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Physiochemical Effect of Selected Oils as Alternative to Foundry Core Binder in Casting

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ABSTRACT: The use of edible oils as core oil in the foundry industries has remained the conventional oil widely used in the past decade. The search for alternative core oils has become challenging due to high demand of these edible oils for consumption and industrial applications. Some non-consumable oils such as neem, jatropha, castor and sheabutter oils were evaluated as core binders in foundry sand. These plants are found littered/wasted around in major parts of Nigeria and its potentials are yet to be ultilised maximally by countrymen. Core specimen containing silica sand bonded with starch, water in variable proportions of non-edible oil were tested for moisture content, permeability, tensile strength, green/baked compressive strength, baked collapsibility and fatty acid to determine if its felicitous for foundry core application. An optimum baked strength of 1648kN/m^2 was obtainable in a mixture of 6% neem seed oil, 2% water, 2% starch and balance sand. This can be attributed to its high degree of unsaturated properties contained.
KEYWORDS: Silica sand, non-edible oil, fatty acid, core oil, casting

I. INTRODUCTION

In foundry practice, casting play a significant roles an important roles (directly or in-directly) in all sectors of industrialization such as power, agriculture, construction, transportation, chemical and petrochemical industries. It simplifies the production of equipments and parts that are difficult to produce with other engineering processes with little or no wastage in material. The use of core for foundry processes especially in mass production of engineering parts becomes very important or possibly inevitable to ignore.

Cores are solid material usually made of sand, metal, evaporative or non-evaporative masses employed in foundry practice to produced simple or complex internal cavities of castings (Ademoh 2010) . Cores constitute silica sand grain, plaster, metal or ceramics, an addictives (if necessary) and a selected binder for optimum properties. It is generally produced differently from sand-mould and baked (hardened) to ameliorate setting into the mould cavity. The use of core becomes inevitable in casting to provide means of forming the main internal cavities; obtaining an improved mould surface finishing; for the production of complex/intricate parts and to prevent the molten metal from filling the entire casting space. Due to the state or condition of foundry core (green or baked) at which it's been handled, they are generally subjected to abrasion and other forms of deformation that can limit the reliability or consistency of cavities they may create in casting, it becomes necessary that sand cores must exhibit an ability to resist defects and able to withstand the hydrostatic pressure of molten metal without distortion or deformation in its shape before and at the process of casting (Shuaib and Lanre 2014). In addition, foundry cores must possess outstanding characteristics such as adequate permeability; sufficient strength (compressive and tensile); better collapsibility (to produce clean cavities in part after casting/ good surface finishing); high refractoriness and good gas permeability (easy escape of gases in mould in casting). Deficiency in any of these properties afore-mentioned may result to defects in casting and production loss. The choice of suitable moulding material for foundry core oils that will enhance casting properties has remain a great interest and challenges to researcher in the past decade. Generally, clay is commonly used in foundry due to its binding ability; however when in use alone do not result in adequate or desirable mechanical properties (Fayomi et al, 2014). Vegetable oils are popularly known core binder because they are relatively cheap; readily available; exhibits good bench life and excellent core properties (Jain ,2003; Akor, 2014). Some locally sourced vegetable oils used as core binders include soybean, groundnut, cotton oil, palm kernel seed, rubber seed oil, etc. Investigation on these oils have shown that an optimum baked strength of 1829kN/m^2 was achieved in a mixture of 3% Rubber seed oil, 7% water 0.5%cassava starch and 89.5% sand (Akor, 2014). Kaolin clay addition to gum Arabic improved permeability by about 18%, shatter index by 5%, green compressive strength by 8% and baked tensile strength by 11-15% over cores bonded with plain grades 1 and 4 Nigerian gum Arabic (Fayomi et al, 2011). Fayomi et al (2014) in their research, it was established that the use of palm oil and pine oil as potential binders on foundry core strength improve foundry properties at different baking temperature (Fayomi et al, 2014). Fayomi at al (2011) concluded that the addition of bounding binder proportion of groundnut oil, cotton oil, palm oil, and starch variation thus improved the strength of the core and enhance the mechanical property Aponbiede O. (2000). Aponbiede, reported an optimum backed strength of 742kN/m^2 using clay as additive in a mixing combination of 3% soybean oil, 1.5% clay, 7% water and 85.5% sand (Akor, 2008). Also, Akor in his research work, recorded a backed strength of 587kN/m^2 in a mixture consisting of 3% soybean oil sludge, 0.5% cassava starch, 7% water and 89.5% sand (Mishra et al, 2013).

Amidst the mineral and edible vegetable oils used as binder in most foundry industries, the demand of these edible oils increases geometrically as a result of their wide and significant application at home, eateries, heat treatment and cosmetic industries. These have resulted in short supply and require high purchasing power to obtain them.

In consideration of high cost of these edible oils and the quest for alternative core oil that will not only provide adequate properties but also produce desirable physico-mechanical properties for application in foundry industries. The use of some locally sourced non-consumable oils (jatropha oil, neem oil and sheabutter oil) as an alternative to conventional foundry oil become necessary.

Sheabutter belong to the family Sapotaceae, is one of those multipurpose forest tree species that provide an answer for the three major F's i.e. food, fodder and fuel (Durowoju et al, 2013). It is widely distributed in the northern parts of Nigeria. Sheabutter, over the years had been of significant use in Africa for a number of purposes, ranging from soap processing, heat treatment, skin and other medical applications. Studies have shown the suitability of sheabutter as bioquenchants on medium carbon steel for industrial heat treatment (Elbehri et al, 2013).

Jatrophas are oil plants belonging to the family of Euphorbiaceae. They are drought-resistant perennial shrubs or trees (Kazi et al, 2010). Jatropha tree grows to a height of 3-4 m, and remains actively productive for up to 30 to 50 years. Most Jatropha species, including Jatropha curcas, contain toxic components in the seeds and its by-products, when not detoxified, are harmful to humans and livestock. Studies have shown that Jatropha oil has potential as an alternative source of energy (Adekunle et al, 2013) and for heat treatment due to its high flash point, heat transfer coefficient and cooling rate. The oils obtained from the seeds are vastly used in making detergents, lubricants, insecticides and medicines. Jatropha seed plants are vastly seen in most plantations especially in northern and eastern part of Nigeria. They are often recognised as weeds and sometimes used as cover in most Africa farm lands and homes. Its significance is yet to be harnessed by millions of the country men.

Neem seed (Azadirachta indica) is an ever green drought resistance tree growing in most northern parts of the country. A mature neem tree can produce fruit weighing 30 – 50kg every year and a productive life span of 150 – 200 years (Hassan et al, 2013). Studies shows the oil can be extracted from all parts of the tree (leaves, bark, fruits) with different proportion of oil yields (Nuhu et al,2016). Suitable for the production of biodiesel with improved fuel properties lower emission of unburned hydrocarbons, carbon monoxide but higher level of oxides of nitrogen (Gaminana, 2011). The oil show significant improvement when use as machining/cutting fluid (Agboola et al, 2015; Salimon et al, 2010) and suitable for quenching media in hardening process for medium carbon steel.

Castor bean (Ricinus communis) oil belonging to the family of Eurphorbiaceae, is a pale yellow non-volatile and non-drying oil, plant indigenously in some parts of the countries. The plant requires less maintenance, fertilizers to survive when compared to other crops. Due to its unique nature, it's widely used as a human laxative-cathartic agent, particularly in cases of certain radiological examinations which require prompt and thorough evacuation of the small intestine It's an asset that is underappreciated in most industries. Little information on the use of this oil in heat treatment processes and possibly foundry core is observed in the literature. This study seeks to bridge the gap in the knowledge of castor oil as alternative to the conventional core oil in the foundry industry.

Their area of application is ascertained by their drying properties which generally determines the green/baked strength of the oil-sand core and is a function of the level of oxygen absorbed during curing. The level of oxygen absorption by the oil is a direct indicator of the drying power of the oil, and is dependent on the degree of unsaturation of the fatty acids (Ademoh, 2009).

The use of cassava starch for sand core processes has not been vastly used; hence the successive need to examine its prospect with the use of other binders such as jatropha oil, neem oil, sheabutter and castor oils in this study becomes imperatively necessary. The oils are generally environmental friendly for the production of sand core and are readily available in most parts of the country. This study is aimed at developing sand core bonded with oils extracted from some non-edible oils such as jatropha, neem, sheabutter and castor oils and as an alternative to conventional foundry core. The objective(s) are to produce bonded specimens with the selected non-edible seed oils; green/oven baked and subjects them to some mechanical properties that directly affect foundry core. These include green/baked compressive strength, tensile, shatter index, collapsibility and permeability tests to ascertain the suitability of the oils for foundry core casting. A successful execution of the study is envisage to provide vital information to local foundry industries to maximally utilize the use of these locally sourced raw material, minimize wastage and be economically viable in foundry technology.

II. METHODOLOGY

2.1 Materials

The materials used in the course of study include silica sand while binders used include starch (manihot esculenta), jatropha seed oil, neem seed oil, castor oil, sheabutter seed oil and water. Equipments include sets of sieve, rammer, measuring cylinder, digital weighing balance, mixer, electrical oven, and permeability meter.

2.1.1 Collection of Material

The silica sand used for the study was obtained from a river in Chanchaga, a local government area in Niger State, Nigeria. The clay used to enhance the binding property of the silica sand was obtainable from Kadna village in Niger State and starch obtained from cassava was harvested in a farm land. The neem seed, jatropha seed were harvested in the school enviroment, College of Education, Niger State, Nigeria, while sheabutter seeds were harvested in Kadna village in Chanchaga local Government area of Niger State, Nigeria. Castor oil was purchased in one of the shop.

2.2 Oil Extraction

The cassava starch was processed locally from garri production. The non-edible seeds (jatropha, neem and sheabutter) were dried in an oven at a temperature of about 70 ^{o}C for 8 hours and grounded locally to powder form. They were subjected to solvent extraction with the use of n-hexane and extraction of oils lasted for 6-9 hours until reasonable amount of oils were extracted. The oils containing n-hexane were poured into a soxhlet apparatus where samples of refined oils were obtained and transferred to transparent bottles.

2.3 Sand Preparation

Silica sand was repeatedly washed thoroughly to ensure free from dirt. It was left to dry under the heat of sun for four (4) days. It was taken for analysis under an ED X-ray fluorescence analyser for its compositions as summarised in Table 1.

2.4 Core Making

The silica sand, starch and clay were measured and mixed thoroughly in different proportions; the oils were then added and finally water. The mixture was manually carried out by hand so that a uniform mixtures can be attainable and to develop new bonding property. The constituent mixtures and their percentage composition of oils used are briefly summarised in Table 2. Ramming of the mixture was carried out in the Nigeria Foundry Limited standard rammer to produce the core. The cores were initially fettled by drying it in an oven for thirty-five minutes at a temperature of 80 ± 3 ^{o}C with the aim of attaining a certain degree of moisture before baking operation. The cores were baked in an electric oven to a temperature 200 ^{o}C (392 ^{o}F) and oven cooled. The baked cores were subjected for further tests at the Nigerian Machine Tools Company Limited, Oshogbo.

2.5 Specimen Tests

Various foundry properties of the sand/sand core were carried out as summarised below.

Particle Size Analysis: A 900g of clean dry silica sand was separated and passed through a British standard sieve (6, 12, 20, 30, 40, 50, 70, 100, 140, 200 and 270) to remove any remains of coarse particles. A 50gm of washed/fine sand obtained was then placed on a shaker for fifteen minutes. The specimen of weight sand that settled on each sieve was used in computing the Grain Fineness Number (GFN) as expressed in equation 1.

$$GFN = \frac{\text{Total product}}{\text{\% grain retained}} \qquad (1)$$

Moisture Content Test: A 50gm of specimen were put into an oven and left for 2hours at a maintained temperature of 110 ^{o}C to reduce/removal of moisture. The dried specimen was removed from the oven and reweighed. The percentage in moisture content was determined by the expression below:

$$\text{Moisture content} = \frac{w_1 - w_2}{w_1} \qquad (2)$$

Where,

w_1 = weight of moist sand

w_2 = weight of dried sand sample

Green Permeability Test: A standard air pressure of $9.8 \times 10^2 N/m^2$ was made to go through a standard cylindrical test specimen diameter of 50 mm and 50mm length placed in the sample tube of the permeability meter. After which a 2000cm^3 air had passed through specimen, green permeability values in numbers was measured instantaneously and calculated by the mathematical expression below.

$$P_A = \frac{V \times H}{A \times P \times t} \quad \text{(Gupta, 2005)} \qquad (3)$$

Where,
V = Volume of air (cm^3)
H = Height of the sand specimen (cm)
P = Air pressure (g/cm^2)
A = Cross sectional area of sand specimen = $\Pi/4 \times (5.08)^2$
t = Time for complete air to pass through (minutes)

Green/Dry Compressive Strength: Rammed portions of the specimen were placed on a universal sand-testing machine (Model...) in its green state. An increased steady compressive load was applied on the specimen until failure occurs, the load required in causing the sample to fail or collapse was also recorded in KN/m^2. Core specimen used for dry compressive strength test was dried in an oven at 110 ^oC for 2hours and left cool at room temperature.

Tensile Strength Test: The universal strength testing equipment with meter attached to read the baked tensile strength (KN/m^2) was used. A gradual and steady tensile force was applied on the baked specimen until failure occurs; baked strength was read and recorded instantly.

Shatter index test: A green core sample was rammed with 10 blows, placed in shatter index test cylinder and was allowed to fall from a height of 6ft on an ½ inch mesh sieve. The degree or extent of disintegration of each core was measured.

Core Collapsibility Test: collapsibility test was determined by subjecting the baked and oven cooled specimen to a furnace temperature of 600^oC and soaked for 2-5 minutes to rupture. Time taken (in seconds) of each sample to rupture was taken and documented.

Further test on fatty acid content or properties were evaluated

III. RESULTS AND DISCUSSION

3.1 Samples Mineral and percentage Composition

The results of mineral composition analysis for the moulding silica sands under investigation are shown in Table 1.

Table 1: Chemical Composition of Foundry Sand used in the Study

Composition	SiO_2	Al_2O_3	K_2O	Na_2O	Fe_2O_3	TiO_2	MgO
Wt (%)	96.45	18.4	0.28	1.05	0.69	0.46	1.61

Table 2 show the varying percentage composition of oils with constant percentage composition of starch, water. This was to determine the effect of oil binder on the physico-mechanical property of the foundry core.

Table 2: Percentage Composition of Mixed oil and Starch

Sample A	2% Starch + 2% Water
Sample B	2% Starch + 2% Water + 2% Oil
Sample C	2% Starch + 2% Water + 3% Oil
Sample D	2% Starch + 2% Water + 4% Oil
Sample E	2% Starch + 2% Water + 5% Oil
Sample F	2% Starch + 2% Water + 6% Oil
Sample G	2% Starch + 2% Water + 7% Oil
Sample H	2% Starch + 2% Water + 8% Oil

3.2 Results of Sieve Analysis

The results obtained from the America Foundry Society (AFS) GFN analysis for the various specimens is presented in Table 3.

Table 3: Sieve Analysis of sample

Mesh	Sample retained in sieve	Retained sample (%)	Cumulative retained sample (%)	Multiplier	Product
6	0.00	0.00			
12	0.10	0.10	0.10	10	1.00
20	1.04	2.08	2.18	12	24.96
30	4.30	8.60	10.78	20	172.00
40	7.99	15.98	26.76	30	479.40
50	22.38	44.76	71.52	40	1790.40
70	5.46	10.92	82.44	50	546.00
100	4.68	9.36	91.80	70	655.20
140	2.55	5.10	99.54	100	510.00
200	1.32	2.64	99.54	140	369.60
270	0.00	0.00	99.54	200	0.00
PAN	0.00	0.00	99.54	270	0.00

	49.82	99.54			4548.56

G.F.N = Product / % retained

= 4548.56

99.54 = 46%

Finess = 2.64 + 0.00 = 2.64%

3.3 Mechanical Properties Test

Figure 1 – 6 illustrates a summary of results obtained after testing for mechanical properties of the core moulding sand specimens.

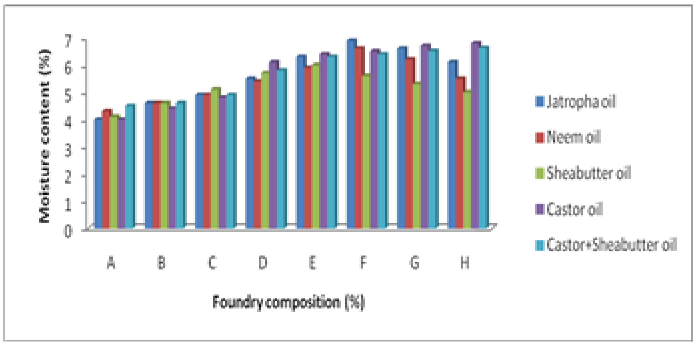

Figure 1: Moisture content (%) against increasing oil binder content

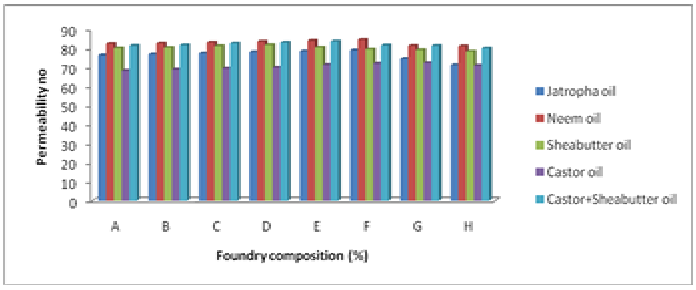

Figure 2: Permeability (No) against increasing oil binder content

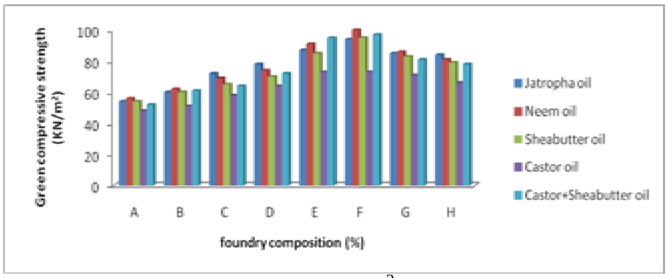

Figure 3: Green compressive strength (in kN/m^2) against increasing oil binder content

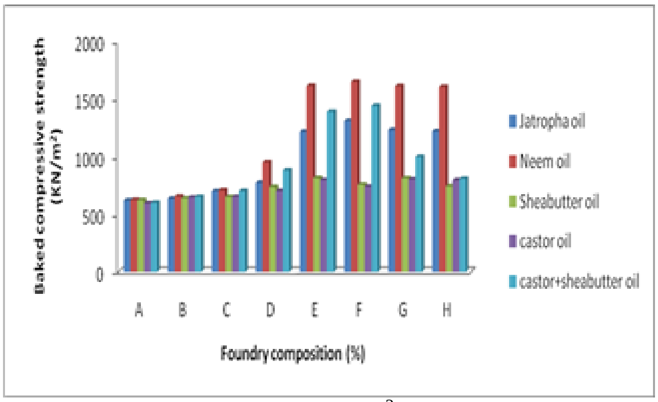

Figure 4: Baked compressive strength (in KN/m^2) against increasing oil binder content

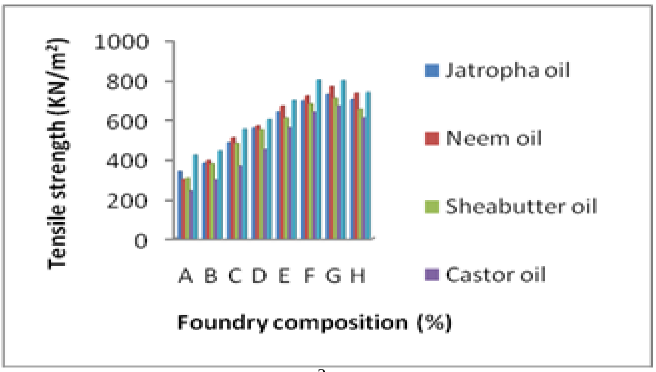

Figure 5: Tensile strength (in KN/m^2) against increasing oil binder content

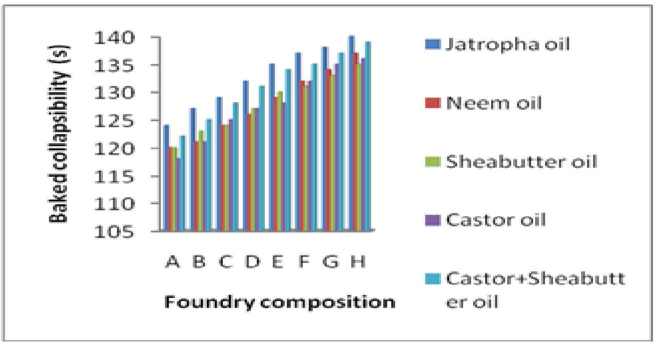

Figure 6: Baked collapsibility(s) against increasing oil binder content

Table 4- 7 summarized the fatty acid properties of the selected oil as core binder in casting

Table 4: Fatty acid properties of Jatropha oil

Fatty acid	Structure	Wt %
Palmitic	16:0	6.01
Stearic	18:0	22.24
Lignoceric	24:0	3.02
Oleic	18:1	40.10
Linoleic	18:2	15.61

Table 5: Fatty acid properties of sheabutter oil

Fatty acid	Structure	Wt %
Palmitic	16:0	7.09
Stearic	18:0	26.15
Lignoceric	24:0	5.29
Oleic	18:1	49.21
Linoleic	18:2	6.23

Table 6: Fatty acid properties of neem oil

Fatty acid	Structure	Wt %
Palmitic	16:0	19.38
Stearic	18:0	37.53
Lignoceric	24:0	3.98
Oleic	18:1	42.29
Linoleic	18:2	24.89

Table 7: Fatty acid properties of castrol oil

Fatty acid	Structure	Wt %
Palmitic	16:0	6.98
Stearic	18:0	35.45
Lignoceric	24:0	4.22
Oleic	18:1	39.63
Linoleic	18:2	18.73

IV. DISCUSSION OF RESULTS

Table 1, indicates the chemical composition of the foundry sand. The composition shows SiO_2 having the highest weight of all the samples with traces of elements such as CaO, Fe_2O_3, Al_2O_3, MgO, TiO_2, K_2O, NaO_2 present within the acceptable limits for mould sand constitute in literature (Babata S and Lanre Y, 2014).

The grain fineness number from Table 3 for the sand sample is 46% which fall within the limits (34 – 90). This indicate that the foundry sand sample used for the study is suitable for foundry purpose and is recommended for medium, heavy steel and dry sand casting (Ademoh et al, 2009).

From Figure 1, the percentage moisture contents are within 4.1 – 6.9% and falls within the satisfactory mould sand properties for different casting types (Shehu and Bhatti, 2012). Core with 2 – 4% oil binder are suitable for heavy steel while cores with 6 – 8% oil binder for light steel and heavy grey steel respectively.

Permeability of a moulding sand is a function of its grain sizes as well as its moisture content. From Figure 2, permeability of jatropha, neem, castor and sheabutter oils increases progressively with addition of core oil binders but decreases with addition of 7% oil binders except castor oil. This shows that sand samples exhibits good permeability number in which with additional oil binders tends to increase the porosity between core particles (increases the escape of air or gases) resulting to high core strength values. The permeability values obtained for oil samples falls within the standard range as related to table in literature (Aponbiede, 2010) and use for casting ferrous and non-ferrous metals.

From Figure 3, highest green compressive strength of 100 kN/m^2 was obtained with 6% addition of neem oil binder,this was followed with green strength of 97 kN/m^2 with addition of 6% castor+sheabutter oil binders while the least green strength was obtained with castor oil binder. Core bonded with 2 - 3% of the oils produces a green compressive strength suitable for aluminium, brass and bronze while cores bonded with 5 – 8% of the oils are suitable for heavy grey steel casting as compared to table showing the satisfactory sand mould properties for sand castings in literature (Shehu and Bhatti, 2012). Green compreen compression strenght increases with correponding increase in oil binders content but decreases with 7 – 8% addition of oil binders for all oil under study. This decrease can be attributed to the presence of moisture content and other organic matters which tend to impede the bond existing between the oil and sand.

From Figure 4, all core oils shows improvement in baked compressive strength and falls within the recommended value table for casting both ferrous and non-ferrous metals. Higher baked strenghts are obtained for neem and castor+sheabutter core oil of 1648 and 1439 KN/m^2 at 5% with corresponding oil content of 6% each respectively. Higher baked strength of neem seed oil than other core oils used in the study can be associated with higher saponification and iodine value (easy absorption of oxygen) which give rise to oxygen reaction of silica sand to bind cores easily with or without heat application. Core oils in the study shows increasing baked compressive strength with increase in core oil and baked temperature. A wide differences in strength values observed betweeen the green and baked compressive strength can be attributed to high baking heat that invigorate rapid and absolute bond reaction at higher baked temperature resulting to stronger oil-sand bonds.

From Figure 5, baked sand bonded with 2% of oils under investigation had sufficient tensile strength for class III iron/steel casting while bonds with 3% of oils under investigation exhibits a tensile strength suitable for alluminium, magnessium core casting. Composition of 4 – 6% oils with sand produce a strength suitable for copper bronze, copper brass cores except 6% of neem seed oil for class I iron/steel cores. Bonds with 7 – 8% of oils under investigation are suitable for class I iron/steel.

Figure 6, indicates the collapsibility behaviour of each oils used as core. Collapsibility is termed as the ability of core to remove or shake-off easily from casting after solidification. According to Dietert, 1966 ‘‘collapsibility of cores within 60 – 120 seconds is referred to as fast resulting to cracking and warpage in casting and above 180 seconds for core to collapse is regarded as slow’’. Baked collapsibility of oils under study ranges from 121 seconds with 2% oils to 142 seconds with 8% oils-sand bonds which shows better collapsibility time and show no cracking and hot tearing in casting. Baked collapsibility increases with a corresponding increase in oil binder. Oils under investigation exhibits better collapsibility for core making and require no additives.

Table 4-7 shows the unsaturated properties of fatty aicds in the selected non-edible oil. Neem exhibit high level of insaturation, thius

V. CONCLUSION

Foundry core properties the selected non-edible oils was evaluated. The following conclusion(s) can be deduced from the outcomes;

i. It can be established that core making with the use of non-edible oils (jatropha, neem, castor and sheabutter seed oils) exhibits better green/baked compressive strength, tensile strength, moisture content, permeability number and core collapsibility.

ii. All oils under study shows improvements in properties with addition of oils when compared to without core oils
iii. An optimum baked compressive strength of 1648kN/m^2 was achieved in a mixture consisting of 6% neem seed oil, 2% water, 2% starch and balance sand. This is attributed to the high level of unsaturation contained.
iv. The results indicate that bonds with the use of non-edible core oils produce strong bonds that can be effectively used in our local industries when compared with standard mechanical properties of sand cores .
v. Green/baked compressive strength, tensile strength, permeability and collapsibility of the core oil binders shows better properties for casting most ferrous and non-ferrous alloys.

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