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STUDY ON THE SHEAR STRENGTH OF FOUNDRY SAND CORES USING CLAY AND CASSAVA STARCH AS BINDER

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ABSTRACT: Sand cores for casting of intricate shapes were produced from Ojolofe silica sand using cassava starch and Iyoloko clay, Idah Kogi State Nigeria as binders. Various compositions (6 - 12% water 4 - 12% cassava starch and 5% Iyoloko clay) with addition of Iyolofe silica sand were mixed together to produce large number of standard cores samples of two different types (green and baked). Baking of the cores samples were done at different temperatures ranging from 90 and 200°C for 60 - 150 minutes. Thereafter, determination of green and baked shear strengths was carried out on a large number of green and baked cores samples using universal tensile machine through standard procedure. It was found that appropriate baking conditions and optimum core mixtures were established for cassava starch/clay bonded cores; and clay addition was found to increase both the green and baked strengths values. The optimum clay/starch core mixture with the best shear strength values was found to be core with 10% starch, 10% water and 5% clay; the appropriate baking temperature and time were 180°C and 2 hours respectively. Their green and baked shear strength values were 31.1 KN/m^2 and 498.1 KN/m^2 respectively. These values were found to be adequate for production of strong sand cores using starch/cay as binders for non - ferrous and ferrous castings as collaborated by successfully casting of a T - joint pipe aluminum casting. Finally, the research showed that good cores can be produced using cassava starch/clay as binders as rationale behind the work.
KEYWORDS: Cassava Starch, Cores, Binders, Shear Strength, Clay and Foundry sand

INTRODUCTION

There are several foundry industries in Nigeria that sourced raw materials (silica sand, clay, binders and additives) used for producing effective foundry sand cores from overseas in 70s so there is need to develop appropriate molding raw materials since all foundry works depended exclusively on imported raw materials including even the molding sand (Ihom et al, 2006). In sand casting operations, sand is used as a molding material to form the external shape of the cast component or as a core material to create internal cavities in castings such as engine blocks (Abdulwahab et al., 2008).

There is a great need to be familiar with the utilization, design and production of suitable cores because cores are crucial to achieving efficient production of cast products with hollow cavities. In fact there are no ways of doing this without the use of cores if excessive foundry wastes and machine scraps were to be eliminated (Charles, 2004).

Sand grains cannot adhere to each other without the introduction of binders that cause them to stick together and produce the cavity into which molten metal is introduced (Brown, 1994). Oyetunji and Seidu (2012) studied the synergistic effects of starch and rubber-latex as core binders for foundry sand cores production. Clay is the general-purpose binder for sand castings and a lot of work has been done in the area of developing suitable clays for sand moulds. Binders are introduced into the moulding and core mixtures in order to improve their properties especially the strength (Nwajagu, 1994). While clay has been found to be satisfactorily used as a binder for molding sands, it is largely unsatisfactory when used singly as a binder for core production. Some of the common binders for core making are vegetable oil, honey, Soya beans, cotton seed, ground nut, palm kernel, beniseed, cashew nut and castor oils (Colin, 2008). The use of cassava starch for sand core production has not been extensively reported in the literature, and hence the need to investigate its potential in this respect. Since cassava is a cheap source of abundant starch with excellent bonding characteristics, cassava starch has therefore been chosen for the investigation.

This work is aimed at producing sand cores using cassava starch and clay as binders and evaluating their suitability for the casting of aluminum alloy T-Joint pipe while the objective of this work are to utilize locally sourced raw materials (cassava starch, Iyoloko clay and Ojolofe sand) to produce cores and determine their green and baked shear strengths property.

The work uses locally produced binders, cassava starch and clay, that constitute no health hazards and are environmental friendly for the production of sand cores. In addition, the utilization *of these binders will reduce the dependence on imported materials for the production of some cast products. In doing this it will promote the development of indigenous technology needed for local production of intricate machine parts such as engine block at reduced costs and for self-reliance. Finally this work will promote economic growth of the country by generating internal revenue and preserving foreign earnings for economic development.*

The scope of this work entails production of cassava starch and clay bonded sand cores using river Niger sand collected from Ojolofe water side in Idah local government area of Kogi State Nigeria while the clay was from Iyoloko stream at Ede-Alaba also in Idah local government area in Kogi State Nigeria. Production of different cores of various compositions (6% to 12% water, 4% to 12% cassava starch and 5% clay) was carried out. Evaluations of green and baked shear strengths were carried out. To be able to establish optimum baking condition and optimum core mixture, several cores mixtures were produced at varying baking times and temperatures for its shear strength determination.

MATERIALS AND EQUIPMENT

Materials used for this work were silica sand collected from Ojolofe water side in Idah local government area of Kogi State Nigeria, Iyoloko clay collected from Iyoloko stream at Ede-Alaba in Idah local government area 0f Kogi state, cassava starch which was extracted from cassava tubers obtained from Akure in Ondo state Nigeria and tap water was used for tempering.

Equipment used are weighing, mixer or muller, measuring cylinder, specimen rammer, permeability meter, universal strength testing machine, oven, sieve shaker and sets of sieve, crucible furnace, hack saw, mould box, core box, wire brush and chisel.

METHODS

(i) Cassava Starch Preparation

Cassava tubers were peeled and properly washed. The washed tubers were pounded followed by grinding into pulp. Water was then added to easy the extraction of starch. On the addition of water, it formed suspension which was left to stay for 2 hours before the water above was decanted. The starch residue was properly dried to white, odorless and tasteless powder in accordance with Anonim, 2009, Oyetunji and Seidu, 2012 and Narayana, 2002.

(ii) Sand preparation

The sand was collected from the site, washed to remove clay and other impurities. It was properly dried and sieved using shaker on which meshes of different aperture were mounted. The clay was collected from the site and pebbles were removed from it. After drying, both the clay and the sand were sent for mineralogical composition analysis using ED X-ray Fluorescence Analyzer in accordance with Ayoola, 2010. The results of the mineralogical composition are as shown in Table 1.

Table 1: Mineralogical Composition of Ojolofe Silica Sand and Iyoloko Clay

Materials	Percentage Minerals											
	SiO_2	Al_2O_3	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	MgO	CuO	Na_2O	LOI
Iyoloko Clay	65.40	20.30	1.05	0.79	3.18	0.05	0.13	0.03	0.18	0.04	0.05	2.80
Ojolofe Sand	95.30	0.55	0.06	0.24	0.40	0.01	0.02	0.25	0.16	0.00	0.04	2.97

The sieve analysis was done to determine the grain size in accordance with Oyetunji and Omole, 2011; and Ayoola, 2010 and the result shown in Table 2.

Table 2: The Sieve Analysis of Ojolofe Silica Sand

ISO aperture (microns)	%Retained (A)	Multiplier (B)	Product (A B)
1000	0.6	1180	708.0
710	0.8	1180	944.0
500	1.1	600	660.0
355	4.0	425	1700.0
250	12.2	300	3660.0
180	13.6	212	2883.2
125	26.4	150	3960.0
90	28.0	106	2968.0
63	11.2	75	840.0
Less or equal 63	2.1	38	79.0
Total	100	-----	18403.2

$$\text{Average Grain Size (micrometer)} = \frac{\text{Total Product}}{\text{Total \% sand retained}} = 18403/100 = 184.03$$

(iii) Selection of Core Mixture

For this work, a large number of cores from mixtures, based on the proportion of the constituent of sand, cassava starch, clay and water, were prepared. The starch/clay bonded cores *were produced from mixtures containing compositions (6-12% water, 4-12% starch 5% clay). The full composition of core mixture is in Table 3*

Table 3: Composition of the Core Mixtures used in the Investigations

S/N	Starch and Clay mixture	S/N	Starch and Clay mixture
1	6% water + 4% starch 6% water + 6% starch 6% water + 8% starch + 5% clay 6% water + 10% starch 6% water + 12% starch	3	10% water + 4% starch 10% water + 6% starch 10% water + 8% starch + 5% clay 10% water + 10% starch 10% water + 12% starch
2	8% water + 4% starch 8% water + 6% starch 8% water + 8% starch + 5% clay 8% water + 10% starch 8% water + 12% starch	4	12% water + 4% starch 12% water + 6% starch 12% water + 8% starch + 5% clay 12% water + 10% starch 12% water + 12% starch

(iv) Production of Test Specimens

After the mixtures were properly mixed and blended, 50 test samples of 50 mm diameter by 56 mm height were made from each of the mixtures. This was done by ramming the mixture in the sleeves of 50 mm diameter and to a height of 56 mm. Ramming was accomplished by dropping a rammer of 5Kg mass three times from a height of 50 mm. The core specimen was ejected from sleeve by a piston.

(v) Core Baking Procedure

Core baking was carried out in an oven capable of attaining a temperature of 500^{o}C and with capacity for 40 cores at a time. Each batch of cores was introduced into the furnace on steel plates after the requisite temperature had been attained and maintained for a predetermined period. The oven had an extraction system for removing the moisture produced during baking. This arrangement ensures a uniform and standard baking procedure (Giesseren, 2004).

TESTS

The following tests were performed on the produced cores:

(a) Green Shear Strength Test

Determination of green shear strength values was carried out using the universal sand testing machine. The specimen to be tested was mounted on a stripping post and a shear load was gradually applied by turning a hand wheel until fracture. The fracture load was automatically recorded on the attached scale (Jain, 2008, Fayomi, et al 2011, Ademoh, 2008 and Oyetunji et al., 2009).

(b) Baked Shear Strength Test

Based on the results from the green strength values, starch/clay cores of different compositions were produced using 10% starch, 5% clay and 10% water. The cores were baked at various temperatures between 90 and 180^{o}C and for different baking periods between 1 and 2$^{1}/_{2}$ hours. Baked shear strength values were determined using the universal sand testing machine. The specimens were tested for baked shear strength (Jain, 2008; Fayomi, et al 2011, Ademoh, 2008).

(c) Determination of Appropriate Baking Temperatures

For the appropriate baking temperature to be obtained, a large number of cores from a variety of core mixtures at different water content were produced and baked at various temperatures of between 90 and 200^{o}C for a fixed time of two hours. The baked cores were later tested for shear strength using the universal sand testing machine in accoradance with standard procedures Fayomi, et al 2011.

DISCUSSION OF THE RESULTS - Mineralogical Analysis of the Sand

The Ojolofe sand and Iyoloko clay mineralogical analysis in Table 1, the Ojolofe sand contains 95.30% $Si0_2$ and 0.55% Al_20_3. The silica content of 95.30% compares well with the minimum acceptable values of 95% recommended for moulding and core sands (Brown, 2000). A high silica value is necessary to withstand the heat of molten metal during casting and increase its refractioness (Jain, 2008). The Iyoloko clay, on the other hand, had 65.40% silica and 20.30% alumina as the principal constituents. These values are common and adequate for general purpose foundry moulding sand and cores. The higher alumina content provides the necessary refractoriness needed by cores (Brown, 2000).

Sand Grain Size

Table 2 shows the sieve analysis of Ojolofe sand used for the production of the core. The sand has an average grain size of 184.03 micron meters which is within the AFS acceptable size range of between 180 and 250 microns used in Foundry. It is clearly on the fine side for mould production but specifically suitable for core making in providing the necessary green and baked strength values, adequate flowability, and good mouldability and permeability (Ihom, et al 2006).

Green Shear Strength Values

In Figure 1, the green shear strengths increased with water content reaching a maximum value at 10% irrespective of the starch level. The green strength values were generally high for cores *containing 6 – 10% water and dropped sharply for all cores with 12% water content. This sharp drop was because of excessive wetness resulting not only in low green shear values, but also difficulty on moulding. The maximum green strength 31.1 KN/m^2 was obtained for the starch/clay bonded cores produced from a mixture containing 10% starch, 5% clay and 10% water. From the results of green shear strength values in Figure 1, it is clear that starch/clay cores have adequate strength values. This is in comparison with the minimum acceptable value of 10.0KNm^{-2} for organic-bonded cores. The strongest cores were produced from core mixtures of 10% starch, 10% water and 5% clay compositions.*

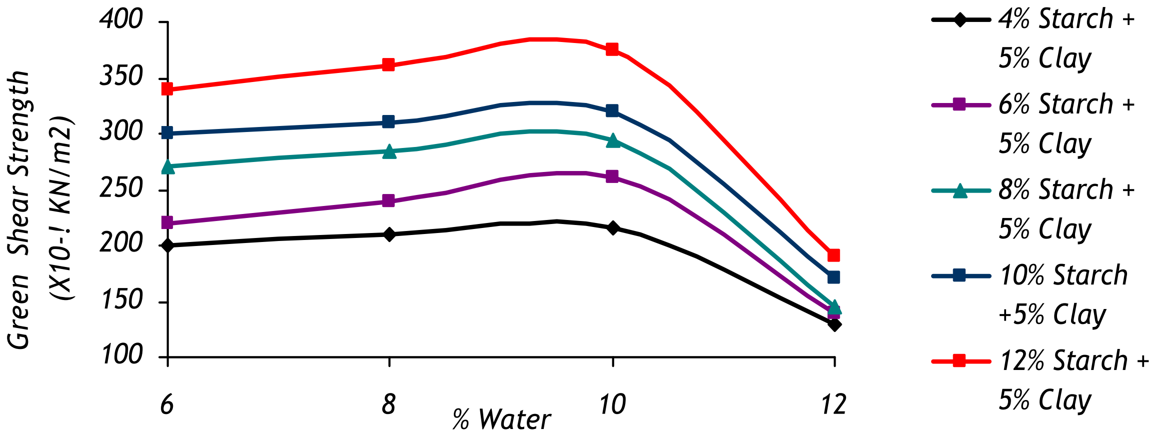

Figure 1: Variation of Green Shear Strength with Water on Starch/Clay bonded Cores

Baked Shear Strength of Starch bonded Cores

Figure 2 shows the effect of baking temperature and baking time on the shear strengths for clay-starch bonded cores produced from mixes of 10% starch, 10% water and 5% clay. These values were based on the maximum strength values obtained from the preliminary investigation. It is seen in Figure 2 that maximum baked shear strengths were obtained for cores when baking was carried out at 180^{o}C for 2 hours. This means that optimum baked shear strength values will not be achieved when these cores are baked outside this specification since polymerization will start. The maximum shear strength for the starch/clay cores was 498.1 KNm^{-2}. This baked strength value agrees very well with standard value of between 400KNm^{-2} and 600KNm^{-2} needed for nonferrous and iron castings (Fayomi et al. 2011).

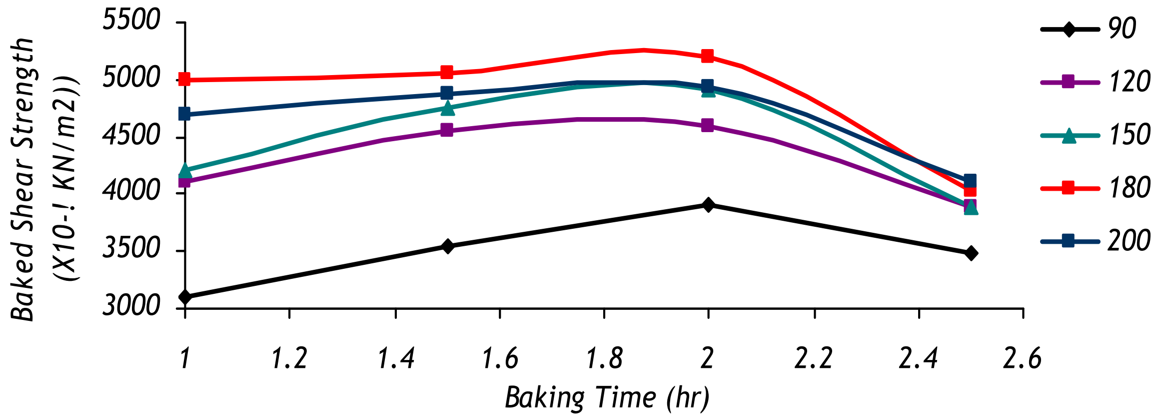

Figure 2: Variation of Baked Shear Strength with Baking Time for Clay-Starch Cores (10% Starch, 10% Water and 5% clay)

Baked Shear Strength versus Baking Temperature for Starch-bonded Cores

Preliminary work was carried out to determine the optimum core mixture and appropriate baking conditions for the starch/clay bonded cores. In this respect, baked shear strength values were measured for cores produced from selected clay/starch additions at different water levels. For each core mixture, baking temperature was varied between 90 and 200^{o}C for two hours. The results are contained in Figures 3-6. From the results, it is clear that clay additions into starch cores significantly increased the baked shear strengths, which further increased as the starch/clay content increased. For all the cores, there was an initial increase in the baked shear strength as the baking temperature increased but attained maximum values at the baking temperature of 180^{o}C for two hours for each core mix. Form these figures; it was observed that good quality clay/starch cores can be produced from core mixes containing 8-12% starch, 5% clay and 6-10% water after baking between 150 and 180^{o}C for 2 hours. For the mixes investigated, the strongest clay/starch cores were produced from mixes containing 8 – 10 starch, 5% clay and 8 – 10% water.

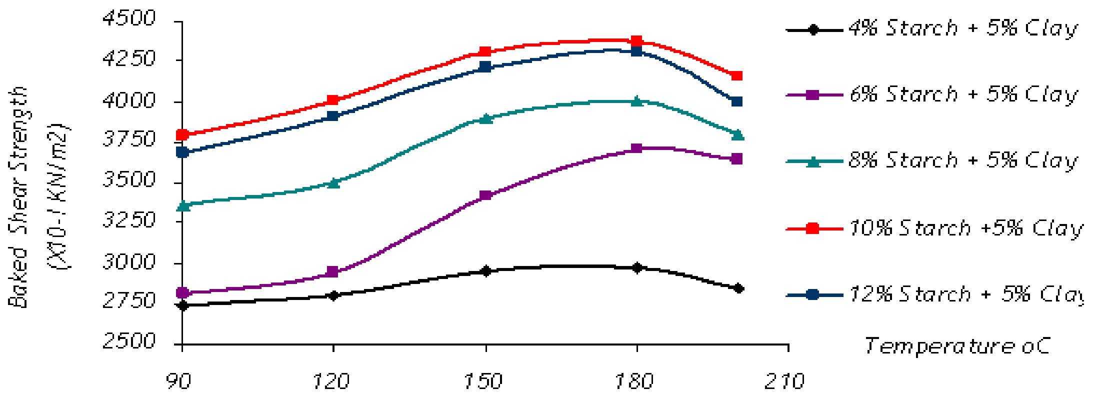

Figure 3: Variation of Baked Shear Strength with Baking Temperature for Clay-Starch Cores with 6% Water

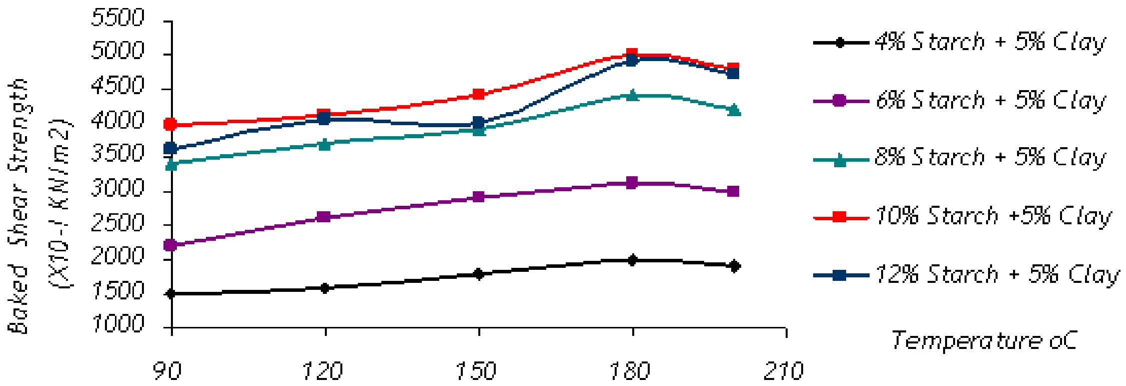

Figure 4: Variation of Baked Shear Strength with Baking Temperature for Clay-Starch bonded Cores with 8% Water.

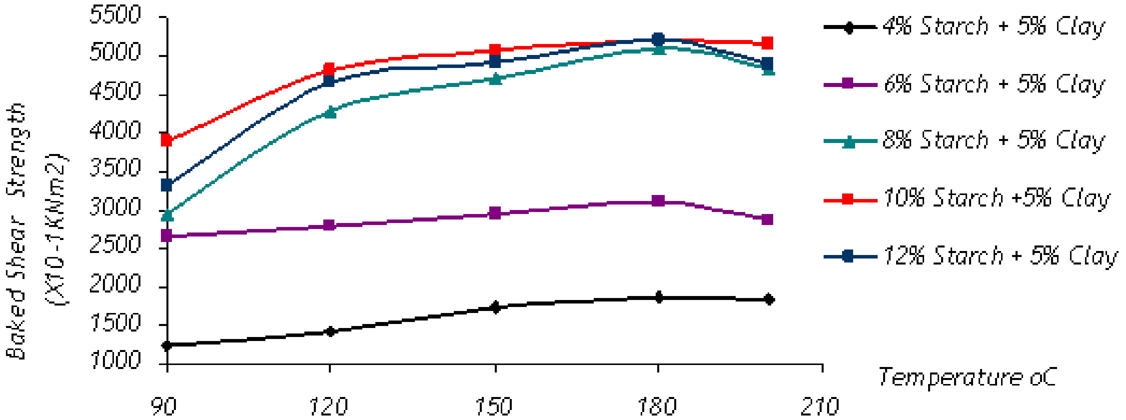

Figure 5: Variation of Baked Shear Strength with Baking Temperature for Clay-Starch bonded Cores with 10% Water)

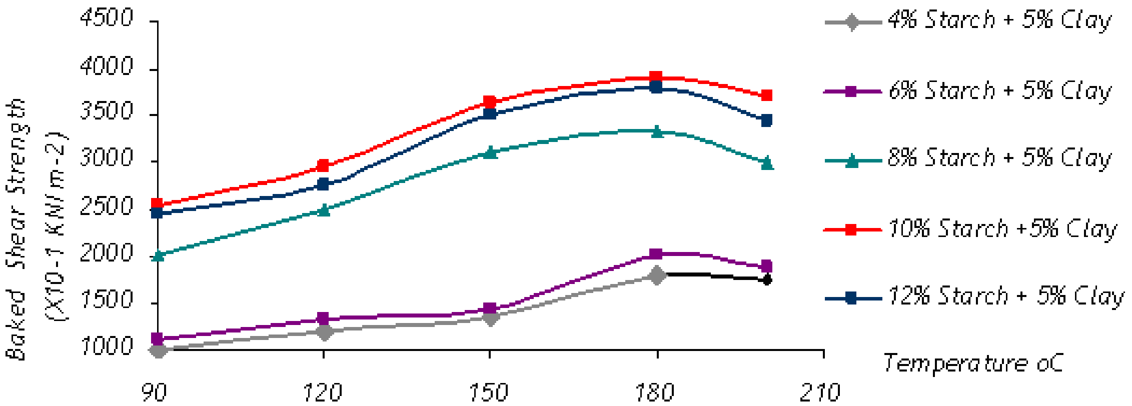

Figure 6: Variation of Baked Shear Strength with Baking Temperature for Clay-Starch bonded Cores with 12% Water)

Performance Evaluation Test

The cast aluminum T-joint pipes, which were produced using a clay/starch cores was found to be of excellent quality and good finish. Satisfactory castings can certainly be produced using these core mixtures containing 10% starch, 10% water and 5% clay.

CONCLUSIONS

The results obtained from the research has clearly shown that using the appropriate foundry sand, good quality cores can be successfully produced using cassava starch in combination with Iyoloko clay. Good quality cores can be produced from core mixtures containing 8-12% starch, 5% clay and 6-10% water after baking between 150 and 180°C for 2 hours. However, in this respect, cores with optimum properties were from mixtures containing 10% starch, 5% clay and 10% water. The green and baked shear strengths values from these tested cores were 31.1 KN/m^2 and 498.1 KN/m^2 respectively. These green and baked shear strengths values obtained from these tested cores made them to be suitable for applications in the production of iron and non-ferrous castings. The successful performance evaluation test carried out in the casting of an aluminium T-joint pipe has proved this to be so.

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