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The Use of Yam Flour (Starch) as Binder for Sand Mould Production in Nigeria

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Abstract: Foundry is the mother of all industries for the reason that it provides components and raw materials for all other industries. This presupposes that there will be no true industrialization without a solid based foundry industry. Foundry as a manufacturing process through liquid route relies on the imported raw materials which are basically expensive. The current standard in Nigeria and other developing countries of the world have a very little advancement due to lack of affordable local sand binders, hence, the room for improvement. Study was carried out using Dukku Silica sand, from Dukku River of Kebbi State, Nigeria which was collected and analysed in terms of its grains size and clay content; its suitability in mould making was accessed to meet the basic requirements of moulding sand. The experimental study focused on the mechanical properties, such as green/dry compressive strengths, shatter index, collapsibility and permeability. In addition, the effect of the local binder addition was also investigated in this study by varying water and binder contents. The results show good properties for casting non-ferrous metals, malleable iron and light grey iron when the optimum amounts of binder, as obtained in this work, are used for optimum performance. The findings of this study might be of help to the foundry men involve in sand mould production in Nigeria and other developing countries of the world.

Key words: Binder · Moulding sand · Yam flour · Foundry

INTRODUCTION

Nigeria is richly gifted with agricultural and mineral resources. Unfortunately most of these resources are in their natural forms rather than usable forms in terms of quality and specification. However, industrial development and national self-reliance can only be achieved when industries start developing the locally available materials, which can in turn improve the economy of the country. It is true to say that the major companies nowadays owe their origin and continued existence to the emergence of new products, improved manufacturing processes and utilisation of natural resources [1, 2].

Foundry technology is developing in Nigeria and therefore, high demand for raw materials. New materials continue to be developed to meet special requirements, which require special processing in order for their properties to be effectively utilised. High cost of imported binders has generated great interest in characterising the locally available materials, therefore necessitating the need to look into domestically available binders that will meet the criteria for manufacturing, i.e. reliability, cost, toxicity and availability [3]. There is high occurrence of yam sourced from Kebbi State, Nigeria and different parts of the country which can be used in many applications such as flavours, adhesive and bakery etc. It is therefore considered pertinent to have their mechanical properties tested to be able to characterise their viability for further industrial and laboratory applications. They are all expected to provide the primary functions of starch (starch bond) and be able to provide green strength to the synthetic moulding sand.

Sand casting involves ramming of moulding sand (silica sand with a proportion of any other binding agent) around a pattern of the part to be made. The pattern, which is generally made of hard wood, has to be made somewhat oversize than the required dimensions of the finished casting, in order to allow for contraction of the casting during the solidification and subsequent cooling. Most metals and alloys can be cast in green sand mould; the size of castings that can be produced ranges from small components to batch production, with very low tooling costs and a recycle of moulding and core sands by means of mulling and sieving operations. The main disadvantages of the process are poor dimensional accuracy and surface finish of the cast products; in addition the mould can only be used once [4-6].

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Table 1: Satisfactory property ranges for sand castings [11]

Metal	Green Compressive Strength (KN/m^2)	Dry Compressive Strength (KN/m^2)	Permeability No.
Heavy Steel	70-85	1000-2000	130-300
Light Steel	70-85	400-1000	125-200
Heavy Grey Iron	70-105	350-800	70-120
Aluminium	50-70	200-550	10-30
Brass and Bronze	55-85	200-860	15-40
Light Grey Iron	50-85	200-550	20-50
Malleable Iron	45-55	210-550	20-60
Medium Grey Iron	70-105	350-800	40-80

This paper reports the result of a study carried out on the investigating the viability of using Yam flour (starch) as sand binder use in local foundries, which can in turn improve the economy and form a basis for the evolution of modern casting technology in Nigeria and other developing countries of the world. Measurement of the mechanical properties such as green/dry compressive strengths, shatter index, collapsibility and permeability of sand mould specimen bonded with yam flour (starch) obtained from Kontagora, Niger State, Nigeria and to compare results with standard to ascertain its efficacy for foundry usage. The standard ranges of these properties are as presented in (Table 1).

MATERIALS AND METHODS

Materials: The materials used are: Dukku silica sand (which was obtained along the River band of Dukku in Birnin Kebbi, Kebbi State, Nigeria), Yam from Kontagora local Government, Niger State, Nigeria), standard specimen moulding box and distil water.

Equipment: A standard foundry equipment - universal sand-strength testing machine, mechanical rammer, moisture tester, permeability machine, BSS set of sieves and shatter index tester in the foundry shop of Waziri Umaru Federal Polytechnic, Birnin Kebbi and National Metallurgical Development Centre Jos, Plateau State, Nigeria was employed to measure the most relevant properties (green/dry compressive strengths, shatter index, moisture content, collapsibility and permeability) of foundry sand.

Particles Size Analysis: The dried known quantity 50gm of Dukku river silica sand grains free of clay was used to determine the fineness number, using a set of standard testing sieves. The BSS No. of 6, 12, 20, 30, 40, 50, 70, 100, 140, 200 and 270 was used. The sand was placed on the coarsest sieve at the top and after 15 minutes of vibration, which is the recommended shaking time to achieve complete classification of the sand, the weight of the sand retained on each sieve was obtained and converted to a percentage equivalent [Table 2]. Each percentage was multiplied by a factor and the fineness number was obtained by adding all the resulting products, dividing the total by the percentage of sand retained and grain fineness number (BSS) were computed according to equations [1, 2]. The purpose of the analysis is to determine the distribution of grain sizes within the sand. Sands used in foundry have a wide range (40-220) of fineness number. Higher numbers represent fine sands generally used for light castings, coarse-grained sands with lower fineness numbers are used in steel castings [7].

Table 2: BSS sieve analysis of Dukku silica sand

Mesh	Amount of sample retained on sieve (50g)	% Retained	Multiplier	Product
6	0.00	0.00	-	-
12	0.10	0.10	10	1.00
20	1.00	2.00	12	24.00
30	6.15	12.30	20	246.00
40	8.12	16.24	30	487.20
50	20.32	40.64	40	1625.60
70	5.12	10.24	50	512.00
100	4.30	8.60	70	602.00
140	3.00	6.00	100	600.00
200	1.20	2.40	140	336.00
270	0.00	0.00	200	0.00
Pan	0.00	0.00	-	0.00
Total	49.31	98.52	-	4433.8

$$Average\ grain\ finness = \text{Total Product} / \%\ retained \quad (1)$$

$$Average\ grain\ finness = 4433.8 / 98.52 = 45 \quad (2)$$

Moisture Content Determination: The moisture contents were determined using a speedy moisture tester. A sample of each mixture was weighed on the weighing balance of the tester and poured into the flask of the moisture tester. The flask was shaken for the recommended 3 minutes and percentage moisture content of the sample was read directly from the calibrated dial instrument at the top of the flask attached to the machine.

Green/Dry Compressive Strengths Determination: The green compressive strength test was carried out to assess the bond strength of the green sand.

Green compressive strength test was performed immediately after the specimen was stripped from the tube to prevent any increase in green strength due to air-drying with increase in exposure time [8]. The silica sand of fineness number of 45, according to the British standard, was used to produce test specimens with different percentages of yam flour (starch) as the binder. 160g sand was poured into the standard cylindrical test tube with diameter of 50 mm and length 50 mm, rammed by impact with three blows of 6.50 kg weight. By manually turning ramming device, the weight was dropped from a height of 50 mm and the test-piece was stripped from the tube. Stead increase in load was applied on the specimen under the universal sand-strength testing machine until failure occurred and the load at which the sample collapsed was recorded. Each of the six samples was subjected to gradual load on the machine in the foundry workshop of Waziri Umaru Federal Polytechnic Birnin Kebbi, Nigeria. Same procedure was used (i.e. as in green compressive strength test) in preparing test samples for dry compressive strength, but in this case samples were sun-dried for two days before the tests.

Shatter Index Determination: The shatter index test was performed with the shatter index tester. The test sample was prepared without stripping. The sand test-piece was positioned at the top of a tower 1.83 m high and ejected from a specimen tube by gently pulling down the handle onto a steel anvil head 75 mm in diameter. On impact, the test-piece shatters, some of the sand remaining on the anvil and the rest being projected on to 12.5 µm mesh B.S. sieve. The sand which passes through the sieve into the sieve pan was weighed and the shatter index was computed. Shatter index values ware used to determine the collapsibility of the moulding sand [9].

Permeability Determination: Permeability was determined by measuring the rate of flow of air through a standard rammed test-piece. Standard air pressure of 9.8×10^2 N/m^2 was passed through the specimen tube that contained green sand placed in parameter of the permeability meter and time for 2000cm^3 of air was recorded to determine permeability in numbers [10]. Direct-reading instrument was used in determining the permeability by increasing percentages of yam flour (starch) content.

RESULTS AND DISCUSSION

Table 3 presents results of the mechanical properties tests including moisture content, green/dry compressive strengths, shatter index, collapsibility and green permeability of specimens moulded with percentages of yam flour (starch) while result of particle size analysis of Dukku silica sand is shown in table 2. The values obtained are within the acceptable ranges [11] of a good moulding sand and active binder. Moisture content test determines amount of dampness of mould specimen; green/dry compressive strengths (Bond Strength) measures the ability of the sand mould to withstand the pressure of molten metal during casting in green or dry state; shatter index measures collapsibility of sand mould after casting for easy shake out and permeability measures ease of escape of evolved gasses during casting to prevent some casing defects such as porosity and gas inclusions.

Table 3: Measured Foundry Properties of sand mould bonded with varying percentages of yam flour (starch) and moisture content

Sample: Yam Flour (starch)	A	B	C	D	E	F
Binder Content (%)	5	10	15	20	25	30
Moisture Content (%)	2.0	3.0	4.0	5.0	6.0	7.0
Green Strength (KN/m^2)	10	43	48	52	54	32
Dry Strength (KN/m^2)	119	152	190	240	309	295
Shatter index (No)	77	75	73	70	68	65
Collapsibility (No)	5.1	4.2	3.7	3.5	3.2	2.4
Green Permeability (No)	135.0	133.0	124.0	112.0	100.0	92.0

The sieve analysis of Dukku silica sand result presented in table 2 shows that the sand has 45 BSS fineness number which make the sand to be coarse in nature and can effectively be used for steel castings, because of its lower fineness number. The moisture was observed to increase with binder content steadily until 6%. This is probably due to the fact that the binder and sand took up some moisture and further increase in binder/moisture resulting in unsatisfactory mixture. This showed that 25% binder with 6% moisture is the optimum mix for mould binding.

The Green/dry compressive strengths increased with binder from 10/119KN/m^2 at 5% to a maximum of 54/309KN/m^2 at 25%and decreased to 32/295KN/m^2 at 30% binder (Figure 1).

This showed that inadequate moiture with incresing binder must have caused the weekening of the compressive strength at 30% binder. This result compared with the standard in table 1 shows that the mix with 25% binder (54/309KN/m^2) is suitable for green/dry sand mould casting of alluminium, brass and bronze, malleable and light grey iron. Although, the finness number of the sand proves its suitability for steel casting but mechanical properties obtained with the mixture did not agree with the standard, probably due to the proportion of organic

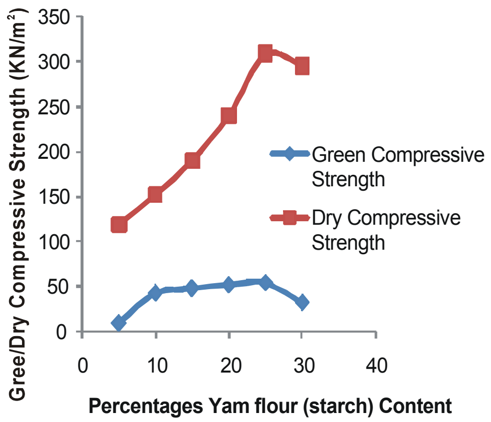

Fig. 1: Variation of Green and dry compressive Strengths (KN/m^2) of Dukku silica sand moulds bonded with percentages yam flour (starch) content.

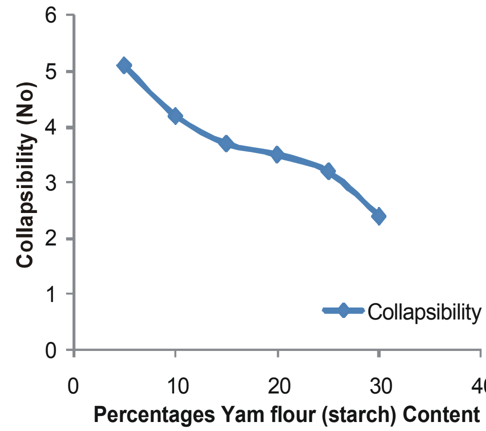

Fig. 3: Collapsibility of Dukku sand mould bonded with varying percentages of yam flour (starch) content.

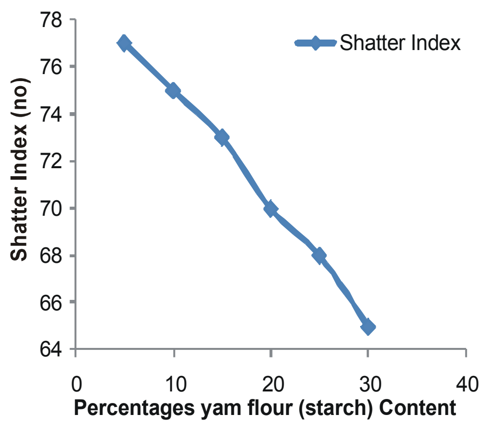

Fig. 2: Shatter index of Dukku sand mould bonded with varying percentages of yam flour (starch) content.

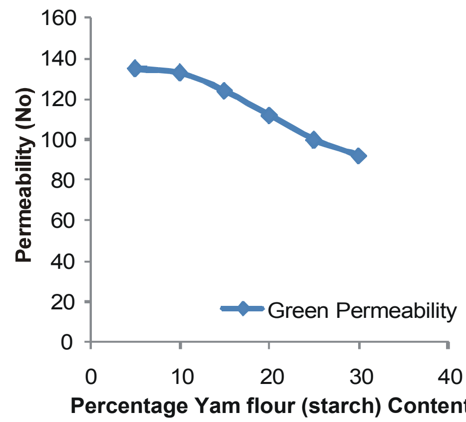

Fig. 4: Green Permeability of Dukku sand mould bonded with varying percentages of yam flour (starch) content.

material in the mixture. This situation may be improved in subsequent research when additives addition may be employed.

The shatter index decreased with increasing binder from 77 at 5% to 65 at 30% (Figure 2).

This showed that with increasing binder, more tightness of sand grains, less permeability and less shatter index, nevertheless all the values are within the acceptable range for optimum performance.

Collapsibility decreased with increased binder from a maximum of 5.1% at 5% binder content to 2.4% at 30% binder (Figure 3).

More grains remained on the sieve with increased binder content and therefore, less collapsibility, which could be caused by excess binder within the mixture. Heat generated within the mould during casting will burn the excess binder and subsequently resulted in the easy removal of the cast product.

Permeability decreased gradually from 135 at 5% binder to 92 at 30% binder (Figure 4).

This is as a result of the fact that increased binder caused less pores in the mould that will allow gas to pass through during casting. Dukku silica sand in Kebbi State Nigeria, bonded with varying percentages of yam flour (starch) exhibits good properties for casting non- ferrous metals, light grey iron and malleable iron. The values of mechanical properties obtained agree with standard values [Table 1]. This makes the Dukku silica sand in Kebbi State Nigeria appropriate for sand casting, when mixed with correct amount of water and binder as previously asserted.

CONCLUSIONS

The study has examined the role played by yam flour (starch) as binder to Dukku silica sand of Kebbi State, Nigeria. The results showed that Dukku silica sand bonded with the material gave strong bonds that can be used in the foundry industry when compared with standard properties of sand casting. Green/dry compressive strengths, shatter index, collapsibility and permeability of the binder indicates good properties for casting non-ferrous metals, malleable iron and light grey iron if correct amounts are used as indicated in this work. This work further verifies that the material is unsuitable for steel casting applications because of low values obtained in its mechanical properties, which can possibly be improved with addition of additives. Because of binder properties noted for yam flour (starch), there is an opportunity to replace some imported binders (e.g. Bentonite) with the material and may be of interest to foundry men in the field of sand casting.

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