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Development of Azare Silica Sand as A Moulding Material Using Kaolin as A Binder

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ABSTRACT: The research focuses on the foundry properties of developed Azare silica sand moulds and their suitability for casting cast iron. Natural Azare silica sand was washed, dried and sieved for grain distribution. Washed Azare silica sand, local kaolin and water were mixed in different ratio: 87.5:8:4.5, 86.5:9:4.5, 85.5:10:4.5, 84.5:11:4.5, 83.5:12:4.5 and 82.5:13:4.5 of A, B, C, D, E and F samples respectively. Developed Azare Silica sand mould test specimens were made from these six samples. The physico-mechanical properties such as green compression, dry compression strength of these developed Azare Silica sand mould specimens were investigated. It was discovered that high green compression strength, dry compression strength ranges between 47.58-125.49kN/m^2, 553.21-726.96kN/m^2 respectively due to local kaolin. The best properties were obtained from sample C and were used to cast large grey iron pulley of about 55kg satisfactorily.

KEYWORDS: Azare silica sand, Moulding sand, Kaolin, Binder, Foundry.

I. INTRODUCTION

Azare silica sand is a naturally clay bonded sand scattered all over area of Azare in Bauchi State of Nigeria. The Silica sand has been used in the local foundry and school workshops in Bauchi state for over four decades and later in Jos and its environs for casting Aluminium cooking utensil, radiator fans and other simple shape of Aluminium products [1]. In the previous research work carried out on natural Azare silica sand showed that mechanical properties such as green/dry compression strengths and green/dry shear strengths are 46kN/m^2/ 85kN/m^2 and 14kN/m^2 /37kN/m^2 respectively. The sand burns and is prone to thermal cracking, spalling or scabbing at temperature above 1300^{o}C. These properties outlined above are essentially very excellent for non-ferrous casting but cannot be used for casting medium and large cast iron [1].

In this present work, various ratios of washed Azare silica sand – kaolin –water system is used for preparing developed Azare silica sand mixtures to make developed Azare Silica sand moulds on which various tests are carried out such as moisture content, flowability, permeability, shatter index, green/dry compression and shear strength and so on. Casting of cast iron of medium or large size from the best sand moulding mixture properties is carried out to confirm moulding mixture properties obtained experimentally from the laboratory.

The mechanical moulding properties of this developed Azare silica sand moulds are intended to eliminate the shortcoming properties that made Azare silica sand unfit for casting medium and large cast iron. The developed Azare silica sand moulds are intended to be used specifically for casting medium and large cast iron. This paper seeks to equip researchers with information about developed Azare silica sand mixtures and moulds for further development and adaptation for use in Nigerian cast iron foundries.

II. MATERIALS AND METHODS

The following materials and methods were used for the research work; raw natural Azare silica sand was collected from deposit sites in Azare of Bauchi State and the kaolin was sourced from Jos in Plateau State.

The natural sand was collected in form of particles and lumps. The lumps of the sand were broken down into particles by the use of hand rammer and then washed in hot water to remove natural clay content from it, dried and sieved for grain distribution analysis as well as for the determination of the physico - mechanical properties.

2.1 Preparation of Standard Test Specimens of Developed Azare Silica Sand Moulds.

Table 1: Percentage Ratios of the Mixtures

Materials	Test sample					
	A	B	C	D	E	F
Sand (%)	87.50	86.50	85.50	84.50	83.50	82.50
Kaolin (%)	8.00	9.00	10.00	11.00	12.00	13.00
Water (%)	4.50	4.50	4.5.00	4.50	4.5.00	4.5.00

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Table 2: 170g Weight of Mix per Specimen (680g for production of four specimens).

Materials	Test sample mix weight (g)					
	A	B	C	D	E	F
Sand (g)	595.00	588.20	581.40	574.60	567.80	561.00
Kaolin (g)	54.40	61.20	68.00	74.80	81.60	88.40
Water (g)	30.60	30.60	30.60	30.60	30.60	30.60

In Accordance with the American Foundry-men Society standards [2], sand mould specimens from six mix sand samples were produced as follows; weights of 170g developed Azare silica sand moulds of diameter 50mm and 50mm height were made from the varying percentages of local kaolin; 8%, 9%, 10%,11%,12% and 13% by weights of kaolin and varied percent weights of washed Azare Silica Sand tempered with constant water of 4.5% shown in the Tables 1 and 2. Each mix was poured into the specimen tube and mounted on standard rammer machine respectively and then rammed by impact with three blows of rammer head weight of 6.35kg which fell freely from a distance of 50mm into each mix sand in the specimen tube to produce moulds of diameter 50mm and 50mm height.

2.2. Sieve Analysis Test

A set of standard testing sieve with size number /aperture 1.40mm, 1.00mm, 0.71mm, 0.50mm, 0.355mm, 0.25mm, 0.18mm, 0.125mm, 0.09mm, 0.063mm and -0.063mm (Pan) was stacked in sequence with the coarsest at the top and fix on shaker devices. One hundred grammes (100g) of washed and dried Azare Silica Sand at the temperature of 110^{o}C in dry cabinet was poured at the top sieve and vibrated or shaken for 15minutes. After shaking, the sand grains in each sieve and the bottom pan were weighed and recorded.

2.3. Clay Content Determination Test

A 50grammes of washed and dried Azare Silica Sand was poured in a wash beaker, filled the wash beaker with 47ml distilled water and added 25ml of 3% sodium hydroxide solutions. This content was stirred together in the wash beaker with the aid of mechanical stirrer in a washing machine for five minutes. Little water was used to wash into the wash beaker the sand particles that adhered to the stirrer. It was kept quiet to settle for 10minutes and the suspension formed as a result of clay was siphoned off. The same procedure was followed using only fresh water on the same sand for several times until the water was clear for the grain particles to be seen below the wash beaker. The water was siphoned off. The remaining sand grains from the bottom of the wash beaker was dried in an oven to a temperature of 110^{o}C and then weighed.

2.4 Green Bulk Density Test

Standard sand mould specimens of diameter 50mm by 50mm height were made from mix sand weights of 170g ejected from specimen tube using stripping post. Each specimen was weighed with a weighing balance (electric) and the volume calculated. These ratios of weight of mix sand mould specimen to the volume gave the green bulk density in g/cm^3.

2.5 Moisture Content Test

Mix sand samples were weighed on a weighing balance of speedy moisture tester out of 170g which was put into speedy moisture tester container with a calibrated scale attached. 2 spoon measure of powdered calcium carbide was added and covered up immediately. It was shaken firstly for 2 minutes with the calibrated side of the speedy moisture tester turning downwards. It was shaken again for one minute with the calibrated side of the speedy moisture tester turning upward this time around. The moisture tester was read directly from calibrated scale on the instrument. :

$$2H_2O + CaO_2 \longrightarrow C_2H_2 + Ca(OH)_2 \quad \ldots. \; 1$$

2.6 Flowability Test

Developed Azare silica sand standard mould specimen in each specimen tube were positioned in rammer machine and weight of a 6.35kg of the rammer head was used to give each standard sand mould specimen the fourth blow and recorded the height of the specimen. This is followed by the fifth blow and recorded the height of each specimen. The movement occurring between the fourth and fifth blow was taken from scales of value assigned to the movement with zero travel corresponding to maximum flowability.

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2.7 Permeability Test

Developed Azare silica sand standard mould specimen of diameter 50mm and 50mm height and of 170g still in specimen tube were mounted on standard permeability meter in inverted form. The standard permeability meter machine was switched on and the pressure lever was pushed and the scale reading was recorded at the time the arrow indicator was stable. Big orifice (1.5mm) was used for permeability above 50 or mould for casting cast iron.

2.8 Shatter Index Test

The standard developed Azare silica sand mould specimens of diameter 50mm and 50mm height and of 170g was each ejected from specimen tube with stripping post which fell from a height of 1.8m to a mesh of 1.25cm on the steel anvil. The fragments that were collected in the 1.25cm mesh sieve were weighed for each specimen. The shatter index being that percentage of the total weight of mix sand retained on sieve.

2.9 Green Strength Test

Developed Azare silica sand standard green mould specimens of diameter 50mm by 50mm height and of 170g were each fixed on the universal sand strength testing machine using compression holding device and switched it on. The point in the scale at which each standard specimen crushed or squeezed was read as the green compression strength of the specimen in kN/m^2. For green shear strength, the same apparatus, materials and procedures were used but with a change of compression strength holding device to shear strength holding device and the point on the scale at which fracture occurred on each specimen was read as the green shear strength of developed Azare silica sand mould specimen expressed in kN/m^2.

2.10 Dry Strength Test

With dry specimens but the same apparatus and procedure for green strength test were used. The point on the scale of the machine at which crushed or squeezed occurred on each specimen was read as the dry compression strength and the point on the scale of the machine at which each specimen fractured was read as the dry shear strength of developed Azare silica sand mould expressed in kN/m^2.

2.11 Refractoriness Test

The cuboid specimens of 10.8 by 5.3 and by 2.0cm of developed Azare silica sand mould specimens were placed on ceramic blocks in electric furnace and were heated to 1,200^oC and gradually increased to 1550^oC for two hours. The changes in dimension and appearance were observed.

III. RESULTS AND DISCUSSION

3.1 Sand Grains Distribution of washed Azare silica sand.

The sand grains distributions in sieves are as shown in Table 3. Each of the sieve-size 1.40mm and 1.00mm retained very less weight of sand grains but sieve –size 1.00mm is of more quantity than that of sieve – size 1.40mm.The weight of sand retained in sieve- sizes 0.063mm and pan together is lesser compared to sieve-size 1.40mm. Furthermore, the weight of sand retained in both sieve-sizes 0.71mm and 0.50mm are much higher than sieve –size 1.00mm. The weight of sand retained in sieve size 0.09mm is as much as that of the sieve-size 0.50mm and finally, sieve-sizes 0.355mm to 0.125mm are where the major sand grains are retained and the sieve-size 0.18mm retained the highest of sand grains of 33.35g. The sand grain size range from medium to fine [3,4]. The only significant difference between washed sand and the natural sand is that washed sand has lesser sand grain retained in each of sieve-sizes 0.063 and the pan. Experimental results for some properties obtained from washed sand sieve analysis are as shown in Table 4.

Table 3: Sieve Analysis Experimental Result Weight of Sand in Sieve Shaker = 100g

S/N	Sieve size (mm)	Weight retained (g)	Weight retained (%)	Passing finer (%)	Cumulative Retained (%)	Multiplier	Product
1	1.40	0.28	0.28	100	0.28	6	1.68
2	1.00	0.86	0.86	99.72	1.14	9	7.74
3	0.71	3.42	3.42	98.86	4.56	15	51.30
4	0.50	4.77	4.77	95.44	9.33	25	119.25
5	0.355	11.20	11.20	90.67	20.53	35	392.00
6	0.25	21.63	21.63	79.47	42.16	45	973.35
7	0.18	33.35	33.35	57.84	75.51	60	2,001.00

8	0.125	19.94	19.94	24.49	95.45	81	1615.14
9	0.09	4.41	4.41	4.55	99.86	118	520.38
10	0.063	0.11	0.11	0.14	99.97	164	18.04
11	Pan	0.02	0.02	0.03	99.99	275	55.00
12	Total	99.99	99.99	0.01			5754.88

$$\text{AFS (GFN)} = \frac{\text{Totalproduct}}{\text{Weightretained}\quad(\%)} = \frac{5754.88}{99.99} = \text{GFN} = 57.55$$

3.2 The Grain Fineness Number of Washed Azare Silica Sand

The grain fineness number (GFN) of the washed Azare Silica Sand is as indicated in Table 3. It falls on a high side of medium size sand of a range 45 to 60, and very close to the range of fine size sand of 60 to 80. This sand is classified as GFN 57.55 and is medium to fine sand grain [3,4]. It is exceptionally suitable for ferrous casting since foundry sand of grain fineness number of 35 to 90 are acceptable for ferrous casting [3,5,6]. There is no significant difference between washed Azare Silica Sand and natural Azare Silica Sand in grain fineness number.

3.3 Trace of Natural Clay of Washed Azare Silica Sand

The trace of natural clay content in washed Azare Silica Sand is very small as shown in Table 4 which has very little or no effect on bond between the grains of the sand both in green and dry state of the sand. This sand can be classified as a synthetic sand because synthetic sand is considered as an aggregate composition of silica particles with very little or no clay content. The average synthetic sand requires working moisture of 3% [4,7]. Natural Azare Silica sand requires no binder such as kaolin hence it cannot be used for casting cast iron.

Table 4: Experimental Results for Some Properties from Washed Sand Sieve Analysis

Characteristics	Description/Quality
Colour	Red
Grain Shape	Round (Spherical)
Grain Size	Medium to fine
Spread of Grains Distribution	Four (4) consecutive sieves
Dust or fines	0.13%
Clay Content	0.85%

3.4 Green Bulk Density of Developed Azare Silica Sand Moulds

The green bulk density of developed Azare silica sand mould at each percentage of local kaolin is indicated in Table 5. This bulk density implies that metal penetration into the walls of mould cavity during liquid metal pouring will be minimized because the sand grains are round and are well spread over four consecutive sieves which give very good compaction to the mould [5,6]. The green bulk densities of the developed Azare silica sand moulds are not quite different from that of natural sand mould.

Table 5: Experimental Results for Some Physico – Mechanical Foundry Properties of Developed Azare Silica Sand Moulds

S/N	Properties	Samples with varied content of Local kaolin					
		A (8%)	B (9%)	C (10%)	D (11%)	E (12%)	F (13%)
1	Green Bulk Density (g/cm^3)	1.73	1.73	1.73	1.73	1.73	1.73
2	Moisture content (%)	2.47	2.57	2.59	2.77	2.95	3.17
3	Flow ability	Maximum	Maxim	Maximu	Maximum	Maxi	Maximu

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	(%)		um	m		mum	m
4	Permeability number	69.3	65.0	61.3	55.7	52.0	49.3
5	Shatter index (%)	52.94	56.20	63.52	66.02	68.22	69.97
6	Green compression strength (kN/m^2)	47.58	57.92	73.09	98.60	115.1 5	125.49
7	Green shear strength (kN/m^2)	26.89	27.58	29.42	31.03	32.41	33.79
8	Dry compression strength (kN/m^2)	553.21	592.97	627.45	658.93	686.9 7	726.96
9	Dry shear strength (kN/m^2)	241.33	275.0	310.28	334.18	365.4 4	393.02

3.5 Moisture Content of Developed Azare Silica Sand Mixtures

The test result of moisture content in developed Azare Silica sand mixtures is as shown in Table 5 and **Fig.1.**

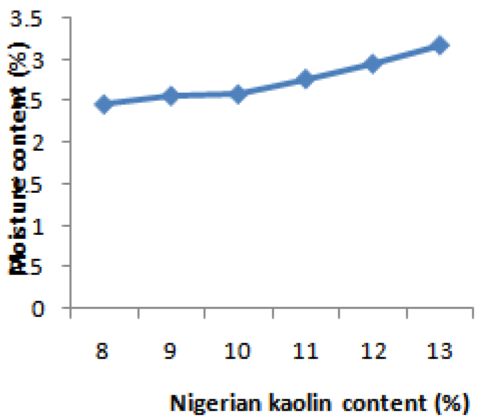

Fig 1: moisture content of sand moulds bonded with varying percentages of Nigerian kaolin and 4.5% water

These contents increased with increasing Nigerian kaolin percentages from 8% to 13%. This moisture content fall within the acceptable range of average synthetic sand working moisture of 3% [4,7]. For Natural Azare Silica Sand, 6.8% of water is used for tempering the sand which gives higher moisture content.

3.6 Flowability of Developed Azare Silica Sand Moulds

From the result of the test carried out shown in Table 5. It was observed that the flowability value of the developed Azare Silica sand mixtures is maximum at any Nigerian kaolin percentage from 8% to 13%. This could be as a result of round grains of the sand which rammed easily with less frictional forces opposing the free movement of the grains to form a compacted mould [3,5]. The sand mixture of natural Azare Silica Sand has a flowability of 68% which is as well acceptable for casting purposes.

3.7 Permeability of Developed Azare Silica Sand Moulds

The result of permeability of developed Azare Silica Sand moulds test is as shown in Table 5 and Fig. 2. The sand permeability decreased with

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increased in Nigerian kaolin percentage from 8% to 13% in developed Azare Silica Sand mould. These permeabilities are as a result of kaolin, low moisture content with less dust or fines and well spread grains distribution and also round grains of the sand [3,8]. The permeability of each of the six samples can be used for all non-ferrous and ferrous alloy metals except all steels [9]. The permeability values obtained are adequate for escape of vapour and gas from the moulds during the pouring of liquid metal. The permeability of natural Azare Silica Sand is 88 which is quite high compared to developed Azare Silica sand moulds.

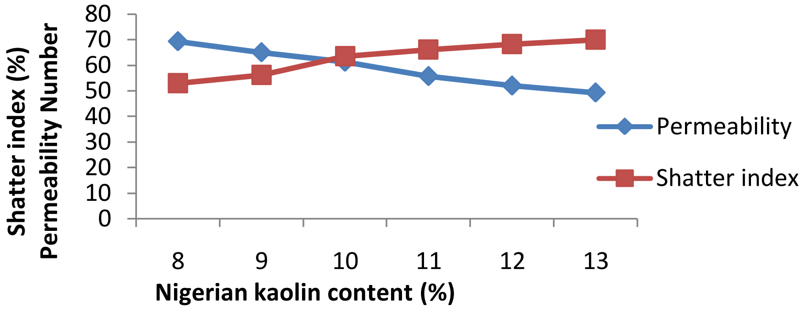

Fig. 2: green permeability and shatter index of sand moulds bonded with varying percentages of Nigerian kaolin and 4.5% water

3.8 Shatter Index of Developed Azare Silica Sand Moulds

The test result of shatter index of developed Azare silica sand moulds is as shown in Table 5 and Fig.2. It was observed that the shatter index values increased as the Nigerian kaolin percentages increased from 8% to 13%. Similarly shatter index increases as a result of increase in strength [10]. These relatively high shatter index values is due to the round-grains, medium to fine grain sand with very less dust or fines (0.13%) tempered with 4.5% of water and high percentages of kaolin used as binder. These values of shatter index indicated that the sand moulds are tough enough to aid satisfactory lift during pattern removal. The shatter index is acceptable in foundry practice since the values between 31 to 84% are quoted as representing the standard mouldable range [11]. The shatter index value of natural Azare silica sand mould is 80% which is quite high compared to developed Azare Silica Sand Moulds.

3.9 Green Compression Strength of Developed Azare Silica Moulds

The trend of increasing green compression strength of developed Azare silica sand moulds with increasing Nigerian Kaolin content from 47.58kN/m^2 at 8% Nigerian Kaolin content to 125.49 kNm^2 at 13% Nigerian kaolin content is as shown in Table 5 and Fig 3.

These relatively high green compression strengths is as a result of the sand being round-grains, medium of fine sand with very less dust or fines (0.13%) tempered with 4.5% water and addition of high percentages of Nigerian kaolin to the sand mix as a binder. The developed Azare silica sand moulds will withstand the withdrawal of

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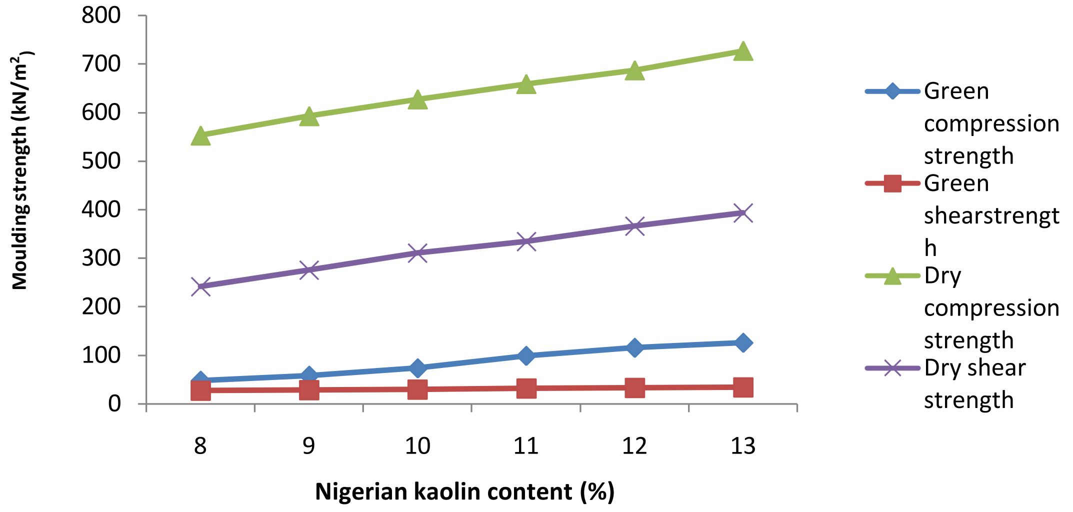

Fig. 3: green and dry compression strengths and green and dry shear strengths of sand moulds bonded with varying percentages of Nigerian kaolin and 4.5% water

pattern from the sand moulds without breakage, also able to resist the turbulent reaction of the liquid metal into the moulds thereby preventing erosion of mould cavity walls and reducing metal penetration into mould walls [3]. The usefulness of green compression strength of the sand moulds are; at 8% kaolin for casting malleable iron only, at 9% kaolin for casting malleable iron and light grey iron, at 10% kaolin for casting all types of steel and cast iron, at 11% for casting medium grey iron and heavy grey iron, 115.15k/Nm^2 at 12% kaolin and 125.15kN/m2 at 13% kaolin are too high for non ferrous alloy metals and all grades of cast iron sand casting [9,10]. Whereas natural Azare silica sand of 46 kN/m2 is only suitable for casting non-ferrous alloy metals and small malleable cast iron.

3.10 Green Shear Strength of Developed Azare Silica Sand Moulds

Green shear strength test result of developed Azare silica sand moulds is as shown in Table 5 and Fig.3. The trend of increasing green shear strength of the developed Azare Silica Sand moulds with increasing percentages of Nigerian kaolin varied from 20. 89 kN/m^2 at 8% kaolin to 33.79 kN/m^2 at 13% kaolin content. The round-grains, medium to fine grain with very less dust or fines of 0.13%, tempered with 4.5% of water and high percentages of kaolin used as binder contributed to the relatively high green shear strength of the developed sand mould at each percentage of kaolin added to the sand mixture.

This implies that the green shear strengths of the moulds should be able to prevent shearing of the sand moulds as liquid metal is being poured through the gating system and vapour and gas escaping through the risers to the atmosphere, and are suitable for casting [12]. The natural Azare Silica Sand mould has 14 kN/m^2 green shear strength which is only suitable for non-ferrous alloy metals.

3.11 Dry Compression Strength of Developed Azare Silica Sand Moulds

The test result of dry compression strength moulds at 8% Nigerian kaolin to 13% Nigerian kaolin is as shown in Table 5 and Fig.3. The trend of increasing dry compression strength of developed Azare Silica Sand moulds with increasing local kaolin content from 8% to 13% was observed. The dry compression strength of the moulds varied from 553.21 kN/m^{2}at 8% kaolin to 726.96 kN/m^2 at 13% kaolin content. The round grain, medium to fine sand with less dust or fines (0.13%), tempered with 4.5% water and high percentages of Nigerian kaolin added to the washed sand as a binder contributed significantly to the high compacted mass of the sand moulds which are further dried to give high dry compression strength sand moulds at each percentage of the kaolin added to the washed sand [3]. These strengths help to hold molten metal in the moulds while solidifying till when it has completely solidified. The dry compression strength of the six samples are all acceptable standards for casting ferrous and non ferrous metals [9,10]. Whereas natural Azare Silica

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sand mould has 85 kN/m^2 dry compression strength which can be suitable for aluminium after the necessary adjustment by the moulder.

3.12 Dry Shear Strength of Developed Azare Silica Sand Moulds

The result of dry shear strength of developed Azare Silica Sand moulds at 8% Nigerian kaolin to 13% Nigerian kaolin is as shown in Table 5 and Fig.3. The trend of increasing dry shear strength of developed Azare Silica Sand moulds with increasing Nigerian kaolin content varied from 241.33kN/m^2 at 8% kaolin to 393.02kN/m^2 at 13% kaolin content. These relatively high dry shear strength is because the sand is round grain, medium to fine sand with less dust or fines of 0.13% tempered with 4.5% of water and high percentages of kaolin used as binder and drying of the moulds which contributed in no small measure to high compacted mass of the sand moulds [3,8,12]. These dry shear strengths help to hold molten metal in the mould until it is completely solidified. These dry shear strengths can be used to cast non-ferrous and ferrous alloys metals. The dry shear strengths are quite higher than that of natural Azare Silica Sand mould.

3.13 Refractoriness of Developed Azare Silica Sand Moulds

The refractoriness of all samples of developed Azare silica sand moulds were found to be 1,500^{o}C as shown in Table 6. As Nigerian kaolin percentages increase so the increase in dry bulk density and decrease in linear expansion at the refractoriness temperature as shown in Table 6. The linear expansion at refractoriness temperature of 1,500^{o}C for the six samples will not significantly affect the dimensional accuracy of castings.

Table 6: Experimental Result for Refractoriness of Developed Azare Silica Sand Moulds

S/N	Samples	Local kaolin (%)	Dry bulk density (g/m^3)	Refractoriness (1500^{o}C) change in length (%)	Refractoriness (^{o}C)
1	A	8	1.80	+3	1500
2	B	9	1.80	+3	1500
3	C	10	1.79	+3	1500
4	D	11	1.80	+3	1500
5	E	12	1.86	+2	1500
6	F	13	1.88	+2	1500

With this refractoriness temperature value of all the samples of developed Azare silica sand moulds showed in Table 6 inferred that it is quite suitable for all types of cast iron and non-ferrous alloy metals with melting temperature below 1,500^{o}C [8], which is much better than that of natural Azare silica sand mould.

IV. CONCLUSION

The research revealed that sample A at 8% Nigerian kaolin and sample B at 9% Nigerian kaolin of developed Azare Silica Sand Moulds have good physico-mechanical properties suitable for casting malleable iron

Sample C at 10% Nigerian kaolin of Developed Azare Silica Sand Mould has the best and excellent properties and was used for casting trial of a smooth large grey iron of about 55kg pulley shown in Appendix; plates i and ii.

Sample D at 11% Nigerian kaolin developed Azare Silica Sand Mould properties are quite suitable for medium grey iron. However, samples E at 12% Nigerian kaolin and F at 13% Nigerian kaolin are not suitable for casting any grade of cast iron due to their very high green compression strengths. Nigerian kaolin significantly enhanced the strong mechanical bonding properties of all the sand samples, and hence it can serve as a binder for Nigerian cast iron foundries.

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APPENDIX: HEAVY GREY IRON CASTING FROM DEVELOPED AZARE SILICA SAND MOULD

plate i: casting as recovered from mould

plate ii: casting after fettling

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