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Impact of Moisture Variation on Some Foundry Properties of Fori Silica Sand

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Abstract

Moulding Sand for metal casting is usually sourced from either natural deposit or synthetic mix of refractory sand grain binder and moisture. Each of the mix constituent is important in determining the characteristics of sand. The binding agent is responsible for bendability thereby determining the size of voids within the sand grain, while moisture level determines the plasticity of the foundry sand. Tests using American Foundry Society (AFS) Standard were followed in carrying out the experiment on Fori sand deposit to determine its suitability for foundry use. The sand was collected from the river bank of Fori, in Fori Community, Maiduguri, Borno State. The experimental test equipment includes: laboratory sand mixer, sand rammer, universal strength testing machine, permeability-meter, oven, mouldability machine, and as well as quick moisture teller. The chemical composition of the materials was carried out using atomic absorption spectrophotometer (AAS) model PG990AFG. The silica content in the material sample is about 78.65%, and with the traces of other elements, such as CaO (1.07%), Fe_2O_3 (0.76%), Al_2O_3 (15.81%), MgO (1.01%), TiO_2 (2.21%), K_2O (3.87%), and Na_2O (1.16%), respectively. These percentages are within acceptable limits. The results of the physical properties revealed that the sand sample has clay content of 15.32% which is above the standard range of 10% - 12% recommended for natural moulding sands required for producing good quality castings. Other foundry properties of Forinatural moulding sand conducted include "moisture content" in the following ranges of percentages, 7.6%, 6.5%, 5.8%, 4.2% and 2.9% with the corresponding value of green compressive strength of (43.95, 53.47, 69.56, 68.21 and 61.16 KN/m^2), dry compressive strength (93.50, 96.52, 105.50, 146.50 and 152.49 KN/m^2), and permeability No. of 340, 390, 410, 430 and 440 respectively. It is clear from the test that, the lower the moisture content, the higher the dry compressive strength of the materials. The refractoriness value of the materials is 1400˚C. The results of the physical and other foundry properties carried out show that Forisilica sand is suitable for casting non-ferrous alloys like bronze, brass and aluminium, and cast iron.

Keywords

Fori Moulding Sand, Mouldability, Moisture Content, Refractoriness, Compressive Strength

1. Introduction

Sand is the ideal and cheapest medium to cast liquid metal into a desired shape or form. Silica sand is the sand found on a beach and is the most commonly used sand in castings. It is made by either crushing sandstone or taken from naturally occurring locations, such as beaches and river beds. The fusion point of pure silica is 1760˚C (3200 ˚F). The abundance of silica sand makes it the most commonly used sand, and its low cost therein is its greatest advantage. Its disadvantages are high thermal expansion, which can cause casting defects with the casting of high melting point metals. It has low thermal conductivity as well. The low thermal conductivity can lead to unsound casting of cast components. The application of silica sand is limited to some metals because it will chemically interact with some metals, forming surface defects, and as well releases silica particulates during the metal pouring, risking silicosis in foundry workers [1].

Moulding sand must have good gas permeability and low compressibility. The grain size is carefully monitored since it has an impact on the surface structure of the cast piece. If the particle size is too large rough casting surface may be produced. Foundry sands usually have a size distribution from 0.1 mm - 0.8 mm with a mean size between 0.2 mm and 0.45 mm. A standard parameter to express the size of moulding sands is the use of American Foundry Society (AFS) Grain Fineness Number (GFN). This number is calculated from the size distribution, which is determined by standard ASTM sieves. Each fraction is multiplied with a weighting factor, and the results are added together and divided by 100 [2] [3].

By itself, GFN does not identify if the sand will be a good moulding material or produce the qualities needed in a particular metal casting sand system. This is because GFN represents an average fineness, and sands with very different grain size distributions may have similar GFN numbers. So, the distribution of sand grains on the screens is a critical factor in effective sand moulding. Sometimes, the standard for AFS-GFN and sand distribution is usually determined by the individual metal casting facility for its particular sand system and depends on factors like casting quality requirements, moulding process used and alloys to be produced [2].

The size of the sand grains in the moulding sand mixture is a critical element in the quality of the castings to be produced. The optimal grain fineness number (GFN) in a sand system is determined by the type of metal poured, pouring temperatures, casting product mix and the required surface finishing. Sand that is too fine (higher GFN) can create low permeability and result in gas defects and also sand that is too coarse (lower GFN) can create high permeability and lead to metal penetration into the mould during casting leading to rough surface finish (burn-in and burn-on).

Foundry sand contains less than 12% of clay material. It's occurring as loose poorly deposit of sedimentary origin or accumulated deposits in rivers along coast. They are also produced through crushing of quartzite sand of fixture and then washing and grading them to get sand of desired shape or size and grain distribution. Moulding sand usually had different shapes as normal sand, ranging from round, angular, etc., but the most suitable among them is the "semi angular", reason being that it enhances flowability and plasticity, and also allowed for permeability, which improved surface finishes and strength [4].

Moulding sand for metal casting is usually sourced from either natural deposit or synthetic mix of refractory sand grain, binder and moisture [5]. Each of the mix constituents is important in determining the characteristics of sand. The binding agent is responsible for bendability thereby determining the size of voids by sand grain while moisture level determines the plasticity of the foundry sand.

Acceptable moulding sand is the one that facilitates the economics production of defects free castings. Moulding material has certain characteristic properties which make it unique for foundry application. These properties include green compressive strength, dry compressive strength, permeability, flowability, mouldability, etc. Binders are added to based sand to bond or glue the sand particle together in other to make it easily mouldable which also gives it sufficient strength and plasticity when mixed with the right quantity of water [6].

Nigeria, like other countries of the world is blessed with abundant minerals resources and silica sand is one of them, with large deposit of over 150 million tons that have been discovered in Benue, Kogi, Ondo, Borno, Niger, Enugu, Delta, Lagos, Bayelsa, Kano, Katsina, Imo, Abia, Cross-River, States, etc. The material is also used in the production of glass, fused silica as fillers in automobiles tires rubbers and in footwear soles [7]. Hence, it is need to tap into the resources for proper utilization for human needs. This work is directed at evaluating the impact of moisture variation on some foundry properties of ForiSilica Sand to determine its suitability.

2. Materials and Method

2.1. Research Materials and Equipment

In order to obtain the Grain Fineness Number of the materials in accordance with American Foundrymen Society (AFS), River Sand collected from Fori community, Maiduguri, Borno State Nigeria was sieved using standard sieve size

40 - 70 mesh. The Grain Fineness Number (GFN) of the materials was obtained as follow, Equation (1).

$$\text{Grain Fineness Number}\left(\text{GFN}\right) = \text{Product}/\%\ \text{Cumulative of GFN} \tag{1}$$

Some of the other experimental equipment used for carrying out the tests include: 1) laboratory sand mixer, 2) sand rammer, 3) universal strength test machine, 4) permeability-meter, 5) hardness tester, 6) dry oven mouldability machine, 7) quick moisture teller and 8) vibrating sand shaker for sieve analysis.

2.2. Specimen Preparation and Test Procedure

The entire tests conducted in this work were in accordance with the American Foundry Men Society Standards [7]. The chemical analysis of Fori natural moulding sand was carried out and the result is shown in **Table 1**.

In order to carry out the physical analysis, the sand specimen was weighed (2 kg), and then washed, oven dried at 110˚C to remove free water. It is then reweighed in order to calculate the clay content. The quantity was sieved using AFS standard to obtain required grains of 40 - 70 mesh, (see **Table 2**). Sample sand specimen was then prepared using a standard sand rammer, that is, model Type "N": Ridsdale Dieter T & Co Ltd Middles Brough England, Serial No: 8421, which produced compaction of three blow, 6.5 kg to form a height of 50.4 mm. Each specimen after three compaction blows measured 50.4 mm in height by 50.4 mm in diameter of the average weight of 130 g. Majorly, specimens are classified into green and dry compression. A speedy teller model Type "C2", Riddle Dieter T Co. Ltd Middles Brough England was used to test and read the moisture content of the specimen. The instantaneous moisture content in percentage was recorded. Moisture content can be calculated using Equation (2).

$$W = \frac{G - G_1}{G} \times 100\% \tag{2}$$

where, W = is the moisture content (%); G = is the weight of the sample before drying (g); G_1 = is the weight of the sample after drying (g).

Permeability is one of the properties of foundry sand with respect to how well the sand can vent, that is how well gases pass through the sand was measured. In carrying out the permeability test, standard air pressure of 9.8 × 102 N/m^2 was passed thought cylindrical specimen tube containing standard moulded green sand specimen placed in parameter of the perm-meter and the time taken for 2000 cm^3 of air to pass through the specimen was determined and the permeability calculated using Equation (3).

$$P_n = \frac{VH}{Apt} \tag{3}$$

where, P_n—is the Permeability number; V—is the Volume of air (cm^3); H—is the Height of specimen (cm); A—is the Cross-sectional area of specimen (cm^2); P—is the Pressure of air in cm of water; t—is the time (in minutes).

The result of the test is shown in **Table 3**.

Table 1. Chemical compositions of fori natural moulding sand.

Constituent	Values
SiO_2	78.65
Al_2O_3	15.81
Fe_2O_3	0.76
TiO_2	2.21
CaO	1.07
MgO	1.01
K_2O	3.87
Na_2O	1.16

Table 2. Physical properties of fori silica sand.

Constituent	Values
Colour	Light Brown
Grain Shape	Sub-Angular
AFS G F N	125.26
Clay Content (%)	15.32
Refractoriness (˚C)	1400

Table 3. Variation of moisture content on some foundry properties.

Constituents	Values				
Moisture Content (%)	7.6	6.5	5.8	4.2	2.9
GCS (KN/m^2)	43.95	53.47	69.56	68.21	61.16
DCS (KN/m^2)	93.50	96.52	105.50	146.50	152.49
P (mmWs)	340	390	410	430	440
M (%)	92.00	95.30	98.40	99.90	98.40
SI (No)	88.01	81.00	73.00	64.05	60.00

The dry and green compressive strength tests were carried out with the universal strength testing machine model Ridsdale Dieter T & Co Ltd Middles Brough England, Serial number-M8415. Steady increase in compressive force was applied on test specimen until failure occurred and strength in KN/m^2 was recorded instantaneously. The dry compressive specimens were first oven dry at 110˚C for one hour and allowed to cool with the oven before the test was conducted. A shatter test apparatus model Ridsdale Dieter T & Co Ltd Middles Brough England Serial No: 8451 was used to measure shatter index of the specimens. Compressive Strength (CS) was calculated from Equation (4):

$$\text{CS} = \frac{\text{Maximum load}\left(\text{kN}\right)}{\text{Cross} - \text{Sectional area}\left(\text{m}^2\right)} \tag{4}$$

The result of the test is shown in **Table 3**.

The most widely used method of measuring the softening behaviour of moulding sand at high temperatures has been the use of the Pyrometric Cone Equivalent (PCE) of a particular material against the virgin materials and as such, the refractoriness value of the virgin material was determined using Pyrometric Cone Equivalents (PCE) in a Furnace of model: NETZSCH 428 PCE Furnace. The test pieces mounted on a refractory plaque along with some standard cones whose melting point are slightly above or slightly below that expected of the test cones were placed in the furnace. The temperature of the furnace was raised at a rate of 10˚C per minute until the tip of the test cone (Fori Sand) bent over level with the base. At the end of the experiment, the final temperatures were recorded (see **Table 2**).

3. Results and Discussion

3.1. Chemical Compositions of Fori Natural Moulding Sand

The results of the chemical compositions of the natural moulding sand collected fromfori river bank are presented in **Table 1**. The Table shows silicon dioxide (SiO_2) as the major constituent with a value of about 78.65%. Silica grains are very important in moulding as they impact refractoriness, chemical resistivity and permeability to the sand [8]. The higher the percentages of silica sand the better the refractoriness of the sand [9]. Other constituents of the samples included; CaO (1.07%), Fe_2O_3 (0.76%), Al_2O_3 (15.81%), MgO (1.01%), TiO_2 (2.21%), K_2O (3.87%), and Na_2O (1.16%) respectively, which are present as impurities. The values of the impurities in the specimen, and chemical constituents recorded are in line with the recommended mould sand chemical compositions in literature, and are within the limited values [10].

The presence of excessive amounts of iron oxide, alkalis oxides and lime can lower the fusion point to a considerable extent which is not desirable [11]. From the chemical composition carried out, it can be concluded that the deposit is safe for use in sand casting.

3.2. Physical Properties of the Sand

The results of the physical properties of the natural moulding sand carried out are presented in **Table 2**, while **Table 3** is the variation of moisture content on some foundry properties.

3.3. Clay Content Determination

The amount of clay content in the sample collected from Forinatural sand deposit shows 15.32% clay. From the standard requirement for casting, these values are above the recommended standard values of 10% - 12% making the natural sands sampled from the deposit unsuitable for ferrous alloy castings without blending [12]. The sand however, can be used for non-ferrous casting with close sand control in order to minimize the production of defective castings.

3.4. Grain Fineness Number (GFN)

The AFS grain fineness numbers of the sample show a finer aggregate with a value of GFN 125.26 AFS. The finer the sand, the higher the compatibility and vice versa [13]. When coarse sand is used it has the tendency to produce rough surface finish on castings due to penetration defects while fine sand produces good surface finishes but with the possibility of having lower permeability which can lead to gas defects.

3.5. Moisture Content

From **Table 2**, the moisture content of the sand varies from 7.6% to 2.9%. Moisture content is extremely critical and it can affect nearly all the physical and mechanical properties that are measured in foundry casting materials [14]. Knowing the moisture content of the natural sand will help in guiding the amount of water to be added during the mould making processes. If the right moisture content (5% - 7%) is not achieved, it can lead to several defects, like scabs and blows holes and it will also affect the strength properties of the mouldingsand [12].

3.6. Green and Dry Compressive Strength

The green compressive strength (GCS) shows a maximum value 69.56 KN/m^2 at 5.8% moisture content while the dry compressive strength (DCS) has a maximum value of 152.49 KN/m^2 at least moisture level of 2.9% as shown in **Table 3**. Green strength is the strength of sand in the wet state and is required for making possible to prepare and handle the mould. If the metal is poured into a green mould the sand adjacent to the metal dries and in the dry state it should have enough strength to resist erosion and the pressure of metal [14] [15]. The strength of the sand that has been dried or baked is called dry strength. At the time of pouring the molten metal, the mould must be able to withstand flow and pressure of the metal at high temperature otherwise, the mould may enlarge, crack, get washed or break.

3.7. Permeability

The maximum permeability value obtained was 440 at the lowest moisture level. The permeability and moisture content (MC) of the natural moulding sand need to be determined because both of them affect the quality of castings produced using the green sand process. In addition, the relationships between the two are such that moulding sand with high moisture content (above 8%) will have a poor permeability and vice-versa. For these reasons their values need to be determined in order to enable proper control of the moulding sand properties. The influence of moisture on permeability is such that as moisture is increased permeability also increases until an optimum point or peak is reached, thereafter any increase in moisture results in decrease in permeability, this relationship was confirmed for both round and angular shaped sands [7]. Clay content increase brings about decrease in green permeability while moisture content increase, initially leads to increase in green permeability, but further increase however, brings about decrease in green permeability. Green permeability is controlled by a number of factors which include; sand particle size and shape, water content of the moulding sand mixture and clay content of the moulding mixture [8]. Insufficient porosity (poor permeability) of moulding sand leads to casting defects such as holes and pores. Permeability decreases with increase in clay content; with the potential of castings produced developing gas defects like blow holes.

3.8. Refractoriness

The refractoriness of the natural sand sample from Fori is 1400˚C and this value recorded can only be used for non-ferrous and cast-iron castings. It is a highly important characteristic of moulding sands. Moulding sand with poor refractoriness may burn onto the casting surface. The degree of refractoriness depended on the SiO_2 *i.e.*, quartz content, the shape and grain size of the particle. The fusion point of pure silica is 1760˚C (3200 ˚F). However, the sand evaluated has a lower melting point due to some impurities present in the materials. For high melting point casting, such as steels, a minimum of 98% pure silica sand must be used, and for lower melting point metals, such as cast iron and non-ferrous metals, lower purity sand can be used [1].

4. Conclusion

From the chemical composition analysis of the materials carried out, the silica (SiO_2) content in the sample is about 78.65%, while traces of other elements, such as CaO, Fe_2O3, Al_2O_3 MgO, TiO_2, K_2O, and Na_2O, are 1.07%, 0.76%, 15.81%, 1.01%, 2.21%, 3.87%, and 1.16% respectively. These figures obtained are within the acceptable limits but have limited the fusion temperature of the materials collected. The results of the physical properties of the materials carried out revealed that clay content of the materials is 15.32%, which is above the standard range of 10% - 12% recommended for natural moulding sands required for producing good quality castings, hence the need to subject the materials to treatment to reduce the clay content before using. Other foundry properties of the materials evaluated include, moisture content (7.6%, 6.5%, 5.8%, 4.2% and 2.9%), with corresponding green compressive strength of (43.95, 53.47, 69.56, 68.21, and 61.16 KN/m^2), and dry compressive strength of (93.50, 96.52, 105.50, 146.50 and 152.49 KN/m^2), as well as permeability number of (340, 390, 410, 430 and 440). The refractoriness of the materials is 1400˚C, less than the standard required. With these results obtained, Fori silica sand deposit may be suitable for casting aluminium alloys and other non-ferrous alloys like bronze and brass, and cast iron. Reusability of the materials has to be closely monitored to ensure timely reconditioning to guard against the production of casting defects.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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