



Full Paper

SUITABILITY ASSESSMENT OF SOME NIGERIAN NATURAL MOULDING SAND DEPOSITS FOR FOUNDRY USE

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ABSTRACT

This paper investigates the suitability of some Nigeria natural sand deposits as foundry moulding sand. Samples of sand were collected from river bed, sea, and desert deposits in Nigeria. Their clay contents were measured and the grain size and grain size distribution were determined by AFS sieve analysis tests. The mineralogical compositions of the samples were also determined by mineralogical analysis. The results obtained from the samples show that the clay contents are in the range of 0.70 – 5.70 wt. %, silica contents in the range of 88.65 – 98.5wt. %, total minerals contents in the range of 1.5 – 11.5wt. %, while AFS Finesse Number ranges from 46.22 – 100.75. The analyses of the results reveal that each deposit has properties that are suitable for particular types of castings. It was inferred that depending on the deposit, small- medium- and/or large- sized ferrous and non-ferrous castings can be produce.

Keywords: Clay content, AFS sieve analysis, Mineralogical analysis, Sand

1. INTRODUCTION

Although there are different types of casting processes, most cast products are accomplished in sand moulds. Sand is the principal moulding material in the foundry shop where it is used for all types of castings, ferrous and non-ferrous alike

This flexibility of sand is credited to its possession of some properties vital for foundry purposes. The most important of these characteristics are its refractoriness, chemical resistivity and permeability (Hein *et al.*, 1976). It does not chemically react or combine with molten metal and can therefore be re-used time and time again (Beeley, 2001). The sand that meets these properties is often found in riverbeds, sea, lakes and desert (Khana, 1996).

However, sand so found may differ in some specific ways. The difference may be in their chemical composition. Silica sand formed in their natural deposits contains minerals and alkalis. The minerals are present in the form of iron oxides, alkalis oxides and lime while alkalis are present in the form of sodium and potassium chlorides (Jain, 1995). Generally, the purest silica sand which contains about 99.8 percent SiO₂ is considered the most refractory and thermally stable (Wiscers, 1980). The presence of excessive amounts of iron oxide, alkali oxides, and lime can cause objectionable lowering of the fusion point in sand and lower chemical resistivity (Rao, 1998).

Average fineness of the sand grains establishes the fineness of the moulding sand as a whole, and the grain size distribution affects many of the sand properties. The sand grain size could be coarse or fine. The fine grains would have lower permeability, however; they provide better surface finish to the casting produced. The distribution of the grain size also plays an important role. For example, widely distributed sand would have higher permeability than the one with the same fineness number where all the grains have the same size. The grain size also affects the refractoriness. The higher the grain size, the higher would be the refractoriness. The purity of sand grains also improves the refractoriness. For example sand grains with AFS of 30 to 45 may have higher fusion point of order of 1650°C (Mansaray and Ghaly, 1998). But finer grains and impurities in the sand tend to lower the refractoriness by promoting fusion, Lui *et al.* (2003). The grain size and shape also affects the strength of moulding sand.

Sand in contact with steel may be heated to an excessively high temperature. For this reason, the moulding sand must be of sufficient purity so that it will not fuse together or deteriorate. The impurities that may be found are iron oxide, feldspar and limestone. For instance, the sintering temperature for grade A silica sand which contains less of these impurities is in the range of 1685 – 1710°C (Wang *et al.*, 2003). Research on some natural sand deposits and binders available in Nigeria have been widely reported in various publications. Test data for various natural sand deposits and their applications for various sizes of ferrous and non-ferrous have not been reported. Sheidi and Ajuwa (2008) in their investigation of moulding properties of River Niger and Bacita sand deposits found out that they have good grain size and refractoriness for sand castings. Olasupo and Omotoyinbo (2009) investigated the moulding properties of Igbokoda (Nigeria) silica sand bonded with Ijero-Ekiti (Nigeria) clay and found out that Igbokoda sand possess adequate permeability, good strength and refractoriness suitable for casting of both ferrous and nonferrous alloys. Ibitoye and Afonja (1997) found out that Ipetumodu potter's clay with addition of powdered charcoal and ground wood flour in amount of 2.4 to 2.7% and 3 to 6.8% respectively results in desirable moulding sand

properties. However, in a latter study, Ibitoye and Afonja (2001) found out that Ipetumodu potters' clay and sand mixed with up to 49% clay showed inferior properties. Ibitoye (1996) further investigated the use of potter's clay as binder in foundry coresand and found out that economic mixes could be made when the cassava starch content ranges from 1.55% to 2.00%.

Loto and Adebayo (1990) investigated effect of variation in water content, clay fraction and sodium carbonate additions on synthetic moulding properties of Igbokoda (Nigeria) clay and silica, and found out that sodium carbonate addition increases the green strength property of mixture of Igbokoda clay and silica sand. Ademoh and Abdullahi (2009) worked on the assessment of foundry properties of steel castings moulds with grade 4 Nigeria acacia (gum arabic) and found out that 4.5 - 8.0% binder content in powdered form is suitable for casting non-ferrous alloys, malleable and grey iron while 8 - 13% is suitable for light steel. In solution form it was found suitable for non-ferrous alloy. Ibitoye (2007) studied bulk density variation on the compression strength of clay/sodium silicate-bonded moulding sand and noted that addition of wood flour and charcoal or their mixture increases the bulk density silicate-bonded moulding sand.

Mohammed (2004) worked on improvement of low-grade silica deposit in Jeddah area and proposed flow sheets and processing plant layouts for upgrading the impure sand to high grade silica sand. Mansaray and Ghaly (1998) studied the agglomeration characteristics of silica sand-rice husk ash mixture at elevated temperatures and found out that rice husk increases the permeability of silica sand at elevated temperature.

The current work is aimed at providing primary database for various natural sand deposits in Nigeria and their applications for production of various sizes of ferrous and nonferrous alloys.

2. EXPERIMENTAL PROCEDURES

Some quantity of sand was obtained from six different deposits in Nigeria. The deposits were Bacita deposit (a desert sand), Atlantic Ocean sand deposit (a sea sand), Eti Osa sand deposit (a sea sand), River Niger sand deposit (a river bed sand), River Benue sand deposit (a river bed sand) and Osun River sand deposit (a river bed sand). From samples of each deposit the size and distribution of sand were determined by AFS sieve analysis test in accordance with test procedures outlined in American Society for Testing Material (ASTM C 136-06), and American Association and State Highway and Transportation Officials (ASTM C 136-06 and AASHTO T027-06-UL), while the mineralogical composition was determined by mineralogical analysis (Aggarwal and Jain, 1999). Also the clay content of each sample was determined by sand washing method (AFS, 1963).

2.1. Clay content test

The percentage clay content test was carried out on the samples of the sand following the test procedure outline in Foundry Sand Handbook (AFS, 1963). A 100g sample was dried to a constant weight at 110°C, thoroughly washed to remove the clay content and thereafter dried again at 110°C to a constant weight. The difference in weight of the dried sand and 100g weight of sample as shown in equation (1) gives the percentage clay content in the moulding sand.

$$\% \text{ Clay Content} = \frac{100g \text{ sample} - \text{weight of dried sand}}{100g \text{ sample}} \quad (1)$$

2.2. Sieve analysis of samples

The size and distribution of sand grains in the collected samples were determined in accordance to AFS Standard procedure, ASTM C 136-06 (2006) and AASHTO T027-06-UL (2006).

The sand retained on each of the sieve was expressed as percentage of total mass and were plotted against the sieve number to obtain the grain distribution. The average grain fineness were thereafter, computed as shown in equation (2).

$$GFN = \frac{\text{Total Product}}{\text{Total Sum of Percentages Collected in each Sieve}} \quad (2)$$

That is,

$$AFS \text{ number} = \frac{\sum M_i f_i}{\sum f_i} \quad (3)$$

Where M_i = multiplying factor for the sieve
 f_i = amount of sand retained on the i_{th} sieve

2.3. Chemical analysis of samples

The sand that forms the major portion of the moulding sand is essentially silica grains, the rest being the other oxides such as ferric, alumina, calcium and magnesium oxides, and alkalis (sodium and potassium, chloride). The composition of these oxides and alkalis were determined by mineralogical analysis. These oxides were extracted from the samples of sands by following procedure outlined in Aggarwal and Jain (1999). Silica was extracted with anhydrous sodium carbonate and HCl; ferric and alumina oxide with ammonium chloride NH_4Cl , NH_4OH and bromine water; lime with ammonium oxalate; magnesia with diammonium hydrogen orthophosphate; and total alkalis with ammonia solution and ammonium carbonate solution.

The percentage of each of these oxides was then estimated from the weight of extracted residue and the weight of sample as follows:

$$\text{Percentage of Oxide} = \frac{\text{Weight of Residue}}{\text{Weight of Sample}} \times 100 \quad (4)$$

3. RESULTS AND DISCUSSION

3.1 Results

The results of the clay test are shown in Figure 1. The AFS-sieve analysis results are shown in Table 1 and the graph showing the grain size distributions are presented in Figures 2-7. The chemical composition of silica, ferric oxide, alumina oxide, lime, magnesia and total alkalis present in the samples are as shown in Table 2.

3.2. Discussion

From the results of total clay test shown in Figure1, the total clay content in Bacita and Osun River sand is highest relative to other deposit, while the total clay content in Atlantic Ocean and Eti Osa sand is lowest. Total clay is a sort of foreign matter of mineral deposit present in moulding sand and has no bonding power. This causes undesirable lowering of the fusion point in sand and hence reduces its refractoriness. The total clay content required of high silica sands should not be more than 2% (Jain, 1995). From this result its only Atlantic Ocean and Eti Osa sand that meets the quality requirements of high silica sand. The implication of this is that these deposits will possess high refractoriness to withstand high temperatures of pouring and volume of metal.

Aside total clay content, the average fineness number and particle size distribution are properties of the base sand of major importance. Average fineness of sand grains establishes the fineness

of the moulding sand as a whole, and the grain size distribution affects the strength and permeability of moulding sand. The average fineness of Osun River sand is the highest at 100.75; Bacita, River Niger and River Benue sands are fairly high; and Atlantic Ocean and Eti Osa sands are low relatively. The implication of this is that Atlantic Ocean and Eti Osa sands are relatively coarse; Bacita, River Niger and River Benue sands are fine; and Osun River sand is finest. According to Jain (1995) the finesse numbers of all the sand deposits except Osun River sand deposit are found to be within the range that could give good mouldable properties.

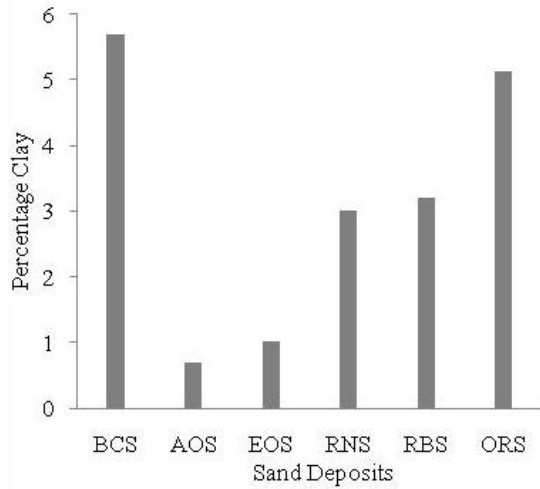


Figure 1: Results of Clay Test

KEY:

- BCS = Bacita sand deposit
- AOS = Atlantic Ocean sand deposit
- EOS = Eti Osa sand deposit
- RNS = River Niger sand deposit
- RBS = River Benue sand deposit
- ORS = Osun River sand deposit

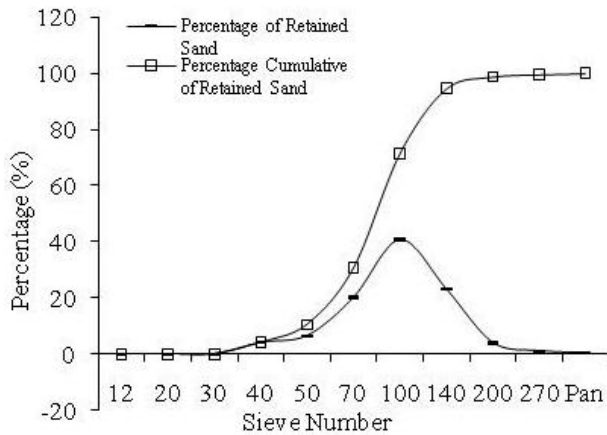


Figure 2: Sand Grain Distribution Of Bacita Sand

However, coarse sand has greater permeability than finer sands, but finer sand gives better surface finishing of castings. Coarse-grained sands are preferred for producing large castings and steel castings as they easily permit the escape of mould gases while fine-grain sands are used for producing aluminium castings, ornamental castings and small sized castings (Sarat and Brij, 1987). Finer grains sand appear to be more easily fused than coarse ones. Where maximum refractoriness is required, as in steel moulding sands, the coarse, high-purity silica sands are used to advantage (Lui

et al., 2003). The implication of these results is that the Atlantic Ocean sand deposit was found suitable for big and medium sized steel and large sized iron castings while Osun River sand deposit can be used for aluminium castings. River Niger and River Benue sand deposits may be suitable for small sized steel; and small and medium sized iron castings. Bacita sand deposit was found suitable for medium and small size iron castings, and nonferrous castings.

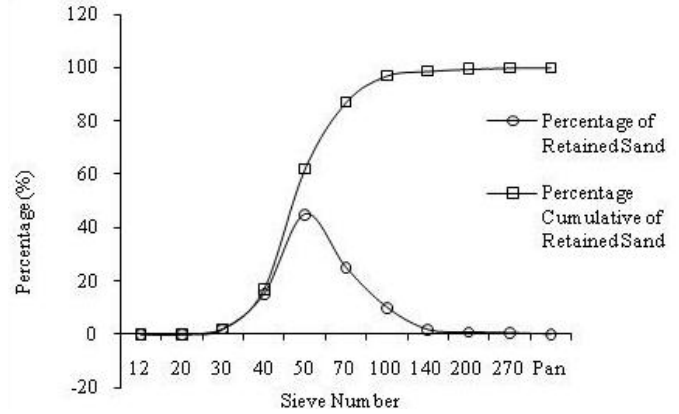


Figure 4: Sand Grain Distribution of Atlantic Ocean Sand

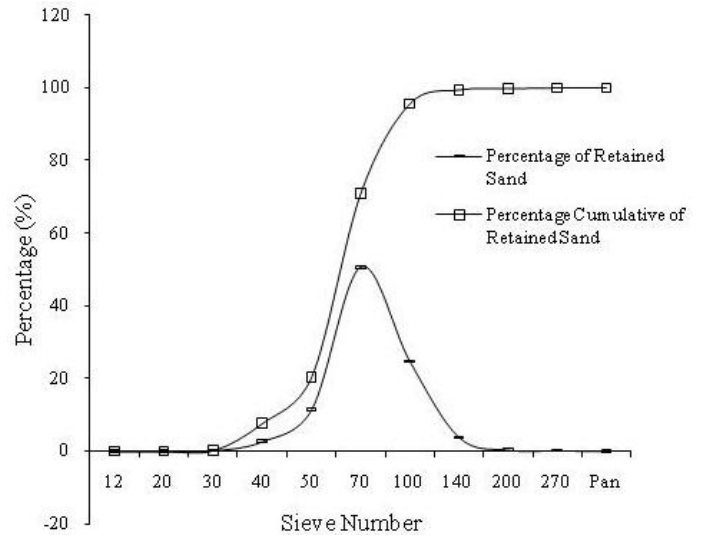


Figure 4: Sand Grain Distribution of Eti Osa Sand

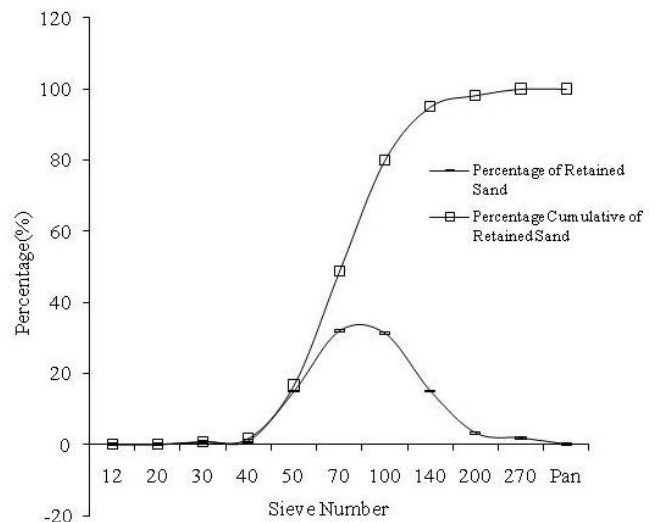


Figure 5: Sand Grain Distribution of River Niger Sand

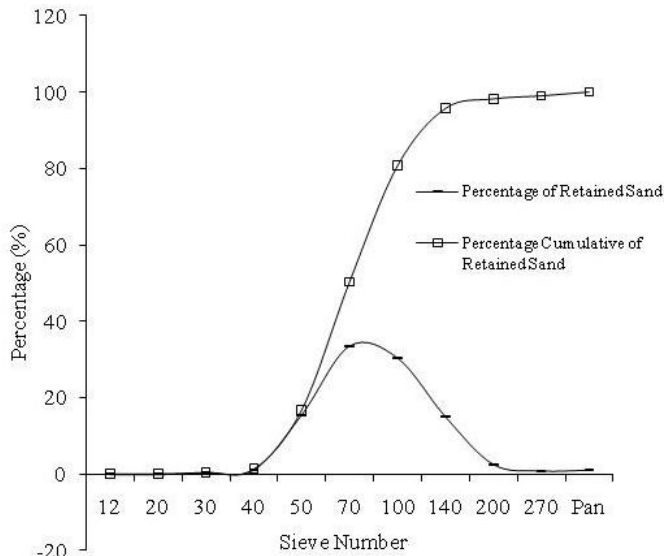


Figure 6: Sand Grain Distribution of the River Benue Sand

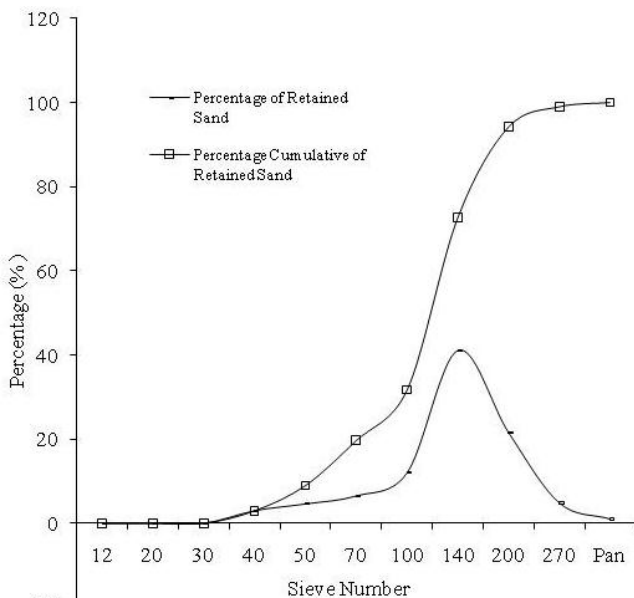


Figure 7: Sand Grain Distribution of the Osun River Sand

The sieve analysis of the test sands is graphically presented as the percentage retained on each sieve and cumulative percentage retained on successive sieves as shown in Figures 2 to 7. There are three major fractions of the sieve: the main fraction, the coarse fraction, and fine fraction. The main fraction is that percentage of sand grains represented by the middle portion of the curves. The sand is defined by the number of screens over which the main fraction is spread as a 2-, 3-, 4-, 5-, etc., screen sand. A screen fraction is defined as one with more than 10% retained on it (Hein *et al.*, 1976). The sieve analysis of Bacita and Eti Osa sands are 3-screen sand as shown in Figures 2 and 4 while Atlantic Ocean, River Niger, River Benue and Osun River sands are 4-screen sand as shown in Figures 3 and 5 to 7. From all the tested samples the main fraction constitutes more than 80% of the aggregate by weight. According to Jain (1995) for a good compaction of sand the amounts retained on 3 or 4 - screen should be above 75%. Hence, it can be said that all the sand tested will have good compactibility property.

The coarse fraction of the sieve analysis is composed of the total percentage of sand grains retained on the screens that is coarser than those of the main fraction. According to Hein, *et al.* (1976), the amount of this fraction should be less than 10%. From the results of tested sand samples it was observed that all of them conformed to this standard except Bacita sand deposit whose percentage coarse fraction is 10.51%. It has been reported that total coarse fraction must be limited in amount, usually to less than 4% for a sand of 4-screen distribution type (Hein *et al.*, 1976). Among the four, 4-screen distribution type in the tested samples it is only Osun River sand whose percentage of coarse fraction is 9%, that does not conform to this. The above limitation of coarse fraction is necessary since excess of coarse particles contributes to a poor casting surface finish. In addition, coarse particles are easily dislodged from mould cavity surface and may become dirt in the casting (Rao, 1998).

The coarse fraction of Bacita sand is on the screen No 50 constituting 10.51% of the weight, Atlantic Ocean sand is on screen No 30 constituting 2% of the weight, while Eti Osa sand; River Niger sand; River Benue sand and Osun River sand are on the screen No 40 constituting 8.99; 1.75; 1.4 and 9.0 per cent of the weight, respectively.

The fine fraction of the sieve analysis is composed of total percentage of sand grains retained on screens finer than those of the main fraction. According to Hein *et al.* (1976), this fraction must be less than 10 per cent and for 4 - screen type distribution, it must be about 5 per cent. This limitation is necessary since an excess of fine particles causes balling to occur during the mulling (Jain, 1995). When water is added, the fines and binder agglomerate to form balls during mulling and thus may prevent the binder from being thoroughly disseminated throughout the mass (Chen *et al.*, 2002). The ability to properly mull the sand and disseminate the ingredients requires the balance of coarse, bulk and fine particles in the base sand (Mohammed-Noor, 2004). All the samples of tested sands conformed to the less than 10% requirement while all the 4 - screen type distribution in the samples also conforms to about 5% requirement. From the results on Table 1 the highest fine fraction is Osun River sand with a value of 5.8.

Moulding sand must have good chemical resistivity. It must not chemically react or combine with molten metal and must not get fused. The presence of excessive amounts of iron oxide, alkali oxides and lime can lower the fusion point in sands (Lui *et al.*, 2003). The purer the silica sand the lower these alkalis and minerals. According to Jain (1995), the total alkali and minerals in high silica sand must be less than 2%. As shown in Table 2 the total minerals and alkalis in Bacita sand, Atlantic ocean sand, Eti Osa sand, River Niger sand, River Benue sand and Osun River sand are 3.17%, 1.5%, 1.02%, 7.91%, 5.44% and 11.35% respectively. This means that Atlantic Ocean sand is the purest, followed by Eti Osa sand. These two sand deposits may be used directly without processing. However, for other deposits the sand must be washed to reduce the total minerals and alkalis to below 2%.

All the sand deposits can be classified into three grades according to IS: 1987 - 1974, as shown in Table 3. Atlantic Ocean sand deposit is categorized grade A, Eti Osa and Bacita sand deposits are grade B, while River Niger and River Benue sand deposits are grade C. However, Osun River sand did not belong to the grade of high silica sand but natural sand that needs a lot of washing and sorting for it to conform to a high grade. According to Mohammed-Noor (2004), low-grade silica sand such as this can be improved upon through techniques involving froth flotation, shaking table and magnetic separation.

Atlantic Ocean sand deposit has the lowest clay content (0.7%), most coarse grain size (46.22), and the purest (98.50% silica) among all the tested samples. A coarse grained and good chemical resistivity sand like this is most suitable for large and medium sized



steel castings, and large iron castings. Eti Osa sand deposit has lower clay content (1.02%), coarse grain size (54.5), and pure (97.98% silica) among the entire tested sample. Because its grain size is above 50 it is not suitable for large-sized steel castings but may be suitable for medium and small size steel castings, and large-sized iron castings.

River Niger and River Benue sand deposits have high clay content (3.0% and 3.2% respectively), fine grain size (67.79), and least pure (92.09% and 94.56% silica respectively) among all the tested samples. The high clay content and poor chemical resistivity makes them unsuitable for large and medium sized steel castings but for small-sized steel castings, medium and small sized iron castings, and nonferrous metals castings. Bacita sand deposit has the highest clay content (5.7%), finer grain size (74.42), pure (96.85% silica) among all the tested samples. Although the sand deposit is pure, because of its high clay content and fine grain size it's not suitable for steel castings but may be suitable for medium and small sized iron castings, and non-ferrous metals casting. Osun River sand deposit has higher clay content (5.14%), finest grain size (100.75%), and is most impure (88.65% silica) among all the tested samples. Due to the fact that this sand deposit is impure and has high clay content and fine grains it is not suitable for ferrous castings and not preferred for all non ferrous metal castings. It may however be suitable for aluminium castings.

Based on the results and analysis of all the tested sand deposits, it is observed that each deposit has properties that are suitable for particular types of castings, as summarized in Table 4.

4. CONCLUSION

Atlantic Ocean sand deposit is found to be a grade A high silica and coarse sand. It has the least clay content with less than 2% alkalis and mineral content of all sands tested. This deposit is characterized by high refractoriness and permeability, which makes it suitable for steel and large castings. On the other hand Osun River sand deposit has the lowest value of refractoriness, poor chemical resistivity and the least permeability, this makes it suitable for only aluminium castings. Both Eti Osa and Bacita sand deposits are grade B high silica sand. Thus former may be suitable for medium and small sized steel castings, and large sized iron castings. Bacita sand deposit is, however, suitable for medium and small sized iron castings and non-ferrous metals due to its high clay content and fine grain size. River Niger and River Benue sand deposits are grade C high silica sand. They have high clay, alkalis and minerals content but have fine grain size. Due to high clay content and poor chemical resistivity they are not preferred for big and medium size steel castings but for small-size steel castings, medium and small size iron castings, and nonferrous metals.

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