International Journal of Research in Engineering and Innovation
(IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Effect of base sand particle size on the properties of synthetic moulding sand

Edoziuno, F.O.[1], Akaluzia, R.O.[2], Odoni, B.U.[3], Nwaeju, C.C.[4]

[1,2,3] Department of Metallurgical Engineering, Delta State Polytechnic, Ogwashi-Uku, Nigeria
[4]Department of Metallurgical & Materials Engineering, Nnamdi Azikiwe University, Awka. Nigeria
Corresponding Author: francisedoziuno@gmail.com, +2348085579152

Abstract

The effects of grain size on the moulding properties of River Niger sand (Onitsha deposit) bonded with Ukpor clay has been investigated in this research. The samples were prepared by washing and sorting to remove impurities and other foreign objects. Weighed samples were sieved and mixed in a Ridsdale laboratory sand mixer (Serial No: 845). American Foundrymen's Society (AFS) standard test specimens (50mm diameter by 50mm height) were prepared using Ridsdale laboratory sand rammer and moulding properties such as green compression strength, dry compression strength, green shear strength, dry shear strength, green permeability and mouldability were measured using universal sand strength testing machine (Serial No: M8415), electric permeability meter (Serial No: 872) and mouldability tester. Results obtained showed variations in green and dry strengths (Compression and shear), green permeability and mouldability with particle size of the base sand, clay and moisture contents. Particle sizes 355µm and 500µm produced optimal green and dry compression strengths (33.60 KN/m^2 and 322.00KN/m^2). The green Permeability number reduced steadily from 8.00 to 6.80 as the grain sizes decreased from 1000µm to 125µm, while the mouldability increased as the sand grains become finer. The results of moulding sand tests obtained from the produced synthetic moulding sand indicated that the sand could be used in the production of cast iron and non-ferrous alloys castings. The results of chemical analysis of the sand and the clay samples indicated that the sand is of high silica content (89.9%) and the clay is rich in both silica and alumina contents (67.2% and 24.5%) which is an indication of their suitability for use in foundry mould production and other refractory applications. The result of sieve analysis for the sand deposit revealed a grain fineness number (GFN) of 40.01 and an average grain size of 421.70µm, which is within the range widely used in sandcasting. Over 99% bulk of the sieved sand was retained after few consecutive sieves, which confirms that the sand met AFS standard specification for foundry sand.

Keywords: Grain size, synthetic moulding sand, grain fineness, sieve analysis.

1. Introduction

Sand is the principal moulding material in the foundry shop used for all types of castings, whether the cast metal and alloy are ferrous or non-ferrous. This is because moulding sand possesses the properties desirable for foundry purposes [1]. Moulding sands, also known as foundry sands, are defined by eight characteristics namely: refractoriness, chemical inertness, permeability, surface finish, cohesiveness, flowability, collapsibility, and availability/cost. Foundry sands are composed almost entirely of silica (SiO_2) in the form of quartz. The degree of the above qualities can also be adjusted, as desired, by varying the composition or the ingredients and additives to the sand. The refractory moulds used in casting consist of a particulate refractory material that is bonded together to hold its shape during pouring of molten metal. Foundry sands are manufactured within strict particle size distribution to tailor the properties of the material to the intended casting process [2]. Silica sand is found on a beach and is also the most commonly used moulding / foundry sand. It is made by either crushing sand stone or taken from naturally occurring locations, such as beaches and river beds. The fusion point of pure silica is 1760ºC, however most sands used for moulding purposes have a lower melting point due to impurities. For high melting

Corresponding author: Edoziuno, F.O
Email Id: francisedoziuno@gmail.com

point casting, such as steels, a minimum of 98% pure silica sand must be used but for lower melting metals, such as cast iron and non–ferrous metals, a lower purity sand can be used (between 94 and 98% pure silica).

Silica sand is the most commonly used sand because of its great abundance, hence low cost. Its disadvantages are high thermal expansion, which can cause casting defects with high melting point metals, and low thermal conductivity, which can lead to defects in castings. It also cannot be used with certain basic metal because it will chemically interact with the metal forming surface defect. Finally, it causes silicosis in foundry workers.

The principal ingredients of moulding sand are: silica sand grains, clay (bond) and moisture. Each constituent is important in determining the properties of moulding sand. The silica sand grains are of paramount importance in moulding sand because they impact refractoriness, chemical resistivity, and permeability to the moulding sand. They are specified according to the average size and shape [3]. Most moulding sands are based on the mineral quartz, which is both geologically abundant and refractory to temperatures approaching 1700ºC, although phase transformations involving volume changes occur at lower temperatures. For maximum refractoriness the content of more fusible minerals, notably the feldspars, mica, and alkali fluxes, should be low. The ideal mixture would be silica sand of high purity with minimum addition of binder [4]. The finer the grains or particle size the more intimate will be the contact and the lower the permeability. However, fine grains tend to fortify the mould and reduce its tendency to get distorted.

Moulding sand is classified as either natural or synthetic sand. The natural moulding sand is taken from beach, river bed or dug out from pits, and it contains the binder which is used in the as received condition with a little addition of water. It contains from 5 – 20% binder and about 5 – 8% water may be added to it. The synthetic moulding sand on the other hand, is synthesized in the foundry by combining a relatively clay free sand with selected clay binder like bentonite. Water and other additives are added as required. With natural moulding sand there is limitation to the extent of control and adjustment on bonding material and moisture, with synthetic sand the three major constituents are carefully selected to give desired properties within limits [5, 6]. This makes it mandatory that optimum effects of the sand grains (particle size) on the properties of moulding sand be investigated to ascertain the best particle size distribution for such synthetic moulding sand produced with available local ingredients.

Moulding sand must be permeable to allow the steam and other gases to pass through the sand mould. The permeability of sand depends upon its grain size, grain shape, moisture, and clay contents of the moulding sand. If the sand is too fine the porosity will be low [1]. It has also been demonstrated that the quality of casting is influenced significantly by moulding sand properties such as green compressive strength, dry strength, permeability, mould hardness, compatibility and shatter index. All these listed properties are invariably dependent on such parameters as the quality and nature of binder used, amount of water and sand grain size. [6, 7].

The particle size and distribution of the base sand influence many properties of a moulding sand mixture. Most evident are the effects on permeability and surface finish. High permeability is characterized by coarse and uniformly graded sands, while surface fineness and low permeability are features of fine grained sands [4]. Coarse and uniform grading are associated with high flowability and with maximum refractoriness for a given chemical composition. Many research finding have shown that the grain size of the base sand influences the strength properties of bonded moulding sand mixtures, an inverse relationship existing between compression strength and grain size in clay bonded sands [8].

Grain size control the permeability of the mould, which is the ability of the mould to allow gases generated during pouring to escape through the mould. The highest porosity will result from grains that are approximately the same size. As the particle size distribution broadens, there are more grains that are small enough to occupy and fill the spaces between large grains. As grains break down through repeated recycling, there are more and more of the smaller grains, and the porosity of the mould is too great, metal may penetrate the sand grains and cause a burn–in defect. Therefore, it is necessary to balance the base sand grain size distribution.

The grain size of sand is expressed by a number called grain fineness number, given by the American foundry men's Society (AFS). The AFS grain fineness number (GFN) of sand is approximately the number of openings per inch of a given sieve that would just pass the sample if its grains were uniformly sized, that is the weighted average of the sizes of grains in the sample.

2. Materials and Methods

2.1 Materials and equipment

The local materials used to compose the synthetic moulding sand were green silica sand from the Onitsha bank of river Niger which lies between latitude 6°06'N and longitude 6°42'E; and Ukpor clay , with the location coordinates 5°56'34"N and 6°55'58"E. The instruments used included set of standard test sieves mounted on a sieve shaker, standard sand rammer (Serial No: 845), motor driven universal sand strength machine (Serial No: M8415), electric permeability meter (Serial No: 872), mouldability tester, laboratory core baking oven (40ºC to 240ºC), laboratory sand mixer and Energy Dispersive X-ray fluorescence Spectrometer (ED-XRFS mini PAL model © 2005).

2.2 Experimental Methods

Impurities such as metallic objects, stones, hard lumps and other unwanted objects were removed from the silica sand collected from the deposit by sorting and washing. The hard lumps of the dried clay were crushed and finely ground to pass through a 200-250 mesh sieve size. The sand sample was sieved using a stack of standard test sieves mounted on a timed sieve shaker. 840g of the sieved silica sand (80%) was placed in the laboratory sand mixer and 168g of the dried clay (16%) was sprinkled over it. The sand milling operation was started and the dry ingredients were mixed for 5minutes before the addition of 42g of water (4%) and further mixed for 3minutes.

After the mixing operation, AFS standard test specimens were prepared using laboratory sand rammer. Dry and green strengths (compression and shear) tests were conducted on the standard specimen using a motor driven universal sand strength machine, while the percentage mouldability and green permeability number were determined using the mouldability tester and electric permeability meter respectively. Separate specimens of the silica sand and the clay samples were collected and used for the chemical analysis using Energy Dispersive X-Ray fluorescence Spectrometer (ED-XRFS).

3. Results and Discussion

The quantitative and qualitative results of the tests conducted are shown in Tables 1 to 6.

Table 1: Chemical composition of Onitsha beach silica sand

Compound	SiO_2	K_2O	CaO	Fe_2O_3	Ag_2O	TiO_2	SeO_2	BaO	HgO	MnO	GeO_2	CuO
Conc %	89.9	3.00	2.63	1.767	1.83	0.319	0.16	0.14	0.10	0.039	0.02	0.0087

The results of chemical analysis (Tables 1) indicated that the sand is of high silica content (89.9%). The purity of sand grains influence their refractoriness. It is evident that silica is the predominant component in the sand sample. This is desirable since high percentage of silica in sand, usually enhance its refractoriness, thermal stability and chemical inertness. It has been noted that the presence of oxides of alkali metals (Ca, K, Fe) in high proportions cause objectionable lowering of the fusion point of foundry sand from 1690°C to about 1200°C [7]. Where maximum refractoriness is required, as in steel moulding, high purity silica sand are used.

Table 2: Sieve analysis and AFS grain fineness number (GFN) of Onitsha beach silica sand.

S.No	Sieve Aperture (µm)	% Sand Retained	BS Sieve No	Product
1	1400	2.48	12	0.00
2	1000	1.40	16	16.80
3	710	4.32	22	69.12
4	500	13.82	30	304.04
5	355	25.91	44	777.30
6	250	28.55	60	1256.20
7	180	16.96	85	1017.60
8	125	5.84	120	496.40
9	pan	0.44	-	52.80
Total		**99.72**		**3990.26**

$$\text{GFN} = \frac{\text{Total Product}}{\text{Total \%Sand Retained}} = \frac{3990.26}{99.72} = 40.01$$

Table. 3: Calculation of average grain size.

Sieve Aperture (µm)	% Sand Retained	Multiplier	Product
1400	2.48	1180	2,926.40
1000	1.40	1180	1,652
710	4.32	1180	5,097.60
500	13.82	600	8,292
355	25.91	425	11,011.75
250	28.55	300	8,565
180	16.96	212	3,595.52
125	5.84	150	876
Total	**99.72**		**42,052.27**

$$\text{Average Grain Size} = \frac{\text{Total Product}}{\text{Total \%Sand Retained}} = \frac{42052.27}{99.72}$$

$$= 421.70\mu\text{m}$$

The result of the sand grain size analysis showed that more than 99% of the bulk sand was retained on the first few consecutive sieves. Thus, the sand deposit met the American Foundrymen's Society (AFS) Standard specification for sand casting [3, 9, 10]. The grain fineness number (GFN) and average grain size of the sand deposit are 40.01 and 421.70µm respectively. This grade of fineness number is suitable for the sandcasting of most types of alloy steels and nonferrous metal as this belongs to the group of fineness number that has wide range of application in sandcasting. The average grain size of the sand falls within the common foundry sand range of 150-400µm [9, 11]. It should be noted that while average grain size and AFS grain fineness number are useful parameters, choice of sand should be based on particle size distribution, as the size distribution affects the quality and properties of casting produced.

Table .4: Effects of grain size on the properties of moulding sand

Sieve Aperture (µm) / Properties	1000	710	500	355	250	180	125
GCS (KN/m^2)	20.30	23.80	32.20	33.60	29.75	29.05	29.75
DCS (KN/m^2)	294.00	318.50	322.00	301.00	300.30	297.50	294.00
GSS (KN/m^2)	12.25	13.30	14.00	14.00	15.75	19.95	21.00
DSS (KN/m^2)	56.00	59.50	63.00	70.00	66.50	66.50	70.00
Green Permeability (No)	8.00	7.80	7.60	7.50	7.10	7.00	6.80
Mouldability (%)	73.31	83.40	89.20	85.78	88.83	95.49	96.68

Where GCS, DCS, GSS and DSS represent green compression strength, dry compression strength, green shear strength, and dry shear strength respectively.

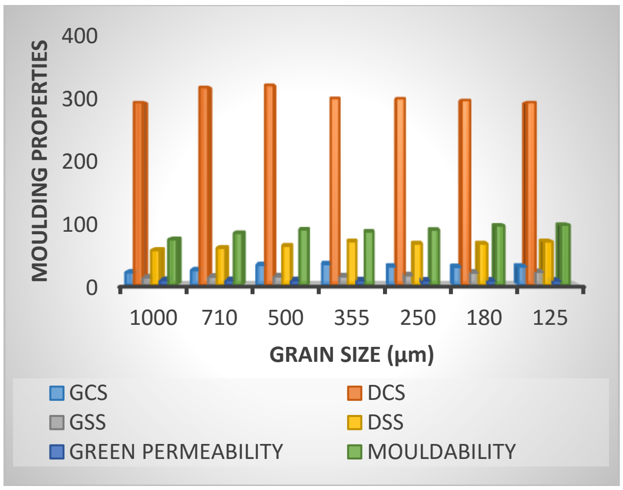

Figure 1: Effect of grain size on the properties of moulding sand

The effects of grain size on the moulding properties investigated are clearly shown in Table 4 and Figure 1. The results show that as the grain size decreased from 1000µm to 125µm, the green compression strength, dry compression strength, green shear strength, dry shear strength and percentage mouldability increased. The green compression strength and dry compression strength increased to the highest value of 33.60 KN/m^2 and 322.00KN/m^2 at 355µm and 500µm grain sizes respectively. It therefore means that if higher green compression strength and dry compression strength are required of the sand deposit, then a distribution of sand retained on the 500µm and 355µm sieve apertures will be needed. Higher dry compression strength and green compression strength are required during metal pouring to withstand the metallo-static pressure of the molten metal, reduce mould-collapse, cracking, erosion, and to enhance quality casting [12].

The green permeability of the sand deposit decreased as the grain size decreased. This agrees with earlier research finding, because, if the sand is too fine the porosity will be low leading to the production of low quality castings [1]. The lowest green permeability of 6.80 was obtained with the finest grain size of 125µm, while the green permeability of the coarse grain size of 1000µm was 8.00. High permeability is characterized by coarse and uniform graded sands, while surface fineness and low permeability are features of fine grained sands [4]. The grain size distribution of the sand affects the quality of the castings. Coarse grained sands allow metal penetration into the mould giving rise to poor surface finish of the castings [13]. Fine grained sand particles will on the other hand affect the porosity of the mould negatively, hence the direct proportionality between the grain size and the green permeability. It is necessary that a balanced distribution of the base sand grain sizes be obtained

Table.5: Summary of Statistical Analysis for the Effects of Grain Size on Moulding Sand Properties

Response	Name	Units	Analysis	Min	Max	Mean	Std. Dev.	Ratio	Model
R_1	GCS	KN/m^2	Polynomial	20.3	33.6	28.35	4.6957	1.65517	Quartic
R_2	DCS	KN/m^2	Polynomial	294	322	303.9	11.5407	1.09524	quadratic
R_3	GSS	KN/m^2	Polynomial	12.25	21	15.75	3.40539	1.71429	quadratic
R_4	DSS	KN/m^2	Polynomial	56	70	62.5	5.50757	1.25	cubic
R_5	Green Permeability	No	Polynomial	6.8	8	7.4	0.44347	1.17647	quadratic
R_6	Mouldability	%	Polynomial	73.31	96.68	87.5271	7.89399	1.31878	linear

Table 6: Optimization Solution for the Effects of Grain Size on the Properties of Moulding Sand.

Grain Size	GCS	DCS	GSS	DSS	Green Permeability	Mouldabilty	Desirability
409.917	33.283	313.310	14.595	68.360	7.474	88.364	0.567

The responses of the variable in table 5, showing the summary of statistical analysis and the predictive model equation types, were generated by Design Expert 10.0.2.0 software. While table 6 show the optimization result based on the models obtained for each variable. All the variables were set at maximum range to achieve maximum responses of the properties of the moulding sand.

4. Conclusion and Recommendations

4.1 Conclusion

The effect of grain size on the moulding properties of foundry sand has been studied in this work and the study was able to identify the following:

(1) If desirable moulding properties are required, a balanced distribution of sand retained on the 500µm and 355µm sieve apertures should be used since these grain sizes produced better combinations for all the moulding sand properties tested.

(2) The grain size analysis showed that more than 99% of the bulk sand was retained on the first few consecutive sieves. Thus, River Niger silica sand (Onitsha deposit) met the AFS standard specification for foundry sand. The grain fineness number (GFN) and average grain size of the sand deposit, all fall within the range recommended for wide application in sand casting.

4.2 Recommendations

Having studied the effects of this variable (grain size) on the moulding properties of River Niger sand (Onitsha deposit) bonded with Ukpor clay, it is pertinent to recommend as follows:
Onitsha deposit of River Niger sand and Ukpor clay are recommended for use as ingredients for synthetic foundry sand preparation.
That 500µm and 355µm grain sizes of River Niger Sand (Onitsha deposit) were identified as the particle size distribution that will produce desirable values for green and dry strengths, green permeability and mouldability.

Acknowledgement

The authors wish to sincerely appreciate the technical assistance of the staff of foundry workshop at the National Metallurgical Development Centre (NMDC), Jos.

References

[1] Jain, P.L., (2006): Principles of Foundry Technology, Tata McGraw-Hill Publishing Company Ltd, New Delhi, Ch3, pp. 55-151.

[2] Sobcezak J. and Purgert, R.M., (2002). The Use of Fly Ash as an Aggregate for Foundry Sand Mould and Core Production. Technical Report of U.S. Department of Energy (DOE), Federal Energy Technology Centre, PP. 1-56.

[3] American Foundrymen’s Society, (1968). Moulding Methods and Materials, AFS Handbook, Pp.1-286.

[4] Beeley, P.R., (2001). Foundry Technology, Butterworth-Heinmann, ch.4, pp.178-236.

[5] Ademoh, N.A., Ahmed, A.T. (2008). Estimation of the Effect of Kaolin Clay Addition on the Mechanical Properties of Foundry Moulding Sand Bonded with Grade 3 and 4 Nigerian Gun Arabic (Acacia Species). Middle East Journal of Scientific Research, vol.3, No.3, pp. 126-133.

[6] Edoziuno, F.O., Odo, J.U., Nnuka, E.E., (2015). Effect of Ukpor Clay Content on the Properties of Synthetic Moulding Sand Produced from River Niger Sand. International Journal of Research in Advanced Engineering and Technology, Vol.1,(3), pp.12-16.

[7] Ayoola, W.A., Adeosun, S.O., Oyetunji, A., (2013). Investigation into Foundry Properties of Oshogbo and Saki Silica Sand Deposits. Annals of Faculty of Engineering Hunedoara- International Journal of Engineering, Vol. 11 (3), pp. 213-218.

[8] Davies, W., (1950). Foundry Sand Control, United Steel Companies, Sheffield.

[9] Brown, J.R., (1994). Foseco Ferrous Foundryman Handbook, Butterworth- Heinemann Publishers, Oxford, PP. 3-6, 15-17, 27-85.

[10] Mclaws, I.J. (1971). Uses and Specifications of Silica Sand. Research Council of Alberta, Report 71-4, pp. 21-28.

[11] American Foundrymen’s Society, AFS. (1963). Foundry Sand Handbook; the American Foundrymen’s Society. Des Plaines, Illinois, 7th ed., pp. 1-216.

[12] Ihom, P.A., Agunsoye, J., Anbua, E.E., Ogbodo, J.N., (2011). Effects of Moisture Content on the Foundry Properties of Yola Natural Sand. Leonardo Electronic Journal of Practices and Technologies, Issue 19, July-December, pp.85-96.

[13] Rundman, K.B., (2000). Metal Casting Reference Book for MY4130 pp.11-16.