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Influence of Particle Size and Clay Content on some Moulding Properties of Ehalumona Sand Blended with Nkpologu Clay for Sand Casting Applications

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Abstract This paper investigated the influence of particle size and clay content on some moulding properties of as- received and graded Ehalumona sand- blended with Nkpologu clay for sand casting applications. X- Ray fluorescence (XRF) technique was used to determine the chemical compositions of the Ehalumona sand and Nkpologu clay sample. Sieve analysis of the sand samples was performed using an electronic sieve shaker whilst the green and dry compressive strength parameters of the “sand blends” were determined using a universal sand strength tester. XRF results showed that the Ehalumona sand is composed of 85.30% silica which can give it good refractoriness property while the chemical composition of the Nkpologu clay indicated that SiO_2 and Al_2O_3 are the major constituents, indicating that it belongs to the alumino-silicate class. The result of sieve analysis showed that the American Foundrymen Society (AFS) grain fineness number (GFN) of the as-received and graded Ehalumona sand can be varied between 15.18 and 50.93 while the average grain size of the sand can be varied between 347 µm and 651 µm showing that the Ehalumona sand can be engineered for suitable foundry operations. The results further showed that both the green and dry compressive strengths of the Ehalumona sand increases as the Nkpologu clay content of moulding sand “blend” was increased.

Keywords Moulding sand, Grain fineness number, Green Strength, Dry Strength, Sand Casti

1. Introduction

Sand casting remains one of the most widely used methods for producing castings despite the development of new technologies in casting such as investment and squeeze casting methods due to the low cost of raw materials, its versatility because of its use in manufacturing large and small components from low and high melting metals and alloys such as aluminium, copper, iron and nickel and because of the possibility of recycling the moulding sand [1].Castings generally find applications in engine blocks, mill rolls, machine tool beds, automobile and locomotive parts, water supply pipes and airplane components etc [2].

Atanda and Ibitoye [3] reported that almost all foundries in Nigeria engage in sand casting technique and that 60% of the needed raw materials such as synthetic sand and binders are imported. There is need to develop local alternatives for these imported foundry raw materials.

The sand casting process consists of pouring molten metal into a sand mould, allowing the metal to solidify, and breaking the sand mould to remove a casting product. The casting product can then be machined to improve surface property and achieve dimensional accuracy. The moulding sand used in sand casting processes can be from a natural deposit in which the base sand- silica is naturally bonded with clay or it can be made from a synthetic mixture of refractory sand such as zircon, olivine, chromite or silica sand with clay mineral or with organic binders such as dextrin, linseed oil, molasses and resins like phenol formaldehyde [4, 5]. The properties of good moulding sand include: permeability, cohesiveness, green and dry strength, plasticity, refractoriness and chemical resistivity etc. These properties depend on the composition, size and shape of the primary constituents of moulding sand which include: base sand (silica, zircon, olivine and chromite); binder (inorganic and organic); and moisture content as well as the type and amount of additives [6].Silica sand imparts refractoriness, chemical resistivity and permeability while clay, when mixed with water, imparts the necessary bonding strength to the moulding sand after ramming. However, as the quantity of clay is increased, the permeability of the moulding sand was reduced. Grain size of the base sand influences both permeability and strength properties of a moulding sand. Whereas the strength of a moulding sand decreases with increase in grain size, its permeability increases as grain size is increased [6]. It is, therefore, imperative that the grain size distribution of a moulding sand must be engineered to optimize its permeability and strength properties.It was reported in [7] that the grain size of moulding sands falls within the range of 0.1- 1.0 mm. According to Akintunde et al [8], sand suitable for moulding consists of silica sand and 5- 6% clay to act as a binder.

Stringent control of the properties of moulding sand is imperative for the consistent production of high quality castings. One of the most important factors contributing to higher productivity in modern foundry practice is the choice of the right type of moulding and binder materials. Amongst the various materials employed in foundry, sand is the chief variable as it occurs in nature with considerable diversity in composition. For this reason, sand for foundry applications needs to be evaluated to ensure that they are put to informed use[9].There is huge potential for the development of foundry sector in south eastern region of Nigeria, but one major challenge is the availability of moulding sand. There is the need to identify and characterize natural moulding sand in south east Nigeria for productive and profitable foundry business in the area.

Clay was added to give cohesion to moulding sands and it provides strength to the moulding sand and enables it retain its shape when compacted. The principal mineral constituent of clay is kaolinite. Clays also have high alumina content which makes them to be refractory in their characteristics [10].When clay is dissolved in water, it forms colloidal solution which binds the base silica sand particles together [10].

Mahesh et al [11], reported that the quality of casting is significantly influenced by the properties of the moulding sand such as green and dry strength, permeability, compactibility, refractoriness etc. All of these properties are in turn dependent on the cohesive qualities of the binder, moisture content and the grain size and shape of the base sand used.

Dieter [12] gave a satisfactory mould property range for the casting of various metals. He stated for instance that quality aluminium casting can be manufacture in a sand mould that has the following property ranges: green compressive strength 50- 70 KN/m^2, dry compressive strength 200- 2000 KN/m^2 and permeability number 10- 30.Some researchers have investigated the suitability of some Nigerian sand depositsfor foundry applications. Nuhu [13] evaluated the foundry properties of River Niger sand at Ajaokuta, Kogi state using kaolin and bentonite as binders and reported that kaolin has better influence on the green and dry strength of the sand. Katsina et al [14] characterized beach sands from Ugheli, Warri and Ethiope rivers in Delta state and reported that they are suitable for foundry applications.Edoziuno et al [15] prepared synthetic moulding sand using the Onitsha deposit of River Niger beach sand blended with Ukpo clay. They reported that both the sand and clay met the compositional requirements for preparing synthetic moulding sand and that the grain fineness number and average particle size of the sand deposit are within the range that is widely used in sand casting operations.

Njoku et al [16] investigated the moulding properties of Ehalumona/Kaolin clay blends for sand casting applications and reported that the sand deposit is high in silica (85.30 wt %) and generally has composition that is comparable with other natural moulding sands and that the grain fineness number and average particle size met the American Foundrymens' society standard specification for sand casting. Udeh et al [17] investigated the effect of cassava starch and water on the moulding properties of Nkpologu sand deposit in Uzo- uwani local government area of Enugu state, and reported that the addition of 8% water and 22% cassava starch conferred good compressive strength and plasticity that could produce good casting.The main objective of this research is to do further work on the experimental optimization of the moulding properties of the Ehalumona sand deposit by attempting to obtain optimal levels of such process parameters like base sand particle size and clay content in order to yield optimum property of the moulding sands and hence optimum quality characteristics of casting.

2. Materials and Methods

The moulding sand utilized was sourced from the bank of Ehalumona River in Nsukka Local Government Area of Enugu State, Nigeria while the clay was collected from a clay mine at Nkpologu in Uzo- uwani local government area of Enugu state.

2.1. Chemical Analysis

The major elements in the Ehalumona sand were determined at the Department of Geology, University of Pretoria, South Africa using an ARL Preform'X Sequential x-ray fluorescent spectrometer equipped with Uniquant software for analyses. The sand samples were mixed with boric acid for chemical analysis. The XRF result is shown in Table 1.

2.2. Grain size distribution test

As- received Ehalumona sand was graded into different grain size distributions by sieving the sand using a sieve with aperture size of 100 µm and collecting sand particles with > 100 µm grain size together. This was repeated with sieve, having aperture size of 250 µm and then with sieve having aperture size of 500 µm.Particle size analysis was carried out for the different graded and as- received samples by measuring the American Foundrymen Society (AFS) Grain Fineness Number (GFN) of the Ehalumona sand. 100 g of dried Ehalumona sand (as-received/graded) sample was poured into the topmost sieve of an array of 9 sieves of different mesh sizes arranged in descending order of aperture size. The nest of sieves was mounted on sieve shaker and shook for 15 minutes. The sand samples that were retained in each of the sieves were weighed and thereafter the Grain Fineness Number was determined as the ratio of the sum of product of the weight retained and the multiplier factor to the sum of weight percentage retained in sieves used as written in equation 1.

$$GFN = \frac{Weight\ retained\ \ in\ seives\ X\ Multiplier\ \ Factor}{Sum\ of\ weight\ Retained\ \ in\ Sieves} \quad (1)$$

2.3. Specimen Preparation

The research used experimental methods to determine the mechanical properties of Ehalumona sand blended with kaolin clay that was varied between 2 to 12% at fixed moisture content. Sand samples were oven dried to remove free water prior to blending. The sand, kaolin clay and added water were mixed in sand mixing machine for ten minutes and then moulded into cylindrical compacts for further analysis. The sand compacts were formed by ramming 130 g of sand blends in a metallic die with three blows of 6.5 Kg load from 10 mm height. Specimens for dry tests were oven dried at 110 ^oC for 1 hour prior to testing.

2.4. Bulk Density/ Apparent Porosity

The bulk density and apparent porosity tests were performed using the liquid displacement method based on the Archimedes' principle [18]. Flat porcelain samples were dried at 110 ^oC, fired to the temperatures of 900, 1000, 1100 and 1200 ^oC, cooled to the ambient temperature and the weights were measured and recorded as M_{DRY}. The samples were immersed in a beaker of distilled water and soaked for 24 hours. Excess water was removed from the samples using a moistened cloth prior to weighing and recorded as M_{SAT}. They were then suspended in a beaker of distilled water using a string and their suspended weights were measured as M_{SUSP} by measuring the weight of the beaker- filled with water with and without suspended porcelain sample and computing the differential weight. The bulk density and apparent porosity were calculated using the following formulae [18]:

$$\rho_{BUK} = \frac{M_{DRY}\ x\ \rho_{LIQ}}{M_{SAT} - M_{SUSP}} \quad (2)$$

$$\%\ Apparent\ Porosity = \frac{M_{SAT} - M_{DRY}}{M_{SAT} - M_{SUSP}}\ x\ 100 \quad (3)$$

2.5. Green and Dry Compressive Strength Test

The green compressive strength was determined using a universal sand strength testing machine by holding a prepared cylindrical specimen measuring Ø50 mm X 50 mm in the head of the tester and incrementally applying a compressive load until the specimen collapsed. Similarly for dry shear strength, the appropriate sample was initially baked in an oven at 110 ^{o}C and cooled in the oven prior to testing. Compressive strength was determined by dividing the load at which the sample collapsed by the cross sectional area of the samples.

3. Results and Discussion

3.1. Composition of moulding sand and clay

Tables 1 and 2 show the results of the compounds (oxides) that constitute the Ehalumona sand and Nkpologu clay respectively. It can be observed that the Ehalumona sand is high in silica (SiO_2) which constitutes 85.30% by wt of the sand. Other oxides include Al_2O_3, Na_2O, CaO and MgO which collectively constitute about 12.40% of the earthy material. It can also be observed that some other oxides such as Fe_2O_3, P_2O_5, TiO_2 and PbO are also present but in negligible amounts. The high silica content is desirable for the enhancement of its refractoriness and improvement of the thermal stability and chemical inertness of the moulding sand [19].The chemical composition of the Nkpologu clay indicates that SiO_2 and Al_2O_3 are the major constituents, indicating that it belongs to the alumino-silicate class.

Table 1: Chemical composition of Ehalumona sand

Compounds	**SiO_2**	**Na_2O**	**CaO**	**MgO**	**Al_2O_3**	**K_2O**	**Fe_2O_3**	**SO_3**	**TiO_2**	**P_2O_5**	**ZrO2**	**PbO**	**ZnO**	**CuO**
Wt %	85.3	2.34	2.32	2.23	5.48	0.51	1.23	0.16	0.08	0.04	0.03	0.02	0.01	0.01

Table 2: Chemical composition of Nkpologu clay

Compounds	**SiO_2**	**Na_2O**	**CaO**	**MgO**	**Al_2O_3**	**K_2O**	**Fe_2O_3**	**MnO**
Wt %	60.7	3.03	1.73	1.04	28.5	2.05	2.81	0.12

3.2. Grain distribution/Particle size analysis

Figure 1 and Table 3 show the results of grain size distribution of the as- received Ehalumona sand while Tables 4 and 5 show the calculation procedure for the American Foundrymen's Society grain fineness number (AFS GFN) and average grain sizeof the as- received and graded Ehalumona sand respectively. As shown in figure 1, about 90% of the as- received Ehalumona sand are retained in sieves that have aperture sizes that ranged between 150- 500 µm. The as- received Ehalumona sand as well as the >100 and >150 graded samples can be said to have a wide sand distribution over a broad range of particle sizes and this enhances compactability while the >300 and >500 graded sandshave narrow sand distribution. As presented in Tables 3 and 4, the grain fineness number of the as- received and graded/screened Ehalumona sand ranged between 15.18 and 50.93 while their average grain sizesare between 347 to 652 µm. Fineness has significant effect on the physical properties of sand grains and clay in foundry sands. The standard value of GFN suitable for foundry operation ranges from 35 to 90. Hence the as received sand, >100, >150 and >212 sands are suitable for both medium and heavy ferrous and non- ferrous castings [20].

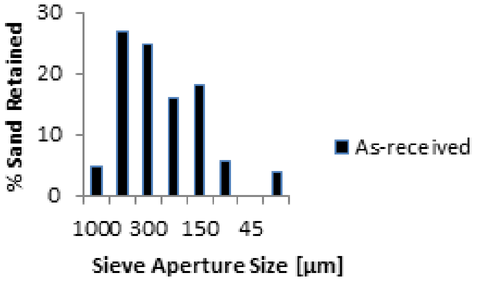

Figure 1: Grain size distribution of as- received Ehalumona sand

Determination of fineness of foundry sand is he AFS grain fineness number is a general indication of sand fineness and it is a useful parameter that represents approximately the number of openings per inch of a given sieve that would just pass the sample if its grains were of uniform size that is, the weighted average of the sizes of grains in the sample. According to the American Foundrymens' Society (AFS) [12], common foundry sands have grain fineness number of 40 to 330 and average grain size of 150 to 400 µm. The as- received, >100 and >150 graded sands met these requirements. The grain fineness number (GFN) and average grain size of the sand deposit are 40.1 and 421.7 µm respectively. This grade of fineness number is suitable for most types of alloy steels and non- ferrous metals as this belongs to the group of fineness number that has wide range of application in sand casting. The average grain size of sand falls within the common foundry sand range of 150 to 400 µm.

Grain sizes and their distribution in moulding sand influence greatly the properties of the sand. The sand with wide range of particles has higher compactability than the sand with narrow distribution. Wide sand distributions favour green strength while narrow grain distributions reduce it. The grain size distribution has significant effect on permeablility. Silica sand containing finer and a wide range of particle size will have low permeability as compared to those containing grains of average fineness but of the same size, i.e. narrow distribution. Coarse sand has the tendency to produce rough surface finish on castings due to the likelihood of penetration of liquid metal through them while fine sand produce good surface finish with the possibility of having lower permeability which can lead to gas defects [9]. The result of the grain size analysis showed that more 99% check 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.

Table 3: Grain size distribution of Ehalumona sand

Sieve Opening	**Percentage of sand retained [%]**					
	As received	**> 100**	**> 150**	**> 212**	**> 300**	**> 500**
1000	4.7	0.3	0.3	0.5	1.7	9.7
500	26.7	25.4	22.1	20.1	50	87.6
300	24.8	30.8	30.2	40.7	33.4	2.5
212	15.9	17.5	20.7	33.7	14.8	-
150	18	15	25.1	4.8	-	-
100	5.6	9.4	1.5	-	-	-
75	-	1.3	-	-	-	-
45	-	0.2	-	-	-	-
<45	3.9	-	-	-	-	-
Total	99.6	99.9	99.9	99.8	99.9	99.8

Table 4: Calculation of grain fineness number

Sieve Opening	**Multiplier (Previous BS sieve number)**	**Products (% sand retained x multiplier)**					
		As received	**> 100**	**> 150**	**> 212**	**> 300**	**> 500**
1000	4	18.8	1.2	1.2	2	6.8	38.8
500	16	427.2	406.4	353.6	321.6	800	1402
300	30	744	924	906	1221	1002	75
212	50	795	875	1035	1685	740	-
150	70	1260	1050	1757	336	-	-
100	100	560	940	150	-	-	-
75	158	-	205.4	-	-	-	-
45	200	-	40	-	-	-	-
<45	325	1268	-	-	-	-	-
Total		5073	4442	4203	3566	2549	1515
GFN		50.93	44.46	42.07	35.72	25.51	15.18

Table 5: Calculation of average grain size

Sieve Opening	**Multiplier (Previous BS sieve number)**	**Products (% sand retained x multiplier)**					
		As received	**> 100**	**> 150**	**> 212**	**> 300**	**> 500**
1000	1180	5546	354	354	590	2006	11446
500	600	16020	15240	13260	12060	30000	52560
300	425	10540	13090	12835	17298	14195	1063
212	212	3371	3710	4388	7144	3138	-
150	150	2700	2250	3765	720	-	-
100	106	593.6	996.4	159	-	-	-
75	75	-	97.5	-	-	-	-
45	38	-	7.6	-	-	-	-
<45	38	148.2	-	-	-	-	-
Total		38919	35746	34761	37812	49339	65069
AGS (μm)		390.8	357.8	348	378.9	493.9	652

3.3. Bulk density and porosity of Ehalumona sand

Figure 2 shows the variation of relative density with clay for different particle sizes of the Ehalumona sand and at constant moisture content. As seen from figure 2, the relative density of the Ehalumona sand increases as the clay content is increased and at constant clay content, it (relative density) increases with the particle size of the base sand (Ehalumona sand) in the following order: 500 µm < as received < 100 µm < 250 µm. The bulk density of the Ehalumona sand/clay 'mix' ranged between 1.72 g/cm3 and 1.9 g/cm3 with many of the blends within the satisfactory range of 1.1 g/cm^3 and 1.8 g/cm^3 [14]. The amount of clay plays significant role in improving the relative density and in turn, strength of the green sand mould and should be controlled to minimize defects in castings. Figure 3 shows the variation of porosity with Nkpologu clay content. As can be seen, the porosity of the Ehalumona sand decreases as the clay content is increased and at constant clay content, porosity increases in the following order: as received < 100 µm < 250 µm < 500 µm. If the clay content is higher in sand mixture, the porosity is lowered due to fine clay particles occupy the spaces between sand grains and this also reduces the permeability of the moulding sand, leading to the production of defective castings [10].

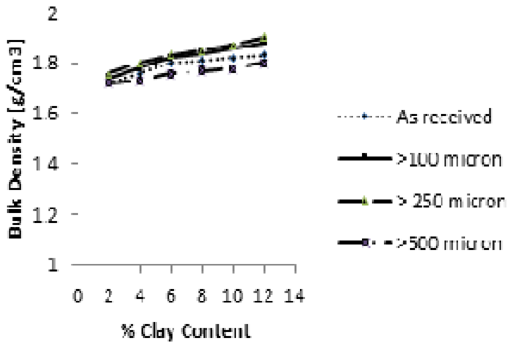

Figure 2: Variation of bulk density of halumona sand with Nkpologu clay content

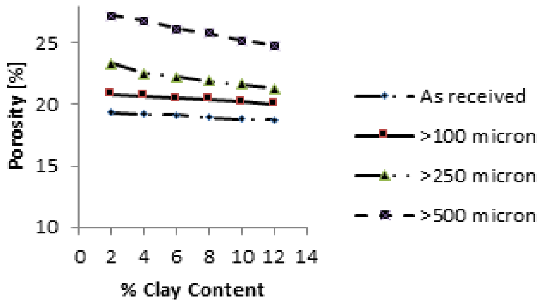

Figure 3: Variation of porosity of Ehalumona sand with Nkpologu clay content

3.3. Green and Dry Strength

An important requirement of a moulding sand is that it must have adequate green strength for making and handling mould and good dry strength to withstand mould erosion and metallostatic pressure of the molten metal and prevent expansion of the mould. The effect of Nkpologu clay content on the green and dry compressive strength of Ehalumona sand are shown in figures 4 and 5. Figure 4: Variation of green compressive strength with clay content.

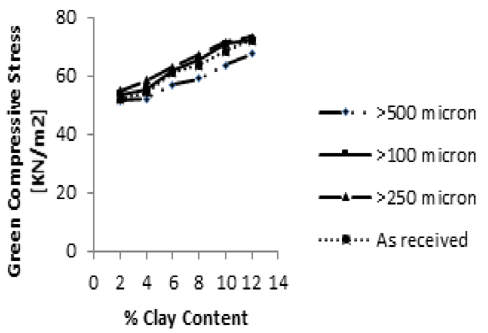

Figure 4: Variation of compressive strength of Ehalumona sand with Nkpologu clay content

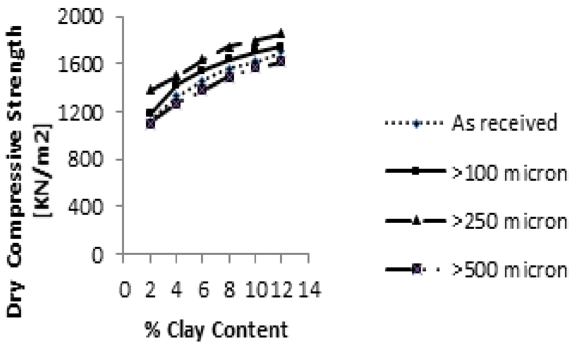

Figure 5: Variation of dry compressive strength of Ehalumona sand with Nkpologu clay

As shown in these figures, both green and dry compressive strength increase with clay content and vary with grain size according to the following order: 500µm < As received < 100µm < 250µm.The green compressive strength of the Ehalumona sand ranged between 51.55 KN/m^2 and 73.45 KN/m^2. Similarly the dry compressive strength is in the range of 1120 KN/m^2 and 1850 KN/m^2 and these properties (green and dry compressive strengths) are within the satisfactory property range for casting aluminium, brass, bronze, light grey iron and malleable iron [12]. Increase in compressive strength with clay content is attributable to fact that any sand when moist will show some bond strength due to the surface films of water absorbed on the sand particles. And it seems that the bond in natural moulding sand is due to a strengthening of the water bond by colloidal material such as ferric hydroxide absorbed on the sand surfaces, and by small particles of silt and clay which act as a reinforcing medium to the colloidal matter between the sand grains. Hence increase in the amount of clay increases the amount of the reinforcing medium. On drying, loss of adsorbed water produces shrinkage of the lattice and further strengthening of the bond [5]. Dry strength continues to increase probably due to improved distribution of the binder and the higher bulk density attainable. The order of variation of compressive strength with particle size is probably because the green strength of a moulding sand has a certain tendency, admittedly, not very pronounced, towards a maximum with a grain size which corresponds approximately to the medium grain size. At constant clay content and as the silica sand grain becomes finer, the film of clay between silica grain particles becomes thinner and this reduction in the thickness of binder film results in the lowering of the green strength. With very coarse grains, however, the number of grains and, therefore, the number of points of contact per unit of volume decreases so sharply that again the green strength is reduced. Thus moulding sand with intermediate particle size that ensures significant number of contact points and binder film thickness would show optimum strength [10].

4. Conclusions

The Ehalumona sand has been graded into sands with varying distributions of particle sizes. The as- received and graded sands were blended with the Nkpologu clay and tested for suitability as a moulding sand. The following conclusions can be drawn from the study:

- The American Foundrymen’s Society grain fineness number (AFS GFN) of the as- received Ehalumona sand falls with the range for general foundry practices while the GFN for some of the graded sands was greater than the recommended standard for moulding operations.
- The porosity of the Ehalumona sand increases with grain size while the relative density of the sand increases in the order: As received < 100 < 150 < 250 < 500 µm particle sizes.
- Addition of Nkpologu clay has beneficial effect on the Ehalumona sand and can increase the green and dry strengths of the Ehalumona sand.

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