Evaluating the Baked Compressive Strength of Produced Sand Cores Using Cassava Starch as Binder for the Casting of Aluminium Alloy T-Joint Pipe

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Abstract
Sand cores were produced using Ojolofe silica sand and cassava starch (Manihot esculenta crantz) as binder. This was with the aim of determining their suitability for casting of intricate shapes. To achieve this, various compositions of starch bonded sand cores were produced. Standard core samples were produced and tested for green and baked compressive strength. The determination of green and baked compressive strengths was carried out on a large number of cores containing 6 – 12% water and 4 – 12% cassava starch. Core baking was carried out at temperature between 90 and 200°C for 60 – 150 minutes. From the results obtained, appropriate baking conditions and optimum core mixtures were established for cassava starch bonded core. The major results in the research showed that good cores can be produced using cassava starch as binder. Optimum core mixture for this purpose was found to be that containing 10% starch and 10% water and at appropriate baking temperature and time were 180°C and 2 hours respectively. The green compressive strength was 290 N/mm2 and that of baked compressive strength was 4122 N/mm2. The above properties were found to be adequate for production of strong sand cores using cassava starch as binder for non-ferrous castings. This suitability was proved by successfully production of a T-join pipe aluminium casting.

Keywords: compressive strength, cassava starch, core mixture, baked strength, green strength

INTRODUCTION
The foundry industry in Nigeria is developing so there is need to develop appropriate moulding raw materials such as silica sand, clay, binders and additives for effective foundry practices. Before the 80s, all foundry works depended exclusively on imported raw materials including even the moulding sand (Ihom et al., 2006). In sand casting operations, sand is used as a moulding 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). When a casting is to be produced with through or dead-ended holes, cores are used to form these interior surfaces (Asuquo and Bobojama, 1991) and are made of sand particles bonded together to form an aggregate. Cores are generally made of core sand mixtures from sand grains and binders. A well formulated mixture gives good green strength and adequate cured strength to prevent premature collapse during usage.

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). 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 moulding 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 aimed at producing sand cores using cassava starch as binder and evaluating their suitability in
terms of their compressive strength for the casting of aluminium alloy T-Joint pipe. The objectives of this work are to utilize locally sourced raw materials (cassava starch and Ojolofe sand) to produce cores; determine the compressive strength of the produced cores; compare the observed properties with those of standard cores and; and evaluate the suitability of the produced cores by casting aluminium T-Joint pipes.

This work used locally produced binders, cassava starch that constitutes no health hazards and is environmentally 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 bonded sand cores using river Niger sand from Ojolofe water side in Idah local government area of Kogi State Nigeria. Production of different cores of various compositions ranges from 6% to 12% water, and 4% to 12% cassava starch. Evaluations of green and baked compression strengths were carried out after baking at different baking conditions. To be able to establish optimum baking condition and optimum core mixture, several compositions ranges from 6% to 12% water, and 4% to 12% cassava starch were produced at varying baking condition and optimum core mixture, several cores mixtures were produced at varying baking conditions. To be able to establish optimum baking condition and optimum core mixture, several cores mixtures were produced at varying baking times and temperatures for compression strength.

METHODOLOGY
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 that was used for the core production. Cassava starch which was extracted from cassava tubers obtained from Akure Ondo State Nigeria was also used as binder. Tap water was used for tempering. Equipment used are weighing balance, mixer or muller, measuring cylinder, specimen rammer, permeability meter, universal strength testing machine, oven, sieve shaker and sets of sieve, crucible furnace, hack saw machine, 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, and Narayana, Subramony, 2002.

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

Table 1: Minerological Composition of Ojolofe Silica Sand

<table>
<thead>
<tr>
<th>Materials</th>
<th>Percentage Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiO₂</td>
</tr>
<tr>
<td>Ojolofe Sand</td>
<td>94.30</td>
</tr>
</tbody>
</table>

The sieve analysis was done to determine the grain fineness number in accordance with Oyetunji and Omole, 2011; and Ayo, 2010 and the result is as shown in Table 2.

Table 2: The Sieve Analysis of Ojolofe Silica Sand

<table>
<thead>
<tr>
<th>ISO aperture (microns)</th>
<th>% Retained (A)</th>
<th>Multiplier (B)</th>
<th>Product (A.B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0.6</td>
<td>1180</td>
<td>708.0</td>
</tr>
<tr>
<td>710</td>
<td>0.8</td>
<td>1180</td>
<td>944.0</td>
</tr>
<tr>
<td>500</td>
<td>1.1</td>
<td>600</td>
<td>660.0</td>
</tr>
<tr>
<td>355</td>
<td>4.0</td>
<td>425</td>
<td>1700.0</td>
</tr>
<tr>
<td>250</td>
<td>12.2</td>
<td>300</td>
<td>3660.0</td>
</tr>
<tr>
<td>180</td>
<td>13.6</td>
<td>212</td>
<td>2883.2</td>
</tr>
<tr>
<td>125</td>
<td>26.4</td>
<td>150</td>
<td>3960.0</td>
</tr>
<tr>
<td>90</td>
<td>28.0</td>
<td>106</td>
<td>2968.0</td>
</tr>
<tr>
<td>6</td>
<td>11.2</td>
<td>75</td>
<td>840.0</td>
</tr>
<tr>
<td>-6</td>
<td>2.1</td>
<td>38</td>
<td>79.0</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>-</td>
<td>18403,2</td>
</tr>
</tbody>
</table>

(iii) Selection of Core Mixture
A large number of cores from mixtures, based on the proportion of the constituent of sand, cassava starch and water, were prepared. The mixtures contained 6-12% water and 4-12% starch. The full composition of core mixture is in Table 3.
**Production of Test Specimens**

After the mixtures were properly mixed and blended, 50 test specimens of 50 mm diameter x 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 50Kg mass three times from a height of 50 mm (Jain, 2008) and the core specimen was ejected from sleeve by a piston.

**Core Baking Procedure**

Core baking was carried out in an electric fired oven capable of attaining a temperature of 500°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 prepared cores:

- **Green Compressive Strength Test**
  
  Determination of green compressive strength values was carried out using the universal sand testing machine. The specimen to be tested was mounted on a stripping post and a compressive load was gradually applied by turning a hand wheel until fracture. The fracture load was automatically recorded on the attached scale (Jain, 2008) and Oyetunji et al (2009). The result of the green compressive strength is as shown in Figure 1.

**Baked Compressive Strength Test**

Based on the results from the green strength values, starch cores of different compositions were produced using 10% starch and 10% water. The cores were baked at various temperatures between 90 and 180°C and for different baking periods between 1 and 2 1/2 hours. Baked compressive strength values were determined using the universal sand testing machine. The specimen to be tested was mounted on a stripping post and a compressive load was gradually applied by turning a hand wheel until fracture. The fracture load was automatically recorded on the attached scale (Jain, 2008). The result of the baked compressive strength containing 10% water and 10% starch is as shown in Figure 2.

![Figure 1: Variation of Green Compressive Strength with Water content on Starch bonded Cores](image1)

![Figure 2: Variation of Baked Compressive Strength with Baking Time for Starch Bonded Cores (10% Starch and 10% Water)](image2)
(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°C for a fixed time of two hours. The baked cores were later tested for compressive strength using the universal sand testing machine. The specimen to be tested was mounted on a stripping post and a compressive load was gradually applied by turning a hand wheel until fracture. The fracture load was automatically recorded on the attached scale. The results of this is as shown in Figures 3 to 6.

**Fig.3:** Variation of Compressive Strength with Baking Temperature for Starch-bonded Cores (Core mixes of constant 6% water content but different starch contents)

**Fig.4:** Variation of Baked Compressive Strength with Baking Temperature for Starch-bonded Cores with 8% water content.
PERFORMANCE EVALUATION

The performance evaluation test was carried out by sand casting of an aluminium T-joint pipe. The T-joint pattern was carved from wood of 150 x 150 x 100 mm as shown in Plate 1.

To cast this pipe, T-shaped cores, of starch bonded were produced to create the internal space. A wooden core box, Plate 2, was made for the production of cores using the optimum core mixtures determined for the starch cores. The cores were appropriately baked.

Plate 1: T-joint Pipe Pattern showing all the dimensions
Two moulds were prepared using the recycled sand after which the cores were properly put in place. 20 kg of aluminum scraps were charged into and melted in a coal-fired crucible furnace (Charles, 2004). Tapping and pouring into the moulds were done after appropriate slag removal. Moulding, melting and casting processes were carried out in the foundry shop of the Federal Polytechnics, Idah in Kogi State. After the molten metal had solidified, the mould was broken and the cast product brought out with the riser, the ingate and other unwanted parts still attached as shown in Plate 3.

The riser, the ingate and other unwanted parts were removed using hack saw and filing to obtain good finished products as shown in Plate 4.

RESULTS
All the experimental results were as presented in Figures 1 to 6.

DISCUSSION OF THE RESULTS
Mineralogical Analysis of the Sand
From the mineralogical analysis shown in Table 1, the Ojolofe sand contains 94.30% SiO₂ and 0.55% Al₂O₃. The silica content of 94.30% compares well with the acceptable values of between 80% and 97% recommended for moulding and core sands. A high silica value is necessary to withstand the heat of molten metal during casting (Jain, 2008).

Sand Grain Fineness Number
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 microns 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, 2006).

Green Compressive Strength values
From Figure 1, the starch bonded cores, green compressive 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 compressive values, but also difficulty on moulding (Colin, 2006). The maximum green compressive strength obtained was 290 N/mm² at 10% starch and 10% water levels. From the results of strength values obtained in Figure 1, it is clear that: (i) starch-bonded cores have adequate strength values. This is in comparison with the minimum acceptable value of 100Nmm² for organic-bonded cores (ii) the strongest cores were produced from core mixtures containing 10% starch and 10% water for the starch-bonded cores.
Baked Compressive Strength of Starch bonded Cores

Figure 2 shows the effect of baking temperature and baking time on the compressive strength of the starch bonded cores. The results contained in this figure are for cores produced from mixes of 10% starch and 10% water. These values were based on the maximum strength values obtained from the green compressive strength test. From this figure, it is seen that maximum baked compressive strength was obtained, when baking was carried out at 180°C for 2 hours. This means that optimum baked compressive strength values will not be achieved when these cores are baked outside this specification. The maximum compressive strength values obtained from this result was 4122 N/mm². These baked strength values agree very well with standard value of between 4000N/mm² and 5000N/mm² needed for nonferrous and iron castings (Ihom, 2004).

The preliminary investigation on the potential of starch as a core binder has revealed that good cores can be produced using starch extracted from cassava (Ihom, 2004) and the followings are the highlights of the results obtained: (i) highest green compressive strength of 290 N/mm² for cores with 10% starch and 10% water contents. (ii) Highest baked compressive strength of 4122 N/mm² occurs for cores when baking was done at 180°C for 2 hours (Agarwal et al., 1978).

Baked Strength versus Baking Temperature for Starch-bonded Cores

Variation of compressive strength with baking temperature was determined for starch bonded cores produced from various mixes. The results are shown in Figures 3, 4, 5 and 6. Figure 3 showed the variation of compressive strengths with baking temperatures of cores with 6% water content at various starch level. From this figure the curve for the core containing 10% starch has the highest baked compressive strength followed by the one with 8% starch. Below and above these values of starch, the compressive strengths fall. Figures 4, 5 and 6 are the curves of compressive strengths with baking temperatures for cores containing 8%, 10% and 12% respectively. Again the highest baked strengths were obtained from the cores containing 9 to 10% starch in all cases. There was drop of compressive strength values above these starch level. These results have confirmed that (i) maximum baked compressive strengths were obtained by cores produced from a mixture containing between 9 and 10% starch and at 10% water level. (ii) For all cores, highest compressive strength values were obtained after baking at a temperature of 180°C for 2 hours.

Performance Evaluation Test

The cast aluminium T-joint pipes, which were produced using a starch core was found to be of excellent quality and good finish. Satisfactory castings can certainly be produced using the cassava starch bonded core with 9 to 10% starch and 10% water level.

CONCLUSION

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 singly. Cassava starch-bonded sand cores produced from 6 – 12% starch and 8 – 10% water and baked at the appropriate baking conditions resulted in cores with the necessary minimum properties. Baking at 180°C for 2 hours was found to be most appropriate. Cassava starch-bonded cores with optimum properties were produced from mixtures containing 10% starch and 10% water contents. Green compressive strength = 290 N/mm². Baked compressive strength = 4122 N/mm². The properties of these cores made them suitable for the application in the production of ferrous and non-ferrous castings as it was successfully demonstrated in the casting of aluminium T – joint pipe.

REFERENCES


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