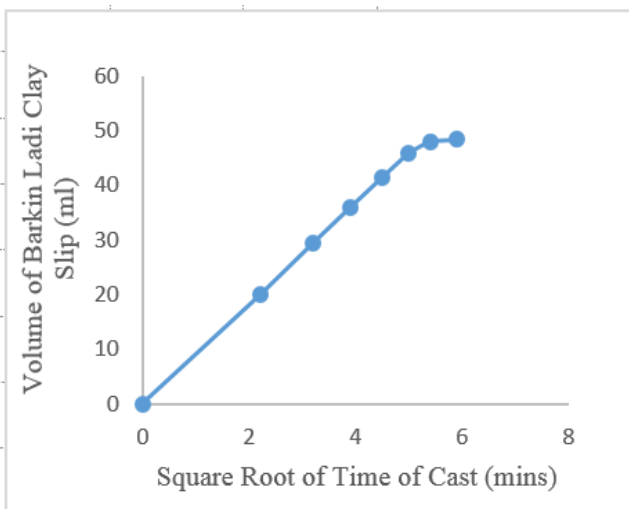


Fig 4: Volume of Barkinladi clay slip (ml) against square root of Time of cast (mins)

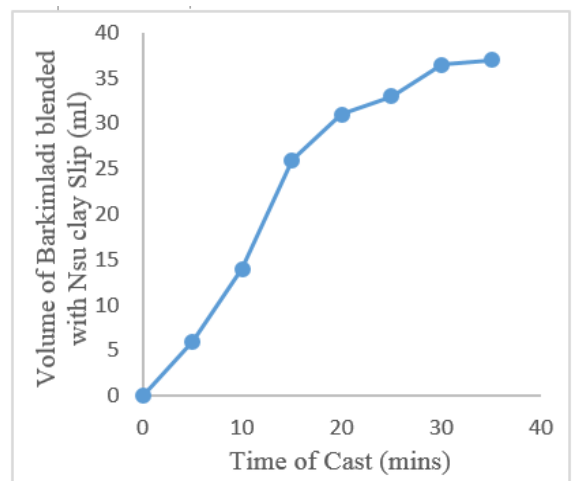


Fig 7: Volume of Barkinladi blended with Nsu clay slip (ml) against Time of cast (mins)

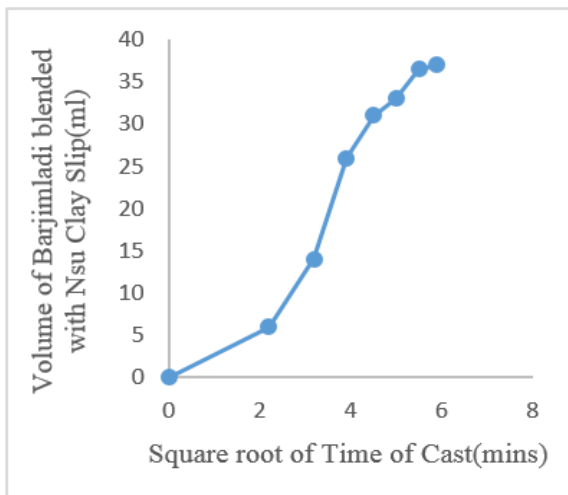


Fig 8: Volume of Barkinladi blended with Nsu clay slip (ml) against square root of Time of cast (mins)

From figures 1 & 2, the large volume of clay slip (13.3ml/min) absorbed by the P.O.P. mould, shows that a thick cast was obtained, and this suggests that Kankara clay have very coarse particles. The rate of casting is fast within a reasonable time. A closer examination of such coarse grained clay may also reveal that they are porous and will shrink remarkably on drying and subsequent firing. Such clay needed to be closed up with fine grained clay particles.

From figures 3 & 4, good cast thickness was formed within a short time (9.3ml/min). This suggest that Barkin Ladi clay particles are neither very coarse nor porous. Therefore, it will yield only slight shrinkage on drying and firing of the cast piece. This clay sample may not need any extensive treatment of blending with other clays since the grains are not too fine nor too coarse.

From figures 5 & 6, it was observed that a thick cast (10.7ml/min) was obtained but not as thick as the case of Kankara clay alone (13.3ml/min). This is an indication that after blending with Nsu clay, the clay particles are no more-coarse grained as was in the case of Kankara clay only. The solid content of the clay slip are now well dispersed such that it can cast quite easily in minimum time interval. A piece of casting from the slip will on drying and subsequent firing yield only slight shrinkage, since the porous grains have been closed up to an extent with Nsu clay addition.

The plot of the volume of Barkin Ladi blended with Nsu clay slip sucked up by the P.O.P. slab against the square root of time gives a straight line whose gradient (6.5ml/min) indicated a very slow rate of casting (Figure 8). Since the rate of casting is proportional to the cast thickness formed, a very thin casting was obtained after an appreciable period compared to Barkin Ladi clay slip alone. This suggests that the clay particles are very fine grained, plastic and nonporous. Thus it needed to be opened up with coarse whitish kaolinitic clays.

Its parabolic curve (Figure 7) also showed a reduced tendency to cast well. The hydrometer reading for this sample is high (1.64g/ml), showing an increase in viscosity which slowed down the ease for slip casting.

4. Conclusion and Recommendation

4.1 Findings

After the examination of the clay slip castability test results,

the following observations were made:

The volume of slip absorbed by the P.O.P. mould in each case is proportional to the square root of time of absorption. Hence the rate of casting is also proportional to the thickness of cast formed.

The Kankara clay slip specimen produced a very thick casting in the shortest time, which indicates coarseness of the grain particles and open nature of the grain arrangement. Thus, this clay needs to be closed up with fine grained clay particles.

Nsu clay was very successful in closing up coarse grained clay sample, this is indicative of the casting rate obtained by blending Kankara clay with Nsu clay (Specimen K + N).

Specimens B and K + N produced a reasonably thick cast within an economically feasible time, therefore can be recommended for use in industries.

The blend of Barkin Ladi with Nsu clay have a very slow rate of casting and yielded a very fine grained plastic and closed up cast, which needed to be opened up or other mixture (percentages) should be tried.

There was commonly for these specimens a reduction in the volume of slip absorbed as time increased from 25 to 35 minutes (Table 3), showing that casting mechanism had ceased.

4.2 Recommendations

Based on the observations and findings from the study of casting characteristics of these local clays, the researchers strongly recommend the following.

That specimens B, K and K + N have good casing behaviours, and therefore are recommendable for industrial productions. But for better quality cast at an economically feasible time, Barkin ladi clay and Kankara blended with Nsu clay are preferred.

Further researches should be made to study the vast clay raw materials in the nation and appropriate data kept for industrial application.

5. Acknowledgement

The authors express their profound gratitude to mr. Onu Kius C. of Project Development Agency (PRODA), Enugu for his technical assistance.

6. References

1. Nurudeen S, Abdulkarim SA, Ala'a HA, Mohammed D, Baba YJ. Metakaolinitization Effect on Kankara Kaolin. Proceedings of the 14th Nigerian Materials Congress, Annual Conference of the Material Science & Technology Society of Nigeria (MSN), Uyo, 2015, 22-26.
2. Ovri JEO, Onuoha C. Characterization of some Nigerian Local Clays for Electrical Porcelain Applications. Proceedings of the 31st Annual Conference of the Nigerian Metallurgical Society (NMS), Abuja, 2015, 28-30.
3. Omotoyinbo JA, Oluwole OO. Working Properties of Some Selected Refractory Clay Deposit in South Western Nigeria. Journal of Minerals and Materials Characterization and Engineering, 2008.7(3):233-245.
4. Nnuka E E, Ogo DUI, Oseni MI. Characteristics and the Application of Some Indigenous Clays in Nigeria. Journal of Agriculture Science and Technology, 2003; 13(2):128-135.
5. Nnuka EE, Okunoye FA. Industrial Potentials of Ukpor Clay. Proceedings of the Annual Conference of NMS 1991, 34-39.

6. Hansen T. Understanding the Deflocculating Process in Slip Casting. Technical Article Accessed, 2008, from <http://digitalfire.com>. August, 2015.
7. Rhodes D. Clay, Glazes for the Potter. Pitman Publishing Company, SA. Ltd. 1973, 6-71:306-311.
8. Worrall WE. Clay and Ceramic Raw Materials. Applied Science Publications Ltd, London 1975, 24-127.
9. Lawrence WG. Ceramic Science for the Potter. Chilton Book Company USA, 1972, 33-80.
10. Landon TE, Thomas RJ. Physical Properties of Commercial Casting Slips. H C. Spinks Clay Company Article, 1997, 1-3.
11. Rastelli E, Salmoni A, Fregni A, Stamenkovic I. Influence of Calcium Phosphate on Rheological Properties of Sanitary Ware Slip. *Advances in Applied Ceramics*, 2008; 107(2):76-82.
12. Edoziuno FO, Odo JU, Akaeze MC, Umeohia NO. Evaluation of the Casting Characteristics of a Blend of Two Nigerian Clays for Industrial Application. *Proceedings of the 31st Annual Conference of the Nigerian Metallurgical Society (NMS)*, Abuja 2015, 28-30.
13. Evcin A, Orencik S, Kavas T. Effects of Inorganic Salts on Rheological Properties of Slips. *Key Engineering Materials*, 2004. 264-268:1609-1612.
14. Zhang Y, Binner J. Enhanced Casting Rate by Dynamic Heating during Slip Casting, *Journal of the European Ceramic Society*, 2002; 22(1):135-142.
15. Grim RE, Cuthberth LF. Illinois State Geological Survey Report 103. *Journal of American Ceramic Society*, 1945, 28(3).
16. Nnuka EE, Agbo UJE. Evaluation of the Refractory Characterization of Otukpo Clay Deposit. *NSE Technical Transactions*, 1991; 35(1):32-40.