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EVALUATION OF ORIHI CLAY AND JATROPHA CURCAS-NIGELLA SATIVA OIL AS BINDERS FOR FOUNDRY SAND CORES

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Abstract

In this study, Orihi (Apa-Benue, Nigeria) clay, Jatropha curcas and Nigella sativa seed oils were evaluated as binders for production of foundry silica sand cores. The results of the physiochemical tests on the clay and oils indicated that Orihi clay contains up to 67.50 % SiO_2, while high iodine content, saponification value, and free fatty acid on the oils suggest their good potential as binder materials for production of foundry cores. Various core test samples were produced and baked at 180 ^oC for 30 - 150 minutes. The results of both shatter index, and permeability tests indicate better binding characteristics combining clay with the oils. The results of strength tests also indicate that, while a maximum backing compressive strength of 234 kN/m^2 could be achieved using clay as binder, up to 842 kN/m^2 was obtained using the oil mixtures at a baking time of 2.5 hours, and combining clay and the oils gave up to 3010 kN/m^2. Based on these results, it was concluded that Orihi clay, Jatropha curcas and Nigella sativa seed oils are suitable for use as binders for the production of silica sand cores in foundries.

Keywords*: orihi clay, sand core, binder, jatropha curcas, nigella sativa seed oils.*

Introduction

Foundry cores play a significant role in the production of machine part, during casting, as all cavities produced in metal casting are supported by the use of cores. Delicate and often complex sand cores are subjected to high stresses during pouring due to hydrostatic pressure exerted by the molten metal [1]. However, it is difficult to obtain natural sand with the full compliments of these properties (shatter index, permeability, green and baked strengths) and thus, sand cores are synthetically prepared by the combining many ingredients including sand grains, core binders and special additives [2]. Besides the high cost of imported binders is a problem that has motivated great interest in characterizing the locally available materials. Investigations by Shehu and Bhatti [3] and Aponbiede [4] have shown that the use of starch such as cassava, maize, and yam separately as binders could not produce cores to be used for heavy castings such as steel castings owing to low bond strength.

The cores produced from starch were found to deteriorate and could not store over a long time.

A study by [5] has shown that resins used as binders give better cores with accurate dimensions, but omit hazardous pollutants during the decomposition to pose serious health hazards [6].

Many studies have been carried out to investigate the properties of foundry cores bonded with various vegetable oils in isolation and as mixtures. Ademoh and Abdullahi [7] in his study of baked tensile strength properties of foundry cores bonded with hybridized binder that composed of neem oil and Nigerian gum Arabic. A maximum strength of about 680 kN/m^2 was obtained by the blend of 3% of each of grade 4 gum arabic and neem oil at a baking time of 2 hours. The bonding properties of cissus populnea for use as binder for the production of foundry

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cores for casting aluminium alloys was carried out by [6], established that using 5 % cissus populnea developed baked strength of 932 kN/m^2 at temperature of 160 ^{0}C and baking time of 1.5 hours. Fayomi et al. [8] studied the suitability of groundnut, cotton seed and palm oils with Ogbomosho clay and silica sand for the production of foundry cores. The tensile strength of the core was as high as 600 kN/m^2, but the increase in oil addition beyond 10 % resulted in the increase in the quantity of smoke during baking.

Aponbiede [9] determined using cassava starch and oils as binders showed a maximum tensile strength of 311 kN/m^2 at a baking time of 2 hours. However there was improvement in the baked strength up to a maximum of 863 kN/m^2 by the addition of soya beans and cotton oils. Fayomi et al. [10] applied bentonite, cassava starch, and yam starch binders separately to River Niger bank silica sand in different proportions, the results showed that bentonite had better binding characteristics of the mould compared to cassava starch and yam starch. It is obviously observed from the studies above that the use of binders such cassava, maize, and yam separately as binders could not produce cores of adequate strength that can be used in industries as related to heavy castings such as steel casting due to low bond strength. Starch binders possess the disadvantages of giving off objectionable gases during baking and casting operation and cores produced starch cannot be stored for long time. In this study Orihi (Apa-Benue, Nigeria) clay, Jatropha curcas and Nigella sativa seed oils were evaluated as alternate binder materials for production of foundry silica sand cores, with a view to moving away from synthetic binders that are hazardous to the environment

Materials and Methods

Preparation of test samples

Pebbles were removed from Orihi clay (Apa, Benue-Nigeria) ground into smaller particles size of 75 µm, after drying. River Benue Sand (Makurdi – Benue, Nigeria) of 86.8 % moisture was washed, clean, and dried for two days (9.76 % moisture). The mineralogical composition (Table 2 and 3) of the Orihi clay and the silica sand was done using using ED X–ray Fluorescence Analyzer). Seed Oils from Jatropha curcas and Nigella sativa were analysed for physicochemical properties including specific gravity, iodine value, saponification, acid value, free fatty acid value, boiling point, and melting point.

Preparation of the cores

The first set of bonded sand cores were prepared by adding clay in various percentages of 3, 5, 7, 9 and 11 % to sand respectively at 6 and 8 % water. The second set of cores were achieved by adding the two oils in various percentages as in the first instance, but the oils were in the ratio of 50:50 in all the weight percentages to sand and water used in the first case without clay. The third set of cores produced were done by adding 3 % Orihi clay, to 4 % of Jatropha curcas and Nigella sativa seeds oil to sand. Test samples of Ø50 mm x 50 mm were baked in an oven at a temperature of 180 °C 30 to 150 minutes at 30 minutes intervals according to the work of [11].

Evaluation of the baked cores

Shatter index and permeability tests

A green test specimens were weighed separately after one another and placed in the shatter index tester. The tester was pushed upwards from a height of 180 cm over the stripping post until it struck the anvil, which fell and shattered the specimen. The retained sand and oversized which passes through the sieve into the sieve pan was weighed and used to compute shatter index using equation (1) [12].

$$\text{Shatter index}=(\text{Weight of sand on the mesh})/(\text{Total weigh of specimen})\times 100 \qquad (1)$$

The specimens for permeability were transferred to the permeability machine without removing them from the specimen tube. The specimen tube was then mounted on the electric perimeter. The machine was switched on and the system lever moved to the test position. The permeability reading was then displayed on the dial of the machine as recorded in the work by [13].

Green and baked strengths test

Green and baked compressive strengths of the three sets of bonded cores were determined using the SMETCO digital universal testing machine (WE100B) in accordance the work done by [14]. However, prior to the determination of baked compressive strength, the green cores were baked at a temperature of 180 °C within 30 to 150 minutes at 30 minutes intervals. Green and baked shear strength values were determined using the SMETCO digital universal testing machine Model; WE100B as reported by [15]. The cores were baked at a temperature of 180 °C within 30 to 150 minutes at 30 minutes intervals prior to the baking.

Results and Discussion

Mineralogical and physicochemical composition of sand, clay and oils

The results of mineralogical analysis for river Benue sand and Orihi clay are presented in Tables 1 and 2 respectively. It was observed that the silica sand contain 95.5 % SiO_2 and 0.02 % Al_2O_3 and 0.77 % Fe_2O_3 as the principal constituents. The 95.5 % silica content compared well with the minimum acceptable values of 95 % recommended for moulding and core sands as reported by [16], while Orihi clay had 67.50 % silica, 18.21 % alumina and 6.76 % Fe_2O_3 as the principal constituents.

Table 1. Mineralogical Composition of River Benue Silica Sand

SiO_3	Al_2O_3	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	MgO	CuO	Na_2O	LOI
95.5	0.02	0.05	0.34	0.02	0.01	0.14	0.77	0.17	0.06	0.05	2.87

These values are reported to be common and adequate for general purpose foundry moulding sand and cores by Brown, (2000). The higher silica and alumina contents provide the necessary refractoriness needed by cores that resist heat from molten metal during casting [17].

The results of physicochemical composition of the Nigelle and Jatropha curcas seed oils used in the investigation are presented in Table 3. Values of specific gravity obtained from Nigella sativa seed oil was 0.8696 while that of Jatropha curcas seed oil was 0.8753 at 38.5 ^{o}C. The variation was attributed to different temperature used in determining the specific density.

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Table 2. Mineralogical composition of *orihi clay*

SiO_3	Al_2O_3	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	MgO	CuO	Na_2O	LOI
67.50	18.21	1.04	0.69	2.52	0.04	0.16	6.76	0.14	0.09	0.05	2.80

The high specific densities recorded by both Jatropha curcas and Nigella sativa seed oils was an indication that the two oils have high viscosities as this normally aids adhesion properties between the molecules of sand grains and the oils as reported by [18]. The results of iodine values (Table 3) gave value of 136 mgI/g for Nigella sativa seed oil and 115 mgI/g for Jatropha curcas seed oil. These values were higher than 106 and 105 mgI/g reported by [19] in their work on Jatropha curcas oil.

Table 3. Physicochemical composition of nigella sativa and jatropha curcas seed oils

Properties	Nigella sativa seed oil	Jatropha seed oil
Specific density	0.8696 gcm/1	0.8753 gcm/1
Iodine value	136 mg/g	115 mg/g
Free fatty acid	2.99 %	0.5797 %
Acid value	5.95 mgKOH/g	1.1536 mgKOH/g
Saponification value	203 mgKOH/g	204 mgKOH/g
Smoke point	82 °C	124 °C
Boiling point	131 °C	124 °C
Melting point	– 9 °C	– 5 °C

The saponification values obtained in this study were found to be 203 mgKOH/g for Nigella sativa seed oil and 204 mgKOH/g for Jatropha curcas seed oil. The implication of these results is that the higher saponification values suggests that these oils can give higher hardness and stability to the cores when used, will allow for longer storage with reduced deterioration. The melting and boiling point for Jatropha curcas seed oil were found to be –5 and 130 °C respectively, and –9 and 131 °C respectively, for Nigella sativa. This suggests that the oils are suitable as binders for making cores, since the lower the melting points, and the higher the boiling point are sign of healthier oil with the stronger the atomic bond between it molecules and sand grain. The low acid values of 5.95 mgKOH/g and 1.1536 mgKOH/g respectively, obtained from the oils, showed that goog potential to be used as binder material for cores production. The FFA value for Nigella sativa and Jatropha curcas seed oils (Table 3) were found to be 2.99 and 0.5797 % respectively. These values also indicate the oils as having low deteriorating rate, which make them suitable as binder material [20].

Shatter index and permeability

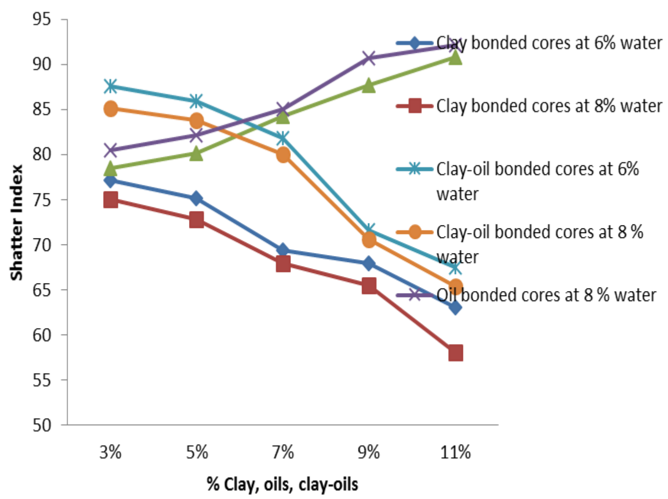

Fig. 1. Variation of orihi clay, jatropha curcas-nigella sativa oils, and clay-oil bonded cores on shatter index at 6 and 8 % water

The results of shatter index as presented in Fig. 1 shows that shatter index of cores produced from clay alone and the mixture of clay with the two oils decreased as their percentages in the formulation increase at 6 and 8 % level of water. However, the shatter index values of the cores produced from the mixture of the two oils were observed to increase as increasing percentages of the binder. The shatter index values ranged from 77.1 – 63.0 and 75.0–58.1 at 6 % water 8 % water respectively for clay bonded cores. The shatter index for cores produced from the blend of Jatropha curcas-Nigella sativa oils increased from 78.50– 90.8 at 6 % water and 80.5 – 92.1 at 8 % water. The values of shatter index for cores produced by blending the two oils with Orihi clay increased from 87.6 – 67.5 at 6 % water, and 58.1–85.1at 8 % water. This may imply that by increasing Jatropha curcas-Nigella sativa oil content the bonded particle of the sand cores becomes loosened, thereby weakening the bond, and resulting in higher collapsibility.

As shown in Fig. 2 permeability values decreased gradually from 135– 115 and 150–120 at 6 % and 8 % water. This is may be due to increase in clay content causing less pores in the mould that could allow gas to pass through. Orihi clay exhibited good properties for casting heavy, light steel as well as heavy grey iron, as the values obtained from green permeability fall within the ranges of 130 – 300, and 125 – 200 as reported by [21] for satisfactory property for sand casting. The permeability values for cores bonded using the oil mixtures were observed to gradually increase from 161 for 3 % oils to 194 for 11% oil at 6 % water and 168 to 210 at 8 % water.

The permeability values of Orih clay and Jatropha curcas-Nigella sativa oil bonded cores were found to decrease and ranged from 160 - 163 at 6 % water and 8 % water for 3 % oils/clay. This may be due to the stronger bond between sand grains which resulting into closer contact of the molecules of the core mixtures. Such intimacy will reduce the porous spaces between core particles and in turn reduced ease of air passage through core causing decrease in permeability values [7]. The permeability values using the oil mixture were found to be higher, than those by clay-oil, and clay bonded cores. This implies that, during the pouring process, gases such as hydrogen, nitrogen, carbon dioxide, and steam, will easily leave the mold or core produce by Jatropha curcas-Nigella sativa oil, while some of these gases will be hindered by Orihi clay bonded cores.

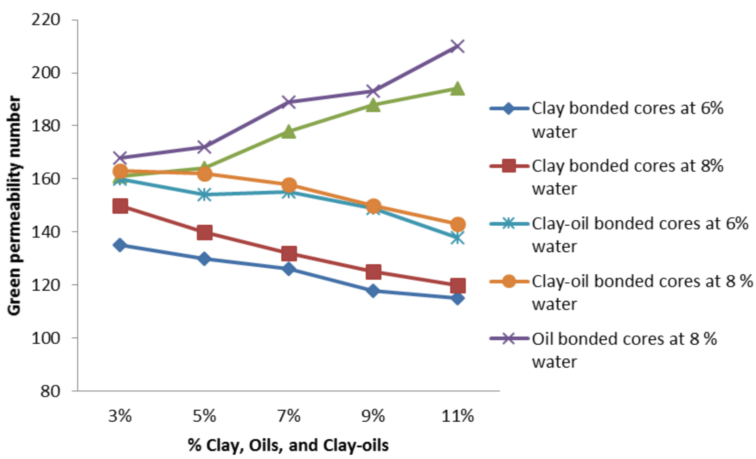

Fig. 2. Variation of orihi clay, jatropha curcas-nigella sativa oils, and clay-oil bonded cores on green permeability at 6 and 8 % water

Strength properties of produced cores

Green and baked compressive strength

As shown in Fig. 3 the green compressive strength of the produced cores at 6 and 8 % water was observed to increase as the clay content (3-11 %), and moisture contents are increased. The green compressive strength for cores bonded with Orihi clay only varied from 18 to 45 kN/m^2 and 21 to 47 kN/m^2 at 6 and 8 % water respectively. While the green compressive strength of cores bonded with clay and the two oils varied from 21-34 kN /m^2 and 18-34 kN /m^2 at 6 and 8 % respectively. The green compressive strengths of 14-17 kN /m^2 and 12-16 kN /m^2 was obtained from cores bonded with the mixture of Nigella sativa and Jatropha curcas seeds oils. The reason for higher values of green strength exhibited by Orihi clay could be due to the molecular structure of Orihi clays which consists of sheets of silicate and aluminate ions, thus setting electrostatic forces within the structure to produce the bonding property.

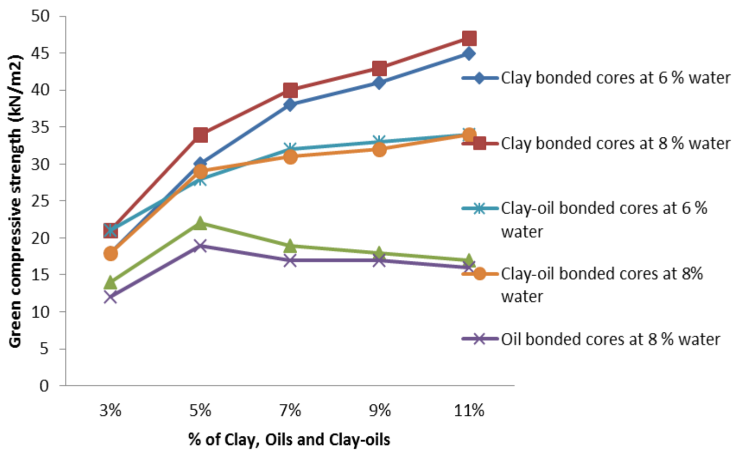

Fig. 3. Effect of orihi clay, jatropha-nigella sativa oil bonded cores on green compressive strength at 6 and 8 % water

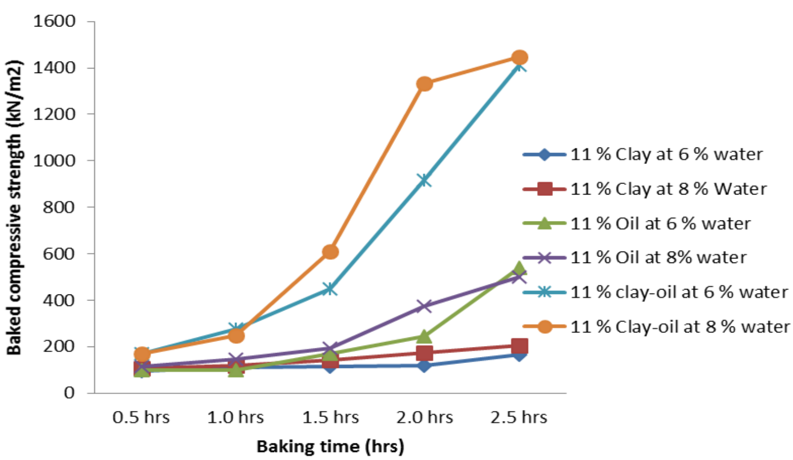

Fig. 4. Variation of baking time with baked compressive strength at 11 % for orihi clay, jatropha curcas-nigella sativa oil, and clay-oil bonded core at 6 and 8 % water at a baking temperature of 180 °c for a baking interval of 0.5-2.5 hours

The green compressive strength values of the cores produced at 6 and 8 % water fall within the range of values recommended for cores for the casting of Class I, II, III, IV, V iron/steel, intricate and non-intricate aluminium as reported by [21].

In Fig. 4 the baked compressive strengths were observed to increase as baking time is increased at interval of 30 minutes (0.5 hr) for all the cores produced. The optimal baked strength of 144 kN/m^2 was given by core from the mixture of clay and the two oils at 8 % water level. According to Akor [22], the introduction of water activates the cohesive properties of the binder, thus giving rise to optimal value at 8 % water. This is because longer baking time provides more time for silica sand and clay components to react together thereby causing increased in bond strength as reported by [8]. The clay-oil bonded cores gave higher values due saturation and presence of iodine in the oils

Green and baked shear strength

As in Fig. 5 green shear index of the cores increased as clay content was increased. It was observed that green shear strength values of specimen bonded using Orihi clay were higher due the better binding mechanism, and increased from 15 to 28 kN/m^2 at 6 % water, 17 to 30 kN/m^2 at 8 % water respectively. In Fig. 6, baked shear strength of cores produced from the blend of clay and the two oils were found to have better strength properties at baking period of 30 –150 minutes at 6 and 8 % water content. The optimal value of baked strength observed was 1292 kN/m^2 for clay-oil bond cores at 8 % water.

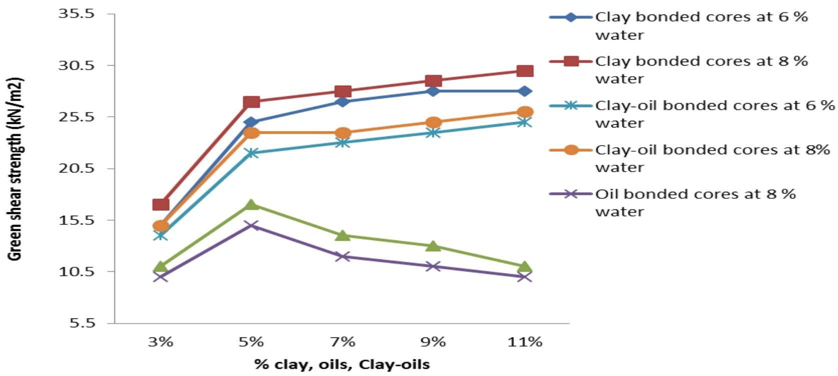

Fig. 5. Effect of percentage of orihi clay, jatropha-nigella sativa oils bonded cores on green shear strength at 6 and 8 % water

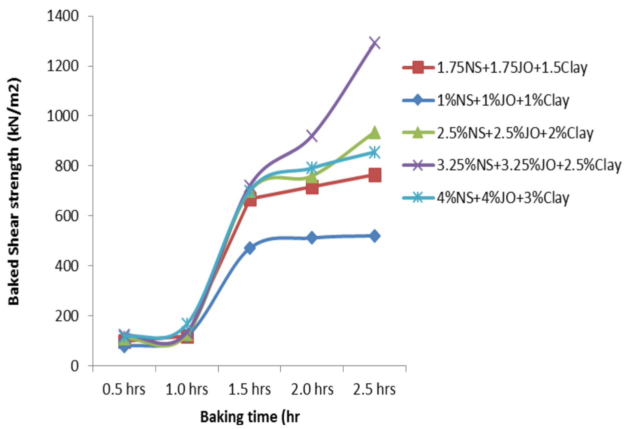

Fig. 6. Effect of baking time on baked shear strength at 8 % water on orihi clay, jatropha curcas-nigella sativa bonded core at baking temperature of 180 °c within a baking intervals of 0.5-2.5 hours

Conclusion

Based on these results, it was concluded that Orihi clay, Jatropha curcas and Nigella sativa seed oils are suitable for use as binders for the production of silica sand cores in foundries, while improved bond strength characteristics may be obtained using these materials individually, higher bond strength (3010 kNm^2) could be achieved by combining the Orihi clay with the oils.

References

[1] M. Abdulwahab, J. O. Gaminana, K. A. Bello and E. O. Ochuokpa, Prospect of Local Core Binders in Foundry Industries, **Proceedings of Nigerian Metallurgical Socie 25th Annual conference** 15-18 October, 2008, Akure, Nigeria, pp. 210 – 213.

[2] E. O. Olakanmi and A. O. Arome, Characterization of the core–binding properties of fatty based oils, **International Journal of Physical Sciences**, 2009, 4, pp. 623 – 628.

[3] T. Shehu and R. S. Bhatti, The use of Yam flour (starch) as binder for sand mould production in Nigeria, **World Applied Sciences Journal**, 2012, 16(6), pp. 858-862.

[4] O. Aponbiede, Development of oil sand cores using local vegetable oil, **Journal of Metallurgy and Materials Engineering**, 2000, pp. 6 – 107.

[5] E. Ireland, K. Chang and J. Krober, American Foundry Men's Society (AFS) Transactions, 2002, pp. 1 – 2.

[6] F. M. Achiv, O. Aponbiede, S. B. and Hassan, Mechanical Properties of Sand Cores bonded with 5% *Cissus populnea* for Production of Aluminium Castings, **Journal of Metallurgy and Materials Engineering**, 2010, 5(1), pp. 62-67.

[7] N. A Ademoh and A. T. Abdullahi, Determination of optimal binding properties of Grade 1 Nigerian acacia species for foundry mould sand, **Middle East Journal of Scientific Research,** 2010, 5(5), pp. 402–406.

[8] S. I. Fayomi, J. S. Ojo and A. P. I. Popoola, Suitability of local binder compositional variation on silica sand for foundry core–making, **International Journal of the Physical Sciences,** 2011, 6(8), pp. 1940 –1946.

[9] O. Aponbiede, Oil Cassava Starch–Bonded Cores for casting applications, **Journal of Emerging Trends in Engineering and Applied Sciences,** 2012, 3(5), pp. 761 –764.

[10] O. S. I Fayomi, F. H. Olatuja and T. O. Joshua, Hybrid Effect of Selected Local Binders on the Moulding Properties of River Niger Silica Sand for Industrial Application, **Journal of Nano science with Advanced Technology**, 2016, 1, pp. 19–23.

[11] A. W. Giesseren, An Environment-friendly Core Production Technology, www. myhomeFoundry. com.

[12] A. A. Nuhu, Bentonite clay as a composite mix with grades 1 and 2 Nigerian acacia species for binding sand moulds, **International Journal of Chemical and Biochemical Sciences, International Scientific Organization**, 2012, 1, pp. 85 – 90

[13] A. T. Ihom and A. K. Anbua, Assessment of Honey as a Binder for Core Making in Foundry, **Proceedings of Nigeria Metallurgical Society**. 20-26 July, 2006, 15(2), pp. 70–76.

[14] R. K. Jain, **Production Technology,** (First edition) Khanna Publishers, Nai Sarak, Delhi. India, 2008, pp. 138–244.

[15] N. A. Ademoh, Establishment of the Beneficial Effects of Addition of Linseed oil to Foundry Sand Cores Bonded with Nigerian Gum Arabic Grades 2 and 4, **American-Eurasian Journal of Scientific Research**, 2009, 4(2), pp. 97–100.

[16] J. R. Brown, **Feseco Foundry Men's Hand Book**, Feseco International Ltd, Birmingham, 2000, pp. 28 – 31.

[17] A. P. Popoola and O. S. Fayomi, Accessing the performance of binders on core strength in metal casting, **Journal of Emerging Trends in Engineering and Applied Sciences,** 2011, 6(34), pp. 7805 – 7810.

[18] R. S. Patel and N. S. Nayak, Physicochemical Characterization of Seed and Seed Oil of Jatropha curcas L. **Sains Malaysiana**, 2010, 39(6), pp. 951– 955.

[19] J. Salimon and R. Abdullah, Physicochemical properties of Malaysian Jatropha curcas seed oil. **Sains Malaysiana**, 2008, 37(4), pp. 379 – 382.

[20] A. K. Aftab, S. A. Mahesar, A. R. Khaskheli, S. T. H Sherazi and Q. Sofia, K. Zakia, Gas chromatographic coupled mass spectroscopic study of fatty acids composition of Nigella sativa L. (KALONJI) oil commercially available in Pakistan. **International Food Research Journal**, 2014, 21(4), pp. 1533-1537.

[21] A. A Nuhu, Effect of kaolin clay addition on mechanical properties of sand moulds bonded with grades 1 and 2 Nigerian acacia species, **International Journal of Physical Sciences**, 2008, 3(10), pp. 240–244.

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