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# EVALUATING THE PERMEABILITY OF PRODUCED SAND CORES USING CLAY AND STARCH AS BINDERS AT DIFFERENT BAKING TEMPERATURES AND TIMES

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**Abstract**: 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 while the clay was from Iyoloko stream at Ede–Alaba also in Idah local government area of Kogi state. Production of different cores of various compositions ranges between 8% to 12% water, 6% to 12% cassava starch and 5% clay was carried out. Green and baked permeability tests were carried out on those different produced cores using permeability meter. For both cassava starch bonded and starch/clay bonded cores, the green permeability increases with starch content but decreases with moisture content. The variation of permeability with baking temperature was investigated for cores produced from mixes containing 6–12% starch and 8–10 water. It was observed that permeability increased with baking temperature, starch and water contents. Also, the permeability values obtained for cores produced from mixtures of 10% starch and 10% water was 128 ml/minute. This increased to 138 ml/minute when starch content was increased to 12%. This value was within the acceptable standard of between 100–130 ml /minute recommended for the casting of both ferrous and non–ferrous metals.
**Keywords**: Green permeability, sand cores, baked permeability, binders, permeability meter

## 1. 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 (Opaluwa and Oyetumji, 2012). 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). Cores are made of sand particles bonded together to form an aggregate. They are used to form the interior surfaces of casting. A well formulated core mixture gives good green strength and adequate cured strength to prevent premature collapse during usage (Colins, 2006). There is a great need to be familia3r with the utilization, design and production of suitable cores because cores are crucial to achieving efficient production of cast products with hollow cavities (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 (Ihom, 2004). Binders are introduced into the moulding and core mixtures in order to improve their properties especially the strength (Ihom, 2006). 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 (Jain, 2006). 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 (Jain, 2008). 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 permeability and has the following objectives:

(i) Utilize locally sourced raw materials such as cassava starch, clay and sand to produce cores

(ii) Determine the permeability of the produced core

(iii) Compare the observed property with those of standard cores.

## 2. EXPERIMENTAL PROCEDURE

### 2.1. Materials & Equipment

Materials used for this work were silica sand collected from Ojolofe water side in Idah local government area of Kogi state that was used for the core production. Iyoloko clay collected from Iyoloko stream at Ede–Alaba in Idah local government area of Kogi state which was used as binder and Cassava starch which was extracted from cassava tubers 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, Oven, Sieve shaker and sets of sieve.

## 2.2. Experimental methods

### 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).

### 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 sent for chemical analysis.

### Clay Preparation

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 etal, 2010. The results of the mineralogical composition both clay and sand are as shown in Table 1.

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

| 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 | 6.03 | 0.18 | 0.04 | 0.05 | 2.80 |
| Ojolofe Sand | 94.30 | 0.55 | 0.06 | 0.24 | 1.40 | 0.01 | 0.02 | 0.35 | 0.16 | | 0.04 | 2.87 |

## 2.3. Selection of Core Mixture

For this work, a large number of cores mixtures, based on the proportion of the constituent of sand, cassava starch, clay and water, were prepared. The first batch of cores was starch–bonded cores prepared from mixtures containing 8–12% water and 4–12% starch. The second batch was starch/clay bonded cores produced from mixtures containing 8–12% water, 4–12% starch 5% clay as shown in Table 2.

**Table 2**: Composition of the Core Mixtures used in the Investigations

| S/N | Clay free mixture | Starch and Clay mixture |
|---|---|---|
| 1 | 8% water + 4% starch<br>8% water + 6% starch<br>8% water + 8% starch<br>8% water + 10% starch<br>8% water + 12% starch | 8% water + 4% starch<br>8% water + 6% starch<br>8% water + 8% starch + 5% clay<br>8% water + 10% starch<br>8% water + 12% starch |
| 2 | 10% water + 4% starch<br>10% water + 6% starch<br>10% water + 8% starch<br>10% water + 10% starch<br>10% water + 12% starch | 10% water + 4% starch<br>10% water + 6% starch<br>10% water + 8% starch + 5% clay<br>10% water + 10% starch<br>10% water + 12% starch |
| 3 | 12% water + 4% starch<br>12% water + 6% starch<br>12% water + 8% starch<br>12% water + 10% starch<br>12% water + 12% starch | 12% water + 4% starch<br>12% water + 6% starch<br>12% water + 8% starch + 5% clay<br>12% water + 10% starch<br>12% water + 12% starch |

## 2.4. Production of test samples for green permeability test

After the mixtures were properly mixed and blended, 150g of wet sand is weighed into the specimen sleeve. It is then rammed 3 times. 5 test samples were made from each group making a total of 15 samples.

## 2.5. Production of test samples for baked permeability test

After the mixtures were properly mixed and blended, 15 test specimen of 50 mm diameter by 50 mm height were made. This was done by ramming the mixture in the sleeves of 50 mm diameter and to a height of 50 mm. Ramming was accomplished by dropping a rammer of known mass three times from a height of 50 mm.

## 2.6. Core Baking Procedure

Core baking was carried out in an 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 and baked at various temperatures of between 90 and 200°C for a fixed time of two hours. 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.

# 3. PERMEABILITY TEST

## 3.1. Green Permeability Test

In the measurement of green permeability, 150g of wet sand is weighed into the specimen sleeve. It is then rammed 3 times. The rammed sand in the sleeve is placed on the permeability meter in inverted form. Then the control knob was adjusted to zero point. Then the lever arm is moved from check position to test position. The pointer would move anti–clock wise and where it stops is the permeability value (Agarwal et al, 2007).

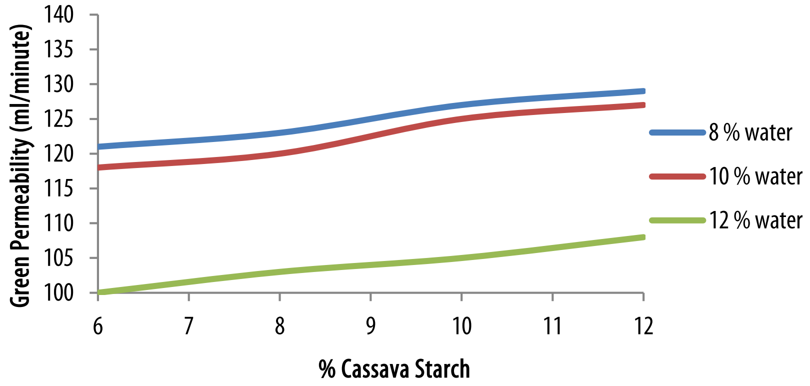


**Figure 1**: Variation of Permeability with Cassava Starch of the Starch bonded Core

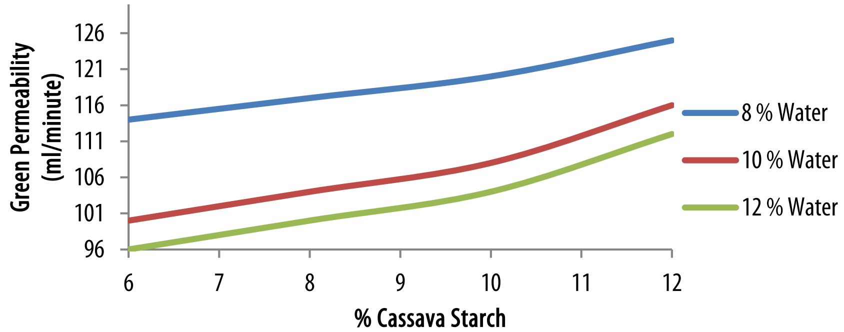


**Figure 2**: Variation of Permeability with Cassava Starch of the Starch/Clay bonded Core

### 3.2. Baked Permeability Test

In the measurement of baked permeability, the samples baked at various temperatures of between 90 and 200°C for a fixed time of two hours were tested by placing them on the permeability meter. Then the control knob is adjusted to zero point. Then the lever arm is moved from check position to test position. The pointer moved anti–clock wise and stopped at the permeability value. The results of baked permeability for the various starch bonded core mixture is shown in Figures 3–5 while the starch/clay bonded one is shown in Figures 6–8.

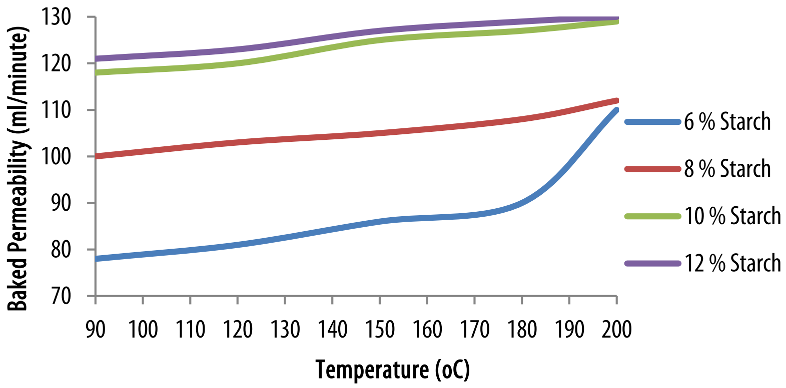


**Figure 3**: Variation of Permeability with Baking Temperature of Cassava Starch bonded Core with 8 % Water and baked for 2 hours

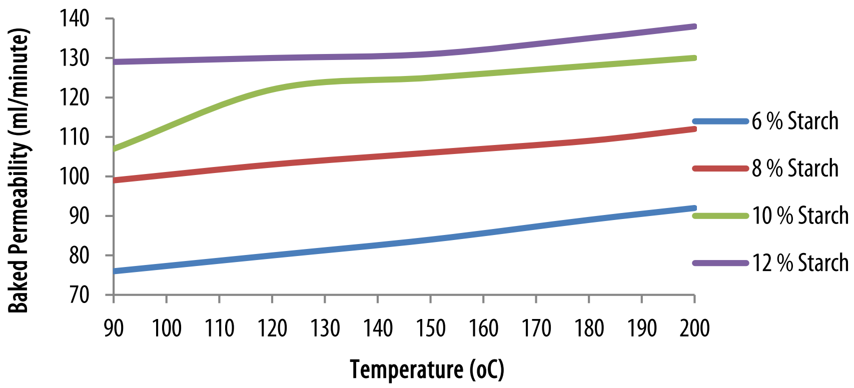


**Figure 4**: Variation of Permeability with Baking Temperature of Cassava Starch bonded Core with 10 % Water and baked for 2 hours

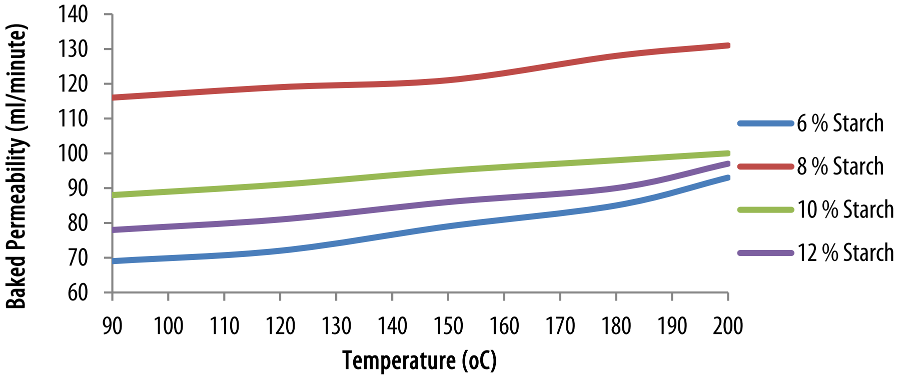


**Figure 5**: Variation of Permeability with Baking Temperature of Cassava Starch bonded Core with 12% Water and baked for 2 hours

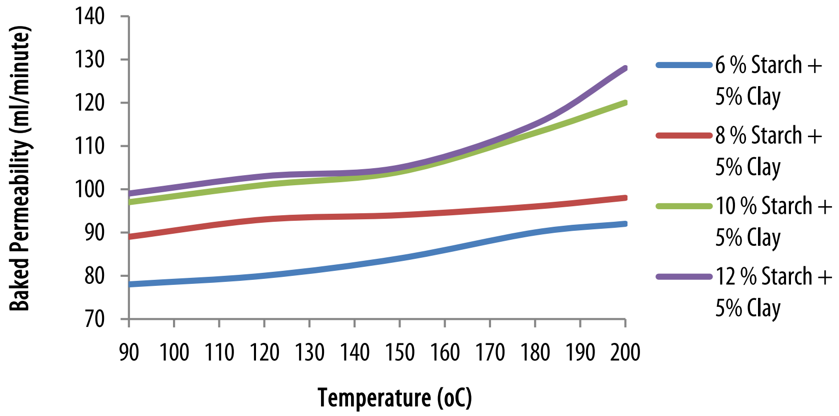


**Figure 6**: Variation of Permeability with Baking Temperature of Starch/Clay bonded Core with 8% Water, 5% Clay and baked for 2 hours

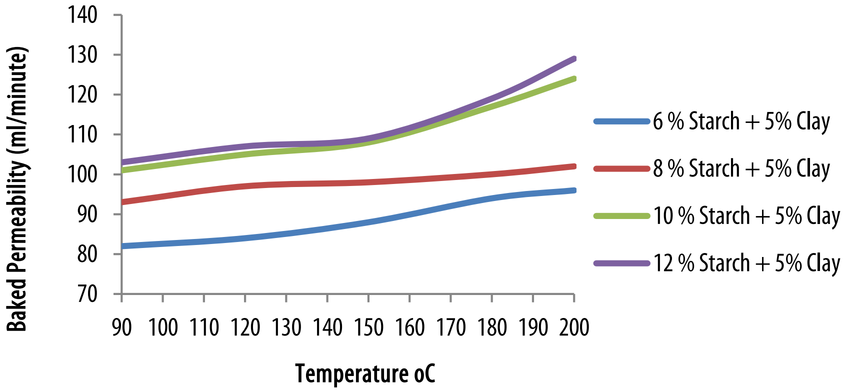


**Figure 7**: Variation of Permeability with Baking Temperature of Starch/Clay bonded Core with 10 % Water, 5 % Clay and baked for 2 hours

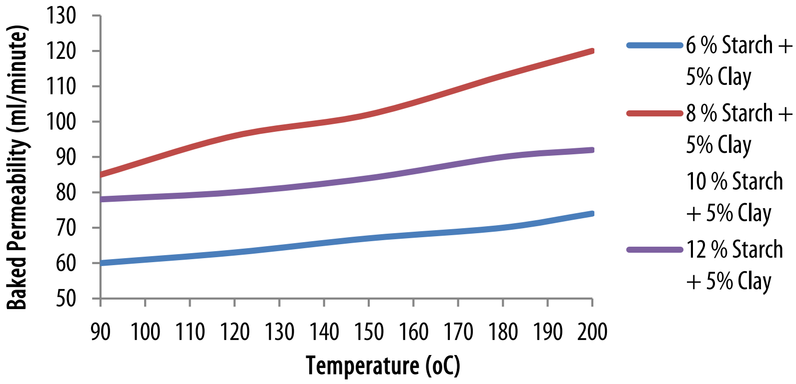


**Figure 8**: Variation of Permeability with Baking Temperature of Starch/Clay bonded Core with 12 % Water, 5 % Clay and baked for 2 hours

## 4. RESULTS AND DISCUSSIONS

All the results of the experiments are shown in Tables 1 to 2 and Figures 1 to 8.

### 4.1. Sand Grain Fineness Number

Table 1 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 permeability values, adequate flowability, and good mouldability (Ihom, 2006).

### 4.2. Chemical Analysis for Sand and Clay

From the chemical analysis shown in Table 2, the Ojolofe sand contains 94.30% $SiO_2$ and 0.55% $Al_2O_3$. 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).

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 moulding sand and cores. The higher alumina content provides the necessary refractoriness needed by cores.

### 4.3. Green Permeability

Green permeability was assessed for the cores bonded with cassava starch alone, and for the cores bonded with starch/clay while still wet. For cassava starch bonded core, the variation of permeability with moisture content was shown in figure 1. From this figure, the green permeability increases with starch content for each of the moisture contents. But the green permeability values decrease as the moisture contents increase in each case. As it can be seen from the curve, the green permeability value for the core containing 8% water is within 121–128 ml/minute, the one with 10% water has a green permeability value of 119–121 ml/minute and for the one with 12% water, green permeability value is within 100–105 ml/minute.

For the starch/clay bonded cores as shown in figure 2, the green permeability follows same trend as that of the starch bonded cores. But there is reduction in permeability value in each case. Here the core containing 8% water, 10% water and 12% water have a green permeability values within 115–122 ml/minute, 100–106 ml/minute and 96–102 ml/minute respectively. This shows that the addition of clay lowers the permeability values.

### 4.4. Baked permeability

For cassava starch bonded cores, the variation of permeability with baking temperature is as shown in figures 3–5. It was seen that:

i. Permeability increased with baking temperature, starch and water contents
ii. Permeability values obtained for cores produced from mixtures of 10% starch and 10% water was 128 ml/minute.

This increased to 138 ml/minute when starch content was increased to 12%.

Figures 6–8 contain permeability data for the clay/starch cores produced from mixtures of varying starch and water contents but fixed 5 % clay baked for 2 hours. It was also found that:

i. Permeability increased with temperature, water and starch content
ii. Permeability values reduce with the addition of clay
iii. Permeability values obtained for clay/starch cores with optimum core mixture, after baking at 180°C for 2 hours was 117 ml/minute.

Higher permeability value of 129 ml/minute was only obtained after baking cores with 12% starch, 5% clay and 10% water at 200°C for 2 hours. These observations can be explained by noting that:

i. Curing process during baking involves a chemical reaction in which the moisture content is retained for bonding purpose whereby individual sand particles are closely bonded together for strength and reduced porosity
ii. Under baking is a physical drying process involving expulsion of loosely held water molecules thus causing an initial porosity
iii. Baking process progresses from the drying stage to the curing stage and finally to burning stage
iv. Curing process in starch–bonded cores causes retention of chemically bonded water in a structure that binds the sand particles and enhances permeability
v. The addition of clay fills the pores created by starch, causes a more rigid bonding structure and impairs permeability
vi. Over baking is a burning process which causes disintegration of the bonds holding the sand grains together and thus resulting in reduced strength and increased permeability
vii. Hence permeability increases continuously with baking temperature, initial water content and starch level
viii. The final stage attained will depend on the clay/starch mixture, baking temperature and baking period.

## 5. 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 singly or in combination with clay. Cassava starch–bonded sand cores produced from 6–12% starch and 8–12% 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. Clay addition was found to slightly reduce the permeability. Good quality cores can be produced from core mixtures containing 8–12% starch, 5% clay and 6–10% water after baking between 150 and 180ºC for 2 hours. However, in this respect, cores with optimum permeability were from mixtures containing 10% starch, 5% clay and 10% water whose permeability is 128 ml/minute. This value is within standard values recommended for the casting of both ferrous and non–ferrous metals in accordance with Agarwal et al (2007), which said that "the permeability of the sand core bonded with both organic and inorganic binders acceptable for the general casting of both ferrous and non–ferrous metals is within the range of 100–130 ml/minute". The properties of these cores made them suitable for applications in the production of iron and non–ferrous castings.

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