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# Characterization of River Niger (Idah Deposit), Ochadamu and Uwowo Sands for Foundry Mould Production

[1]Aji D. A., [2]Igu N., [2]Oseni M. I., [1]Apata A. O., and [1]Baba G.

[1]Department of Metallurgical and Materials Engineering
Federal Polytechnic Idah, Nigeria.
[2]Department of Mechanical Engineering
University of Agriculture, Makurdi, Nigeria.

**Corresponding Author: Apata A. O**

**Abstract**
Characterization of River Niger (Idah deposit), Ochadamu and Uwowo Sands has been carried out to ascertain their suitability for foundry mould production. The sand samples were subjected to both physical (Green compressive strength, Green shear strength, Dry compressive strength, Dry shear strength, Permeability, Compactibility, Refractoriness and Sieve analysis) and chemical test (Energy Dispersive X-Ray Fluorescence Spectrometer). Permeability and compactibility of the sand samples compared favorably with standard values of 200ml/s and 45% respectively. Refractoriness of River Niger and Ochadamu sands compared favorably with the standard values of between 1600 – 2500$^{o}$C and therefore can be used for ferrous and non-ferrous castings. Refractoriness of Uwowo sand is low and can only be used for non-ferrous castings. The chemical analysis of the sand samples compared favorably with the standard (AFS). From the results it showed that, River Niger and Ochadamu sands are silica because of their high silica content. The three Sand samples were used to sand cast aluminium product, their hardness and tensile strengths as well as the microstructural analysis of the cast products were determined. Both the Hardness and Tensile Strength values are within the standard values of 35 – 120 Hv10 and 100 – 500 N/mm$^2$ respectively. The microstructure of the cast agreed with the Hardness and Tensile strength results. Fine grained materials show high Hardness and Tensile strength values, while coarse grained materials show lower hardness and tensile strength values.

**Keywords:** foundry, sands deposit, composition, chemical and physical properties, refractoriness

## INTRODUCTION

Foundries are work establishments where ferrous and non-ferrous metals are melted by application of heat and then cooled in a mould to yield a solid mass. This solidified metal takes the shape of the pattern cavity made in a mould. The pattern itself is a replica of the object which the foundry man wants to produce (Asuquo and Bobojama, 1991). The technique of melting and cooling a metal to give a desired product is known as casting. The furnace used in melting, tools and accessories as well as the shop floor on which castings are made constitute the foundry.

The suitability of any particular sand for foundry mould production is determined by the properties and composition it possesses. These properties and composition are of great importance to both foundry engineers and technologists. Therefore, adequate investigations on sand are necessary before embarking on mould production. Sand may be defined as a granular particles resulting from the breaking down of rocks due to the action of natural forces such as frost, wind, rain, heat and water. Sand is the most essential ingredient in the foundry shop. It is used for all types of casting irrespective of whether the cast material is ferrous or non-ferrous metal.

Moulding sand ingredients consist essentially of the sand as base material, clay, cassava starch or bentonite can be used as bonding material; water for strength and plasticity and other additives for special purposes.

River Niger (Idah deposit), Ochadamu and Uwowo sand deposit are located in Igala land in Kogi State of Nigeria. The sand deposit has being used for many years by local foundry men for the casting of various house-hold items and small scale industrial goods of various sizes. The sand has been generating employment through the production of cast aluminium pots, commercial frying pan, electric motor fan and other simple shapes aluminium components.

The local foundry men have been using this without the knowledge of its physical, chemical and foundry (moulding) properties. Except these characteristics of the sand are known, it will be very difficult to use the sand and achieve the desired results. In a survey of sands used by some Nigerian foundries (RMRDC, 1989), it was established that most of these foundries are using these sands without knowing their characteristics. Therefore a research of this nature is very important and timely and this work is aimed at determining the chemical composition and physical properties of River Niger (Idah deposit) Ochadamu and Uwowo sand deposit.

## MATERIALS AND METHODS

### Materials

The sand samples were collected from River Niger (Idah deposit), Ochadamu and Uwowo sands deposit all in Igala land in Kogi State of Nigeria. The sample were collected at different locations randomly which was then thoroughly mixed by quartering conning method to obtain a representative homogeneous samples.

### Methods

#### Sand Preparation

The sand collected from each of the sites in River Niger (Idah deposit), Ochadamu and Uwowo were washed to remove clay and other impurities. The sands were allowed to dry naturally under the sun for four (4) days. Since the sands are naturally bonded no other additive was introduced into the sands prior to samples preparation other than water which was added to provide for the hydrostatic bond requirement of the sands.

#### Sieve Analysis

Sieve analysis on each of the sand sampled was carried out using a sieve shaker on which meshes of different aperture were mounted from 0.10mm being the bottom and 1.60mm at the top of the sieve. Each of the sand samples was poured on the top sieve one after the other and was shaken for 15 minutes on a sieve shaking machine.

#### Production of Test Samples

The foundry properties of the sands were determined by preparing sixteen (16) test samples. The test specimens were prepared using Rids dale Standard sand rammer conforming to imperial (2"Dram x Height) or DIN (5cm Diam x Height) standard specification for preparation and testing of sand. The prepared specimens were used to test for the following foundry physical properties: Green Compression Strength (GCS), Green Shear Strength (GSS), Dry Compression Strength (DCS), Dry Shear Strength (DSS), permeability, compatibility and Refractoriness.

#### Chemical Analysis of the Sand Samples

The percentage composition of the constituent elements in its oxide form in the sand that would make it suitable for foundry operation were determined using ED-XRF (Energy Dispersive X-ray fluorescence spectrometer)

#### Production of Cast Specimen

Cast specimens were made using the three sand samples. It was mounted in bakelite and mechanically ground progressively on grades of SiC impregnated emery paper (120 – 1200 grits) using water as the coolant. The specimens were then polished using one-micron size alumina polishing powder suspended in distilled water. The microstructures of samples were obtained using software driven optical microscope. Hardness test and Tensile strength were carried out on the cast samples.

## RESULTS AND DISCUSSION

The results of the carried out experimental works are presented in Table 1–4 and Figures 1a–c and are discussed as follows.

#### Physical Observation of Sand Samples

River Niger Sand (Idah deposit) contained large amount of mixture of coarse and fine particles. It was reddish brown in colour and had very sharp particle size. The mixture of coarse and fine particles was as a result of the flowing river and the colour was as a result of large amount of Silica. This was in agreement with Akoje (2008) who worked on the river Niger analysis of Ibaji deposit.

Ochadamu Sand contained coarse grain size. It was whitish coloured sand with equally distributed round coarse grain particle size which was as a result of the Hilly deposit.

Uwowo sand was grey in colour. It was very friable and easy to crush. The particle size was very fine and powdery when rubbed between the fingers. The grey colour was as a result of high alumina and titanium oxide content in the sand.

#### Sieve Analysis of Sand Samples

From the sieve analysis (Table 1), Uwowo sand was finer than River Niger sand and River Niger Sand was finer than Ochadamu Sand. This is as a result of grain size and distribution. Fineness is required in the moulding sand for the prevention of metal penetration and the production of smooth casting surfaces. It could be seen also that the cast using Uwowo sand mould had smooth surfaces as a result of its fineness (Figure 1c compare to Figure 1a and b). Uwowo sand sample had good Grain Fineness Number (GFN) 90.19 which is compared favorably with American Foundry Society (AFS) standard of 100. However Idah and Ochadamu sand with GFN 36.14 and 35.22 respectively are not compared favourably with American standard. It showed that the finer the sand particles, the more the grain fineness number and the coarser the sand particles, the less the grain fineness number.

Table 1: Particle size distribution of Idah, Ochadamu and Uwowo Sand deposit

| Sieve No (mm) | % Wt Retained | | | Multiplier | Product | | |
|---|---|---|---|---|---|---|---|
| | Idah deposite | Ochadamu deposit | Uwowo deposit | | Idah deposit | Ochadamu deposit | Uwowo deposit |
| 1.60 | 0 | 0 | 0 | 5 | 0 | 0 | 0 |
| 1.00 | 13.5 | 14.5 | 0.01 | 10 | 135 | 145 | 1 |
| 0.71 | 24.0 | 24.1 | 0.14 | 20 | 480 | 482 | 2.8 |
| 0.63 | 8.5 | 9.0 | 1.00 | 30 | 255 | 270 | 30.0 |
| 0.40 | 29.5 | 29.5 | 2.24 | 40 | 1180 | 1180 | 89.6 |
| 0.31 | 7.5 | 7.0 | 16.15 | 50 | 375 | 350 | 807.5 |
| 0.20 | 6.0 | 6.5 | 32.59 | 70 | 420 | 455 | 2281.3 |
| 0.16 | 1.5 | 1.5 | 30.77 | 100 | 150 | 150 | 3077 |
| 0.12 | 1.2 | 1.2 | 11.05 | 140 | 168 | 168 | 1547 |
| 0.10 | 0.6 | 0.2 | 2.02 | 200 | 120 | 40 | 404 |
| Pan | 0.2 | 0.2 | 1.98 | 300 | 60 | 60 | 594 |
| | 92.5 | 93.7 | 97.95 | | 3343 | 3300 | 8834.2 |
| | | Grain Fineness Number (GFN) | | | 36.14 | 35.22 | 90.19 |

**Physical Analysis of Sand Samples**

The results showed that River Niger Sand (Idah deposit) was found to have green compression strength of 0.001 Pa, dry compression strength of 0.54 Pa, and dry shear strength of 0.261 Pa. Ochadamu sand had green compression strength of 0.036 Pa, green shear strength of 0.001 Pa, dry compression strength of 0.418 Pa, and dry shear strength of 0.330 Pa. Uwowo sand had green compression strength of 0.093 Pa, green shear strength of 0.012 Pa, dry compression strength of 0.137 Pa, and dry shear strength of 0.069 Pa.

The need for physical analysis arises when the pattern is withdrawn and the mould must retain shape independently without distortion or collapse. The result showed that the three sand samples had good foundry properties, but deviated slightly from standard value of 0.031-0.041 Pa for green compressive strength and 0.137 - 0.207 Pa for dry compressive strength according to Beeley (1972). The physical properties of the sand could be enhanced to meet up with standard by the addition of a good binding agent.

From the analysis, River Niger Sand was more permeable than Ochadamu Sand and Ochadamu Sand was more permeable than Uwowo Sand. This was as a result of the fact that River Niger Sand contained a mixture of coarse and fine sand particles. Therefore, the sand became more porous than Ochadamu and Uwowo Sand samples. This was in agreement with Jain (2008) and Bam (2006), who observed that the sand used for casting must be porous enough, so as to allow the gases, water and steam vapour to escape freely when the molten metal is poured into the mould. Molten metal contains some dissolved gases which are evolved on solidification. Further, molten metal in contact with moist sand forms steam and vapour which must find passage to escape completely. Insufficient porosity of moulding sand leads to casting defects such as blow holes and pores. The permeability of River Niger Sand and Ochadamu Sand did not compare favourably with standard value of 8-30ml/s for Non-ferrous metals and 65-200 ml/s for ferrous metals. The permeability of Uwowo sand sample compared favourably with standard value of 65ml/s according to Burns (1986). Ochadamu and Uwowo Sand moulds should be adequately dried of moisture before pouring of liquid metal. Uwowo Sand that had lower permeability can be used for the production of cores.

From the analysis, Uwowo Sand had a higher compactibility than Ochadamu and River Niger Sand. Compactibility was a direct measure of the degree of temper water of the sand. This was in agreement with Jain (2006) who observed that as the composition of the system sand changes, the moisture must change to maintain the desired moulding characteristics, indicated by the compactibility level. Compactibility level is selected on the basis of moulding performance and casting quality. Its value is maintained through appropriate adjustments in moisture additions. High compactibility would indicate voids on the vertical faces of the mould. Low compactibility would render the sand friable and subject to cuts and washes.

The compactibility of Uwowo Sand sample compared favourably with standard value of 45-52% according to Burns (1986). The finer the sand particles, the higher the compactibility.

Analysis showed that River Niger sand had refractoriness slightly higher than Ochadamu sand. Uwowo sand had the lowest refractoriness. At a temperature of $1,500^0$C, River Niger and Ochadamu sand do not change colour and do not sinter. Both sand sinter between $1,720$-$1750^0$C. At this temperature, both sands did not change colour but separates when cooled. Uwowo sand changed colour to brownish red at $1,200^0$C and the sand sintered at this temperature. This was in agreement with Olufeagba (1982) who observed that the ability of a moulding sand to withstand high heat without breaking down or fusing is known as its refractoriness. Sand with poor refractoriness may burn at high temperature. The fusion point of moulding sand can be increased by removing the impurities, particularly metallic oxides. Sand also should not form glassy mass which hampers stripping.

The reason for the high refractoriness of River Niger and Ochadamu sands was possibly as a result of the presence of large percentage of silica than alumina. Both sand could be used for ferrous and non-ferrous castings. Due to the low refractoriness of Uwowo sand, it could only be used for non-ferrous castings as it could not withstand a temperature of 1,539$^0$C being the melting point of iron. The low refractoriness of Uwowo sand could possibly be traced to its high titanium oxide ($TiO_2$) of 4.01% as against the standard of 0.12-0.43% according to Beeley (1972). The high value of $TiO_2$ also prevented veining and penetration of metal into the mould. However, the refractoriness of Uwowo sand was raised by the addition of zircon sand so that it can be used for ferrous castings.

Table 2: Physical Analysis of sand samples

| Sand sample | G.C.S. (Pa) | G.S.S. (Pa) | D.C.S. (Pa) | D.S.S. (Pa) | Permeability (ml/s) | Compactibility (%) | Refractoriness ($^0$C) |
|---|---|---|---|---|---|---|---|
| Idah | 0.017 | 0.001 | 0.57 | 0.261 | 450 | 33 | 1750 |
| Ochadamu | 0.036 | 0.001 | 0.418 | 0.330 | 310 | 43.3 | 1720 |
| Uwowo | 0.093 | 0.012 | 0.137 | 0.069 | 69 | 45 | 1260 |

**Chemical Analysis**

The chemical compositions of the sands deposit are shown in Table 3. From the analysis, it revealed that River Niger and Ochadamu sands were silica sands due to large amount of silica present in the sand. Both sands needed a binder during moulding operation. Uwowo sand contained less of silica and more of alumina and therefore, it can be called natural foundry sand (it needs no additional binder during moulding operation). The chemical analysis of the sand was aimed at determining the constituent elements in its oxide form in the sand that would make it suitable for foundry operation. The chemical composition of the three sand samples compared favourably with standard sand in Table 4 according to AFS (2007).

Table 3: Chemical composition of Idah, Ochadamu and Uwowo Sand deposit.

| **Component** | **% Composition** | | |
|---|---|---|---|
| | **Idah Sand** | **Ochadamu Sand** | **Uwowo Sand** |
| Aluminium Oxide ($Al_2O_3$) | 0.45 | 0.55 | 7.90 |
| Silicon Oxide ($SiO_2$) | 96.20 | 95.30 | 85.00 |
| Potassium Oxide ($K_2O$) | 0.06 | 0.06 | 0.12 |
| Calcium Oxide (CaO) | 0.22 | 0.24 | 0.28 |
| Manganese Oxide (MnO) | 0.18 | 0.16 | 0.12 |
| Iron Oxide ($Fe_2O_3$) | 1.46 | 1.35 | 1.91 |
| Magnesium Oxide (MgO) | 0.18 | 0.16 | 0.12 |
| Titanium Oxide ($TiO_2$) | 0.13 | 0.14 | 4.01 |
| Chromium Oxide ($Cr_2O_3$) | 0.01 | 0.01 | 0.25 |
| Sodium Oxide ($NaO_2$) | 0.04 | 0.06 | 0.04 |
| Zirconium Oxide ($ZrO_2$) | 0.02 | 1.98 | 0.27 |
| Copper Oxide (CuO) | 0.03 | 0.13 | 0.06 |

Table 4: Chemical composition of a typical Foundry sand

| **Component** | **% Composition** | |
|---|---|---|
| | **Chelford ws** | **Mansfield** |
| Aluminium Oxide ($Al_2O_3$) | 1.13 | 10.12 |
| Silicon Oxide ($SiO_2$) | 97.91 | 78.20 |
| Calcium Oxide (CaO) | 0.11 | 2.40 |
| Iron Oxide ($Fe_2O_3$) | 0.50 | - |
| Magnesium Oxide (MgO) | 0.02 | 1.80 |
| Titanium Oxide ($TiO_2$) | 0.04 | - |
| Sodium Oxide ($NaO_2$) | 0.07 | 0.20 |
| $Ka_2O$ | 0.65 | 3.10 |
| Loss on ignition | 0.21 | 4.10 |

**Mechanical Properties of the Cast Products**

The results showed that cast product using Uwowo sand mould, had a higher hardness value than casts using Idah and Ochadamu sand moulds (Table 5). The high hardness value using Uwowo sand mould could possibly be traced to the high value of compactibility. Analysis also showed that the smaller the indentation the higher the hardness value. The wider the indentation mark, the softer the material and the smaller the hardness value in agreement with Oahkhinan (2005).

Cast using Uwowo sand mould was found to have a higher tensile strength than River Niger and Ochadamu sand moulds. This mechanical property indicated the strength and ductility of the material under the application of a tensile load. The tensile test helped in determining the tensile properties such as tensile strength, yield point or yield strength, percentage elongation, percentage reduction in area and modulus of elasticity according to Khanna (2009). Analysis showed that the higher the hardness value, the higher the tensile strength and vice versa. Cast using Uwowo sand mould was found to have high hardness value and as such had higher tensile strength than River Niger and Ochadamu sand moulds. The low tensile strength of cast using Ochadamu sand mould was as a result of its coarse nature.

Table 5: Mechanical properties of the cast products

| Sand Samples | Hardness ($HV_{10}$) | Tensile Strength ($N/mm^2$) |
|---|---|---|
| River Niger | 48.1 | 162.69 |
| Ochadamu | 46.3 | 161.97 |
| Uwowo | 90.3 | 170.96 |

**Microstructural Analysis of Cast Products**

The microstructural analysis showed that Uwowo sand cast product had fine grain structure than using River Niger and Ochadamu sand moulds (Figures 1c vs a and b). River Niger and Ochadamu sand cast products had coarse grains (Figures 1a and b) This was in agreement with Khanna (2009), who observed that fine grained materials possess higher strength, toughness, hardness and resistance to suddenly applied force. Fine grained materials also possess better fatigue resistance and impact strength. Fine grained materials are more crack-resistant and provide better finish in deep drawing unlike coarse grained ones which gives rise to orange-peel effect. A coarse grained material is responsible for surface roughness. A coarse grained also possesses more ductility, malleability and better machinability. This is evident as can be seen from the results of hardness, tensile strength and microstructure of cast using Uwowo sand mould. The finer the grain structure, the harder the material and the higher the tensile strength. In the same vein, the fine grain structure of Uwowo sand cast sample was as a result of its rapid rate of heat extraction from the liquid metal which generates fine grains. Fine grain structure results in high hardness, tensile strength and toughness. A coarse grain structure possess more ductility, malleability and better machinability. It could be said that River Niger and Ochadamu Sand cast products were more ductile, malleable and better machinability than Uwowo sand mould product.

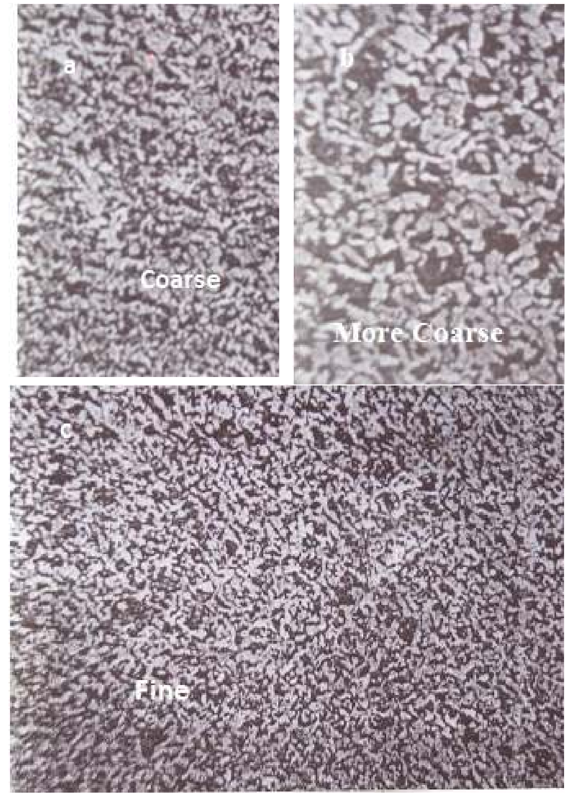


Figure 1: Microstructure of Aluminium cast using (a) River Niger Mould (coarse) (b) Ochadamu Sand Mould (more coarse) and (c) Uwowo Sand Mould (fine). Nital etched x100.

**CONCLUSIONS**

River Niger (Idah deposit), Ochadamu and Uwowo sands have been analyzed. Physical, chemical, Mechanical and Microstructural analyses were carried out.

The following conclusions are drawn:

i. River Niger sand (Idah deposit) contains 96.20% Silica and 0.45% alumina and it is classified as silica sand. It can be used for both ferrous and non-ferrous castings.
ii. Ochadamu sand contains 95.30% silica and 0.55% alumina and it is classified as silica sand. It can be used for both ferrous and non-ferrous castings.
iii. Uwowo sand contains 86% silica and 7.90% alumina and it is classified as natural foundry sand as it needs no additional binding agent due to high alumina content. The sand can only be used for non-ferrous castings due to its low refractoriness.
iv. Addition of zircon sand to Uwowo sand improved refractoriness.

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