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# AN INVESTIGATION ON THE FOUNDRY CHARACTERISTICS OF UPPER RIVER BENUE SAND

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## ABSTRACT

Foundry properties of upper River Benue sand were determined. Two categories of samples, A and B were prepared. Sample A contained 40g of $H_2O$, 40g of bentonite in 1000g of silica sand while sample B contained 50g of $H_2O$, 50g of bentonite in 1000g of silica sand. Seven specimens each were produced from both samples for various tests. The results show that the permeability for sample A is 135 while that for sample B is 128. The compactability is 45% for sample A and 50% for sample B. The mouldability indices are 3.5 for sample A and 2.1 for sample B. The moisture contents are 3.1% and 4.7% in samples A and B, respectively. The green and dry compressive strengths are 39.37kN/m$^2$ and 1241.06kN/m$^2$ for sample A and 42.13kN/m$^2$ and 1413.43kN/m$^2$ for sample B respectively. The green and dry shear strengths are 9.03kN/m$^2$ and 268.9kN/m$^2$ for sample A and 9.72kN/m$^2$ and 310.26kN/m$^2$ for sample B respectively. These results conform to the AFS standard for foundry hence upper River Benue sand is considered suitable for foundry work.


**KEYWORDS:** Sand, Mouldability, Compactability, Refractoriness, Grain

## INTRODUCTION

Foundries are work establishments where ferrous and non-ferrous metals are first of all caused to be molten by the application of heat in a furnace and then cooled in a mould to yield a unit solid mass (Shrayer,1949). In foundry practice, the quality of cast metal is dependent on the quality of mould and the grade of sand which may be fine, medium or coarse grain grade (Gupta, 1992). Moulding sand consists principally of sand, clays, water and additives. These ingredients when properly mulled or mixed together in the right proportions increase the plasticity and green strength of the sand. Basically, two types of sand exist and these are natural or synthetic sands. In natural sand, the only binders are water of about 6-8% and clay of about 18-30%. Synthetic sands are artificially prepared in foundry by mixing clay free sand, binder (water and bentonite) and other materials as required.

Irrespective of the sand, modern day foundry takes into consideration certain important factors and characteristics of the sand which has helped to produce products with better dimensional accuracy, surface finish and high strength of castings. Some of the basic characteristics of foundry sand includes permeability, refractoriness, grain size distribution, grain shape, green and dry shear strengths, green and dry compressive strengths, compactability of the sand, moisture content, chemical resistance, electrical conductivity, thermal shock resistance of sand, and mouldability of the sand (Burns, 1986).

Grain shape may be angular, sub-angular, round, or compound. When rammed, round grains have least contact with one another; have high permeability and low strength. Angular grains have defined edges. They give more strength and have low permeability and can interlock more easily. The compound grains are the combination of round and angular grain (Gupta, 1992). Silica sand being moulding sand is granulated in size. The size of moulding sand range from 53 to 4000μm and the shape could be spherical, angular, sub-angular, or compound (Niebel *et al*, 1989).

According to Gupta (1992), sands generally are specified based on their average size and shape. Grain size and shape affect both the escape of gases evolving from the molten metal and the surface texture of the sand. Fine sand grains are closer to each other and impart more strength to the mould hence they are desirable for small and intricate casting in which all the details of the mould are brought out more sharply. Fine sands with A.F.S GNS of 80-120 are hence used for aluminium casting (Niebel *et al*, 1989). Medium size grain with GNS of 60-70 is used for large casting 4.54-45.36kg where accuracy is not of much importance. Coarse size grains having A.F.S, GNS of 35-40 are more suitable for steel casting since they are able to withstand the elevated temperature of steel compared to fine grains which get burnt-out at elevated temperature (Niebel *et al*, 1989).

Grain size greatly influences the surface finish of a casting. The proper grain size is determined by the size of the casting (small, medium or heavy casting), the quality of the surface required and the surface tension of the molten metal. The AFS standard for the strength of casting sand meant for various castings is available in literature. Burns (1986) gave the range of properties of foundry sand as follows: green shear strength, 3.45-10.3kN/m$^2$; dry shear strength, 206.84-379.21kN/m$^2$; green compressive strength, 31.03-48.26kN/m$^2$; dry compressive strength, 1310.00-2688.96kN/m$^2$ for small and medium castings and as much as over 3447.38kN/m$^2$ for heavy castings. The refractory range of silica sand is 1500-1850$^o$C.

In foundry/casting processes, sand is one of the cheapest raw materials employed with the silica sand more frequently employed than any other type of sand such as quartz, zirconium, fosterite, etc because of its lower cost and availability (Gupta, 1992). According to Nwachukwu and Nwajagu (1998), a good sand casting cannot be made without a good mould and a good mould is dependent on the desired foundry properties of the sand mixtures. In addition, efficient sand control is a very important factor in the production of quality casting and reduction of the production cost through minimising defects in casting (Nwachukwu and Nwajagu, 1998). Therefore, foundry properties were determined experimentally to ascertain the suitability of upper River Benue sand for foundry work.

## MATERIALS AND METHODS

### Materials, Equipment, Tools and Apparatus

The major materials used for this study are silica sand, distilled water, bentonite, moulded sand sample and NaOH.

The equipment and tools used for this study include permeability tester, sand rammer, electric furnace, weighing balance, ramming machine, cylindrical tube, muffler furnace, steel needle, porcelain dish, magnifying glass, beaker, moulding machine equipped with net, dark board, microscope, horizontal holder grip, electric oven. Others are A.F.S standard sieve, time clock, collector pan, jar, stirrer, universal strength testing machine, and holder.

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**Sand Sample Preparation**

Sand sample weighing 10kg was collected from the bank of River Benue in Yola at 5 different locations and then mixed together to attain uniform distribution and homogeneity of the sand. The sand was then washed with distilled water and sun dried for about 4 days. Thereafter, 1000g of the sand mixture was weighed out and mixed with 40g of bentonite and 40g of water and the resultant product was designated as sample A. Another 1000g of sand was also collected and mixed with 50g of water and 50g of bentonite; the mixture was designated as sample B.

**Determination of Permeability**

Some quantity of sample A was placed in a 5mm diameter rammer tube of 12cm height and was rammed three times using a weight lever of 5kgf. The resulting specimen in tube was then placed on a permeability testing machine (Electric Permmeter) and the machine was then switched on. The lever was adjusted to "Test" and control volume of air pressure of $9.8 \times 10^2 N/m^2$ was applied for 15 seconds. The pointer became stable indicating the permeability number of the sand. The experiment was repeated for sample B.

**Compactability Determination**

Compactability was determined using the sand rammer attached with a compactability scale. Silica sand was poured into the cylindrical ramming tube whose height is known using specimen hopper with a strike which was used to remove the excess sand. The specimen tube was then placed in a ramming machine and five repeated impacts were delivered with the aid of a hand lever weight. The compactability was then indicated by the compactability scale.

**Determination of Refractoriness**

Some quantity of sand sample was washed with distilled water to remove impurities inherent in it. It was then sun dried for about 4-5 hours after which 100g of the sample was weighed out and placed in a porcelain dish in an electric furnace. The sample was initially heated to a temperature of 1000°C then raised in steps of 100°C to 1300°C and finally raised in steps of 50°C until sintering occurred. At each temperature level, the sample was kept for at least 3 minutes and then taken out of the oven for examination with the aid of a magnifying glass for surface characteristics and to know if sintering has occurred by scratching with a steel needle.

**Determination of Mouldability**

The standard sample prepared was cylindrical in shape. The sample was weighed and noted. It was then placed in a moulding machine having nets and the machine was then switched on and allowed to rotate for a definite period of time (30s). The quantity of sand which passed through the net was collected, weighed and noted.

The ratio of the loss in weight to the original weight expressed in % was determined as follows:

$$M_o = \frac{W - W_1}{W} \times 100$$

The mouldability index ($M_i$) according to AFS standard was found thus:

$$M_i = \frac{M_o}{2}$$

**Determination of Grain Shape**

Silica sand (100g) was measured out and washed with $1000cm^3$ of distilled water in a beaker. It was then sun dried for about 3 - 4 hours after which it was examined on a dark board with the aid of a microscope with a magnification of 50.

**Green and Dry Compressive Strength Determination**

Two samples were prepared. One was dried for 1hr in an electric oven at a temperature of 110°C. Afterwards, it was removed and allowed to cool for 1hr. Each sample was placed on a horizontal plate in a universal testing machine and the arm of the tester (wheel) was adjusted to just touch the sample. The machine was then switched on and the arm was gradually and continuously adjusted towards the specimen, that is compressive force was applied until at a point where failure of the material occurred. The value at which failure occurred was read from the calibration on the green compressive strength and noted.

**Green and Dry Shear Strength Determination**

Two samples were prepared, green and dry. The shear strength of the green sample was determined directly by placing it on the holder of the universal testing machine designed in a way that shear stress was induced on the material specimen when the hand wheel was rotated until a point where failure resulted. The failure point was noted and recorded.

For dry shear, the specimen was placed in an oven and dried to a temperature of 110°C. Afterwards, it was removed and allowed to cool in air for about 1hr. It was then placed on the flat plate on the tester and the hand wheel was rotated which induced a shear stress on the sample. The point of failure was noted and recorded.

**Determination of Grain Size Distribution**

A measured 100g of silica sand was placed on the sieve-shaking machine. The machine was switched on and allowed to vibrate for about 15min.; thereafter all the sand retained on each sieve was then collected and weighed. The product was obtained by multiplying the preceding sieve ASTM No with retained weight on the current sieve. The AFS grain fineness number (GFN) was then determined thus:

$$GFN = \frac{Total\ \ product}{Total\ \ sum\ \ of\ \ percentage\ \ collected\ \ in\ each\ \ sieve}$$

**Clay Content Determination**

To conduct this test, some silica sand was dried in an electric oven to 110°C to evaporate all the water present and 100g of the dry sample was weighed out ($W_1$). A measure of $20cm^3$ of sodium hydroxide (NaOH) and $475cm^3$ of distilled water was mixed with the sand in a jar. The content was stirred for 6 minutes and it was filled up to 6cm with water, the content was then allowed to settle for 10 minutes. The water was then siphoned off to a depth of exactly 5cm in the bottom of the jar.

This process was repeated one more time. Distilled water was added to 6cm and suspension was allowed to settle for 5 minutes. The process was repeated and particles that failed to settle at the rate of 25cm per minute were removed from the sand grain. The remaining sand in the jar was removed, dried and weighed ($W_2$). The ratio of the difference in weight to the original weight multiplied by 2 gives, according to AFS standard (Gupta, 1992), the clay content

$$Cc = \frac{W_1 - W_2}{W_1} \times 2$$

## RESULTS AND DISCUSSION

**Results**

Results of the experiments and tests are presented in Tables 1-5.

**Table 1:** Particle Size Analysis (Sieve Analysis) of Upper River Benue Sand

| S/N | Aperture (Microns) | ASTM S/No | Weight Retained, g | % Weight Retained | Cumulative % Weight Retained | Product | AFS Grain Fineness Number |
|---|---|---|---|---|---|---|---|
| 1 | 1400 | 14 | 1.11 | 1.11 | 1.11 | 0.00 | 35.45 |
| 2 | 1000 | 18 | 2.59 | 2.59 | 3.70 | 36.26 | |
| 3 | 710 | 25 | 11.35 | 11.35 | 15.05 | 204.30 | |
| 4 | 500 | 35 | 25.80 | 25.80 | 40.85 | 645.00 | |
| 5 | 355 | 45 | 37.72 | 37.72 | 78.58 | 1320.20 | |
| 6 | 250 | 60 | 14.91 | 14.91 | 93.48 | 670.95 | |
| 7 | 180 | 80 | 2.80 | 2.80 | 96.28 | 168.00 | |
| 8 | 125 | 120 | 0.89 | 0.89 | 97.17 | 71.20 | |
| 9 | 90 | 170 | 1.14 | 1.14 | 98.31 | 136.80 | |
| 10 | 63 | 230 | 1.60 | 1.60 | 99.91 | 272.00 | |
| 11 | -63 Pan | -230 Pan | 0.09 | 0.09 | 100.00 | 20.70 | |
| Total | | | | | 100.00 | 3545.51 | |

Table 2: Mouldability of Upper River Benue Sand Samples

| S/No | Sample | Initial weight w (g) | Final weight $w_1$ (g) | Mo | Mi |
|---|---|---|---|---|---|
| 1 | A | 1000 | 930 | 7.0 | 3.5 |
| 2 | B | 1000 | 958 | 4.2 | 2.1 |

**Table 3:** Permeability and Compactability of Upper River Benue Sand Samples

| S/No | Sample | Permeability number | Compactability, % |
|---|---|---|---|
| 1 | A | 135 | 45 |
| 2 | B | 128 | 50 |

**Table 4:** Clay Content of Upper River Benue Sand

| S/No | Initial weight $w_1$ (g) | Final weight $w_2$ (g) | Cc, % |
|---|---|---|---|
| 1. | 100 | 99.76 | 0.48 |

The summary of results of all the various tests conducted on River Benue sand is given in Table 5.

**Table 5:** Moulding Mixture Property of Upper River Benue Sand Samples

| S/No | Properties | Sample A | Sample B |
|---|---|---|---|
| 1 | Compactability, % | 45 | 50 |
| 2 | Mouldability index | 3.5 | 2.1 |
| 3 | Green shear strength (GSS), kN/m$^2$ | 9.03 | 9.72 |
| 4 | Green compressive strength (GCS), kN/m$^2$ | 39.37 | 42.13 |
| 5 | Dry shear strength (DSS), kN/m$^2$ | 268.9 | 310.26 |
| 6 | Dry compressive strength (DCS), kN/m$^2$ | 1241.06 | 1413.43 |
| 7 | Permeability | 135 | 128 |
| 8 | Moisture content, % | 3.1 | 4.7 |

## DISCUSSION

### *Grain Size Distribution, Grain Fineness Number, Particle Size and Shape*

The grain size distribution is as shown in Table 1. From the analysis, we can deduce that the River Benue sand is a coarse sand as it has GFN of 35.45 which satisfies the AFS Standard for coarse foundry sand with values of 35-40GFN (Niebel *et al*, 1989). It can, therefore, be used for heavy castings and to cast steels since the particles size is large and is sub-angular in shape hence the particles can interlock more easily thereby giving more rigidity and strength to the sand. Coarse grain size and too open texture encourage metal penetration and too fine a grade produces an ideal smooth skin which lacks the required permeability.

### *The Moisture Content of the Sand*

As obtained from the experiment, the moisture content is 3.1 for sample A and 4.7 for sample B which is satisfactory when compared to the standard obtained from literature as 2-8% moisture content (Faculty of Mechanical Engineering, PSG College of Technology, 1989). Excessive moisture content tends to increase defects in castings. As the water content is converted to steam at high temperature, its volume is increased tremendously; this excessive gas results to casting defects like blow holes, porosity, etc.( Dibinin and Sokolov, 1985; Mikhailov, 1989). Therefore, in order to obtain a satisfactory casting there is need to control the moisture content of the sand.

### *The Refractoriness of Sand*

This explains ability of the sand to withstand elevated temperature without appreciable deformation during service condition. The selection of sand for foundry work strongly depends on the refractory and permeability property of the sand. The refractoriness of River Benue sand is between 1600 and 1650°C and according to Burns (1986), the AFS refractory standard for foundry sand falls in the range (1400-1800°C).

### *The Strength and Mouldability of the Sand*

The strength of sand describes the sands ability to withstand impact load without appreciable deformation. The green shear and compressive strengths compared to the dry shear and compressive strengths of the sand are usually less because of the lower bonding effect due to wetness. The dry strengths, on the other hand, have higher values because of the higher bonding effect due to dryness. The strengths of sand obtained for the two mould mixtures are GSS- 9.03 and 9.72kN/m$^2$; GCS- 39.37 and 42.13kN/m$^2$; DSS- 268.9 and 310.26kN/m$^2$; DCS- 1241.06 and 1413.43kN/m$^2$. Comparing these values with those from Dieter cited in Guma (1998) and shown in Appendix 1, the sand is good considering the fact that it met the AFS standard for foundry sand. The mouldability values for the mould mixture is good (4.2 and 7.0) when compared to the values from literature.

## CONCLUSIONS/ RECOMMENDATIONS

Upper River Benue sand is good sand for foundry work. The sieve analysis test shows that the sand meets the sieve bulk distribution standard for foundry sand. The GFN of 35.45 shows that the sand is coarse hence can be used for casting steel and other heavy castings. It is sub-angular in shape hence it has more strength since it can interlock very easily thereby controlling permeability and porosity properties.

The Federal, State Governments and multi-national organisations are encouraged to harness this untapped resource. The gainful harnessing and effective utilisation of this deposit would go a long way in producing cast parts for our refineries, automobile industry and other areas of technology.

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## Appendix 1

**Satisfactory Sand Properties Ranges for Various Types of Casting**

| Metal | Green compression strength, kN/m$^2$ | Permeability, NO | Dry strength, kN/m$^2$ |
|---|---|---|---|
| Heavy steel | 70-85 | 130-300 | 1000-2000 |
| Light steel | 70-85 | 125-200 | 400-1000 |
| Heavy grey iron | 70-105 | 70-120 | 350-800 |
| Aluminium | 50-70 | 10-30 | 200-550 |
| Brass and bronze | 55-85 | 15-40 | 200-860 |
| Light grey iron | 50-85 | 20-50 | 200-550 |
| Malleable iron | 45-55 | 20-60 | 210-550 |
| Medium grey iron | 70-105 | 40-80 | 350-800 |

Source: Dietert in Guma (1998)