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Characterization of Foundry Sand Cores Bonded with Raw Nigerian Water Melon Seed Oil

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Abstract
Raw oil extracted from Nigerian variety of water melon seed was used as sole binder for foundry sand cores. Specimens were characterized for foundry properties that included baked tensile, green and baked compressive strengths; baked collapsibility, green permeability, bulk density and shatter index to determine the efficacy of the oil in the absence of additives for core application. Except the baked collapsibility test that was carried out at a temperature of 600^0C, other specimens were oven baked at 200^0C and oven cooled before the tests. Green permeability and compressive strength tests were carried out on freshly moulded specimens. Standard foundry laboratory/workshop equipment available at Nigerian Machine Tools Company Limited, Oshogbo was used to conduct tests under standard conditions. Results showed that cores with compositional mix of 1-3% water melon seed oil had adequate foundry characteristics for production of classes II-V iron and steel castings. Cores bonded with the oil were unsuitable for classes I and II iron/steel and non ferrous castings including copper, aluminium and magnesium alloy due to the poor baked tensile strength and collapsibility values. Results of green permeability, shatter index and compressive strength of tested cores were very sufficient for casting both ferrous and non-ferrous alloys.
Keywords: Melon seed, oil, cores, baked, foundry, characteristics.

1.0 INTRODUCTION

Cores are solid masses made of sand, metal or evaporative and non-evaporative materials employed in foundry practice to form simple or complicated internal cavities in castings. As interior implants, cores made from sand are subjected to high stresses due to hydrostatic pressures exerted by molten metal during casting. Apart from these in-process hazard, sand cores are usually handled as separate entities in dry state during mould assembly despite their high fragility, delicate and often complex nature. These subject them to abrasion and other forms of distortion that can limit the precision of cavities they create in casting. Therefore sand cores must not only be able to resist external handling defects but also withstand the hydrostatic pressure of molten metal without change in the geometric configurations or breakage before and during casting. In addition, cores must allow easy escape of gases evolved in mould during casting and collapse easily to leave clean cavities in component after casting. These imply that cores must possess characteristics like sufficient compressive and tensile strength; adequate shatter index, good collapsibility; sufficient gas permeability and other features. Shortage of any of these properties results to defective castings and escalates the cost of production.

As it is quite difficult to obtain natural sand that possess these desired characteristics, sand cores are synthetically prepared through careful selection and combination of many ingredients such as sand grains, binders and special additives for optimum performance. Production of good cores lowers casting rejects and significantly reduces production cost. This research aims at studying the foundry property characteristics of sand cores bonded with pure oil extracted raw from seed of water melon. The objectives are to produce specimens bonded with water melon seed oil, selectively oven bake some and subject them to property tests including baked tensile and compressive strength; shatter index, collapsibility and bulk density; green compressive strength and permeability; compare results with other works to ascertain usability of such cores. The significance lie in the fact that foundries would be availed with information on another type of human and equipment friendly binder as the oil is noncorrosive. It will expose more industrial uses for the oil. Water melon is botanically known as citrullus lanatus. It is a member of cucurbit ace family. It is a fruit from plant of a vine-like herb that originated from Southern Africa. It is one of the common types of melon though not in genus cucumis. The flesh of citrullus lanatus is similar to kind of watermelon often known as citron melon though distinct from actual citron (El-Adewy and Taha, 2001). Major constituents of water melon oil are fatty acids like oleic, linoleic (linolein), palmitic and (palmitin). It has stearic acid, arachidic acid, arachidonic acid, behenic acid, lignoceric acid and traces of other fatty acids (Ademoh, 2012).

Nigerian water melon oil has always only been used as additive to main core binder as practiced by Ibitoye and Afonja (1996). They mixed clay and wheat extract as core binder with water melon oil as an additive. The behaviour of core oil as an additive in foundry sand was evaluated in controlled investigation by Zrimsek and Vingas (1963), the result of which showed improved green strength, collapsibility and knockout in sodium silicate bonded sand and also improved binding characteristic of given core sand mix. The oil helped build smooth hard exterior surface of core that enabled it to resist metal penetration defects, resulting into smoother, cleaner and better casting finish. According to Stefanescu (1992), clay would not function as a good binder unless it is activated by tempering water and some core oil that gives it high strength development that is an important moulding sand property. According to Mikhailov (1989), fatty acid based oil is combustible and can be destroyed by heat thereby contributing some degree of collapsibility to core. Heine et al (1967) discovered usage of oil in most core sand mixes in amounts of 0.5 to 3% by weight depending on requirements. Mathew and Waniko (1983) reported that cottonseed and soya beans oil were unsuitable as binders for heavy casting because the oils produced fast collapsing cores. When cotton seed oil was added to clay bonded core baked at a temperature of 200°C, tensile strength and hardness increased with oil content to optimum values. Vegetable oil, synthetic resin, clay and cereal binders were identified by Beeley (1982), Olakanmi and Arome (2009) as widely used in core practices. However, each of these binders has its own merits and limitations. Clay binders are cheap, facile and convenient for cores but are rarely used because of their low bond strength and poor permeability. Synthetic resins have high strength and good moisture resistance but their high cost, high gas forming capacity and non-recycling nature restrict their widespread use in foundry. It is this background knowledge that prompted this study of characterizing sand cores bonded with Nigerian water melon seed oil.

2.0 MATERIALS AND PROCEDURES

2.1 Research Materials:- The materials and equipments used in the experiments included silica sand, portable water, raw watermelon seed oil, digital weighing scale and universal strength testing machine. The others are electrically powered baking oven, permeability meter, sand rammer, shatter machine, filter papers and assorted foundry hand tools.

2.1.1 Raw materials collection and processing:- Sand was collected from foundry department of Nigerian Machine Tools Limited, Osogbo, Nigeria where the experimental works were carried out. Samples were collected from ten different points within the mass, mixed and washed thoroughly to reduce clay content to less than 0.3%. It was then allowed to dry. A representative sample of dried sand was taken by cone and quartering sampling method described by AFS (1989). The sample was classified with BS sieve and grains passing through apertures 0.063 mm – 0.140 mm were collected for test specimen production so as to ensure averagely uniform grain size distribution. The sand was oven dried at 110 ^{0}C for about ten minutes to reduce retained moisture content to less than 0.1%. Watermelon seed was obtained from Birnin-kebbi in Kebbi state, Nigeria. The seed was sun dried with its rind and later thoroughly re-dried after removing the rind. Oil was extracted using a known method of Cold Expeller Pressed Shelf Life (CEPSL) as adopted by Ibitoye and Afonja (1996). It oil was passed through filter papers to remove the impurities. Some quantity was taken to National Research Institute for Chemical Research, Zaria, Nigeria for physiochemical analysis to determine its active constituents contained in table 1. Portable water obtained from domestic supply was used.

2.2 Procedures: - Core specimens were prepared for baked tensile and compressive strength; shatter index, collapsibility and bulk density; green compressive strength and permeability tests. Specimens for the baked compressive strength; shatter index, collapsibility and bulk density; green compressive strength and permeability analyses were shaped and dimensioned as shown in figure 1 while those for the tensile strength were as shown in figure 2 below.

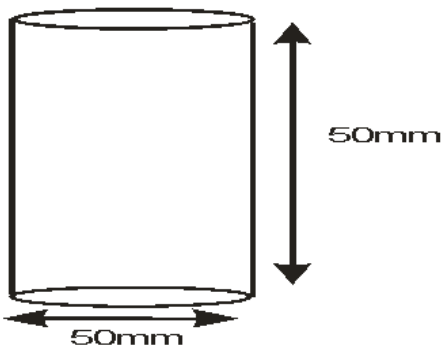

Figure 1:-Shape of specimens for the other tests

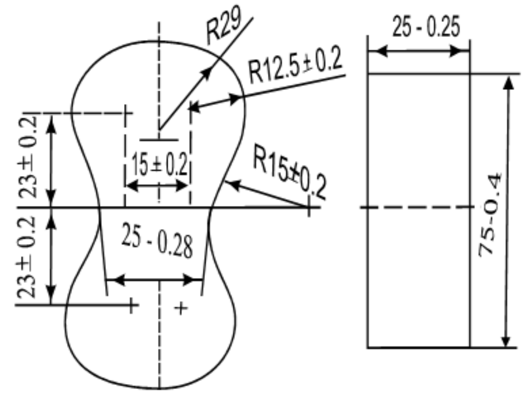

Figure 2:-Shape of tensile test specimens (dimensions in mm)

2.2.1 Test specimen preparation:- Ten different sand mixes were prepared for experimental test based on water melon oil content. Each core composition had 3% added water 1-10% water melon oil binder and oven dried silica base sand. Each core sand mix was further sub-divided into seven portions and set aside to prepare core specimens for scheduled experiments to determine properties including baked collapsibility, tensile and compression strength; green compression strength, bulk density permeability and shatter index. Specimens were compacted in split core boxes in a standard rammer with three blows each of 6.5Kg from a height of 50mm. In accordance with Busby (1993), as adopted by Ademoh (2012) while freshly moulded specimens were used for green property test, specimens for baked property tests were first oven baked at 200°C for 2 hours and oven cooled to room temperature before the tests.

2.2.2 Specimen Tests:-The specimens were classified into the above foundry property groups and subjected to the respective tests using standard equipments in the foundry laboratory of the Nigerian Machine Tools Limited, Osogbo, Nigeria as described below.

(a) Baked tensile strength test:- A standard universal strength testing machine equipped with meter to instantaneously read the tensile strength (in KN/m^2) with proper specimen gripping attachments was used for baked tensile strength test (Titov N.D and Stepanov Y 1982). During the test, steadily increasing tensile force was applied on specimen by machine until failure just occurred and baked tensile strength was read instantaneously and recorded in a raw result table.

(b) Baked compressive strength test:- The procedure was similar to that of baked tensile strength test using the same universal strength machine except that baked cylindrically shaped compression test specimen was used in place of the figure number eight shaped tensile strength test specimen. The attachment of test machine was also changed to that for gripping compression test specimen.

(c) Green compressive strength test:- Same procedure and test machine was used with that of baked compression strength test except that freshly made cylindrically shaped compression test specimens were used in place of baked compression strength test specimen. Values were recorded in KN/m^2.

(d) Green permeability test:- A standard air pressure of $9.8x10^2 N/m^2$ was passed through the test specimen place in the sample tube of the permeability meter. After $2000cm^3$ air had passed through specimen, green permeability in numbers was read instantaneously and recorded in raw data table.

(e) Shatter index test:- A green test specimen placed in the shatter index test machine container was pushed upward from a height of 180 cm over the stripping post until it struck the anvil, fell and shattered (AFS, 1989). The retained sand and over size were measured and used to automatically compute shatter index in numbers and recorded in raw results table.

(f) Baked collapsibility test:-This was determined by loading standard oven baked and oven cooled core specimen into collapsibility test machine and the in-built furnace automatically heated it to a temperature of about 600^oC and soaked for 6-10 minutes for it to rupture. Time taken in seconds by each specimen to rupture was then taken and recorded in raw table of result.

(g) Bulk density test:-Bulk density is the mass per unit volume of a specimen. This was computed by dividing weight of each oven baked and oven cooled for each core composition (measured with a digital scale) by the calculated volume of 50cm diameter by 50cm height cylindrical specimen. The values obtained (in g/cm^3) were recorded against the water melon oil content of core mix in a table.

3.0 RESULTS

The physiochemical analysis of the water melon seed oil is as presented in table 1. The free fatty acid is composed of 62.3% linoleic acid, 10.22% stearic acid, 12.3% palmitic acid and 14.5% oleic acid. Results of the core analysis of the main experimental work were processed into graphical plots and are presented in figures 3-11. Figure 3 presents the result of baked tensile strength test, figure 4 present that of green compression and figure 5 present results of baked compression tests. Figure 6 presents result of baked tensile, baked compressive and green compressive strengths in combined graph for cross comparison of results. Figure 7 presents result of green permeability test and figure 8 presents that of shatter index test while figure 9 presents the combined results of permeability and shatter test for comparison. Figure 10 presents result of baked collapsibility and figure 11 presents result of bulk density tests. According to Titov and Stepanov (1982), these are the most measured properties since they also give information on other desirable core properties and its main binder.

Table 1:- Laboratory analysis showing the physiochemical composition of the water melon seed oil.

Prop-erty	Colour	Specif gravity	Viscosity	Iodine Value	Acid Value	Saponifiction. Value	Flash point	Refra index	Comb Heat	Fatty Acid	Boiling point
Values	Amber yellow	0.9139	33.59 mm^2s^{-1}	121.8 mgI/g	2.04 mgKOH/g	192 mgKOH/g	187 °C	1.47	38.76	1.02%	69.0°C

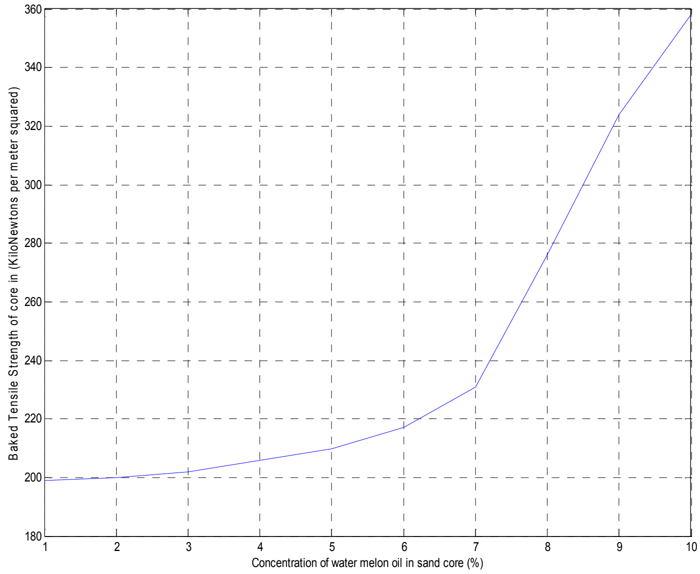

Figure 3:-Baked tensile strength (in KN/m^2) against increasing water melon oil binder content

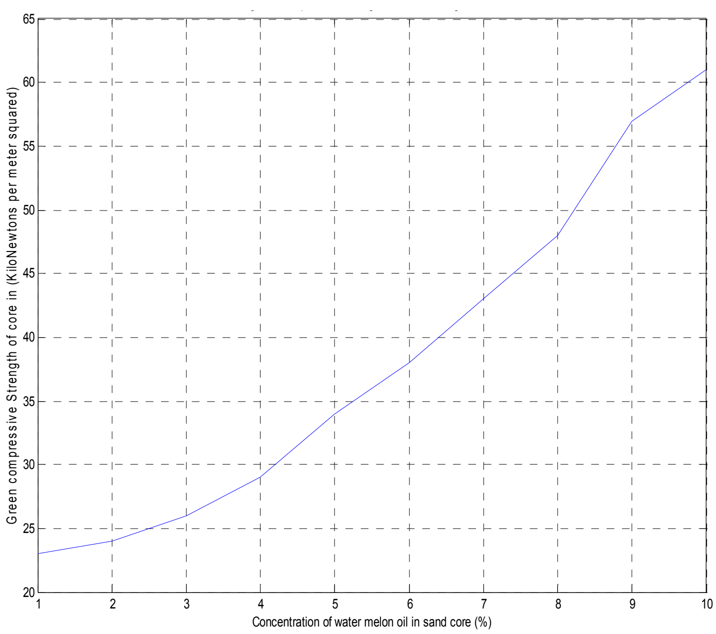

Figure 4:-Green compressive strength (in KN/m^2) against increasing water melon oil binder content

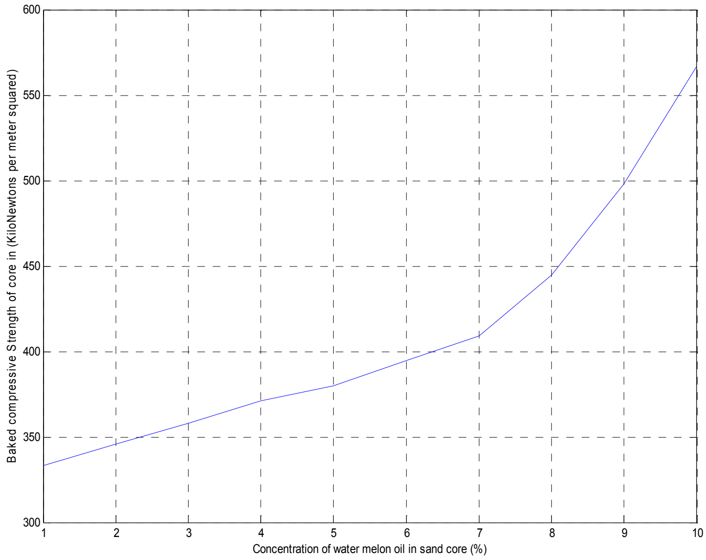

Figure 5:-Baked compressive strength (in KN/m^2) against increasing water melon oil binder content

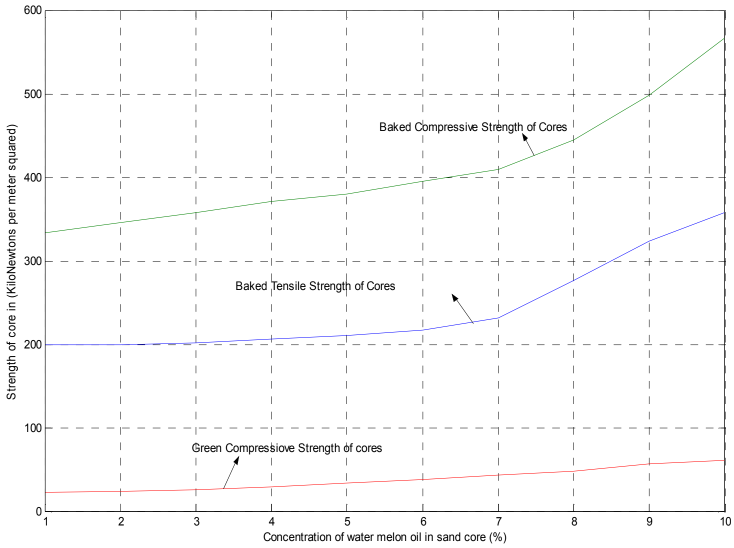

Figure 6:-Variation of Green compressive strength, baked compressive strength and baked tensile strength (in KN/m^2) against increasing water melon oil binder content

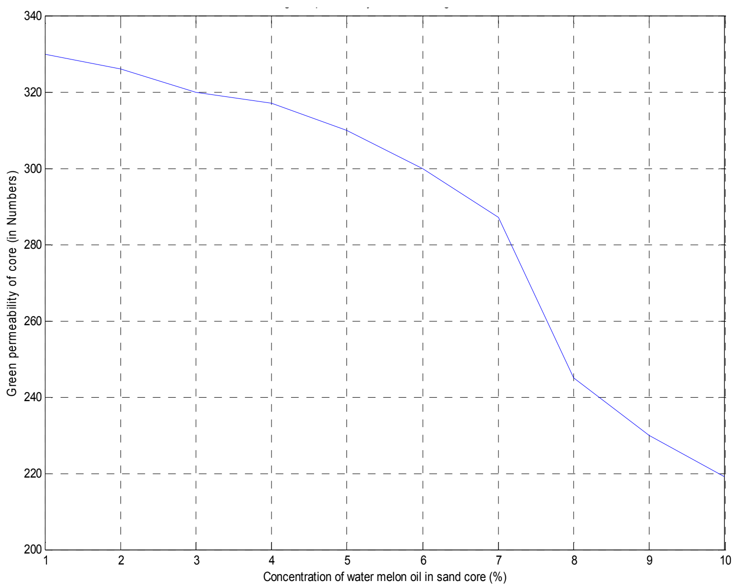

Figure 7:-Green permeability (in Numbers) against increasing water melon oil binder content

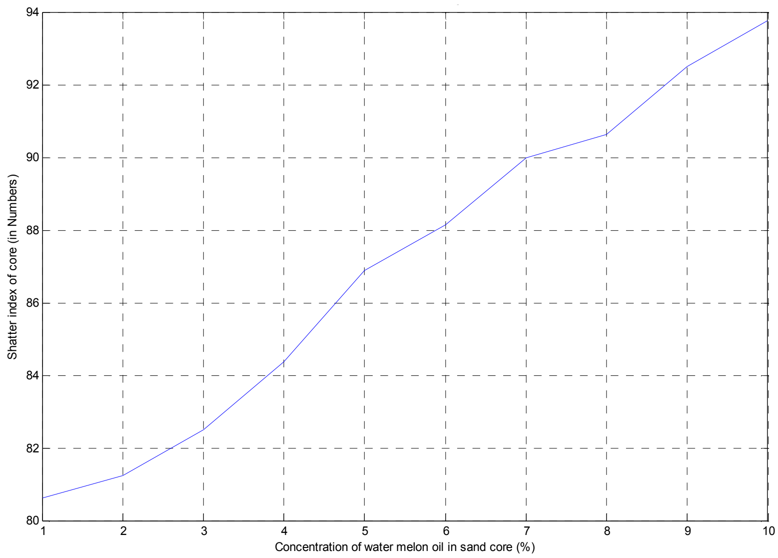

Figure 8:-Shatter index (in Numbers) against increasing water melon oil binder content

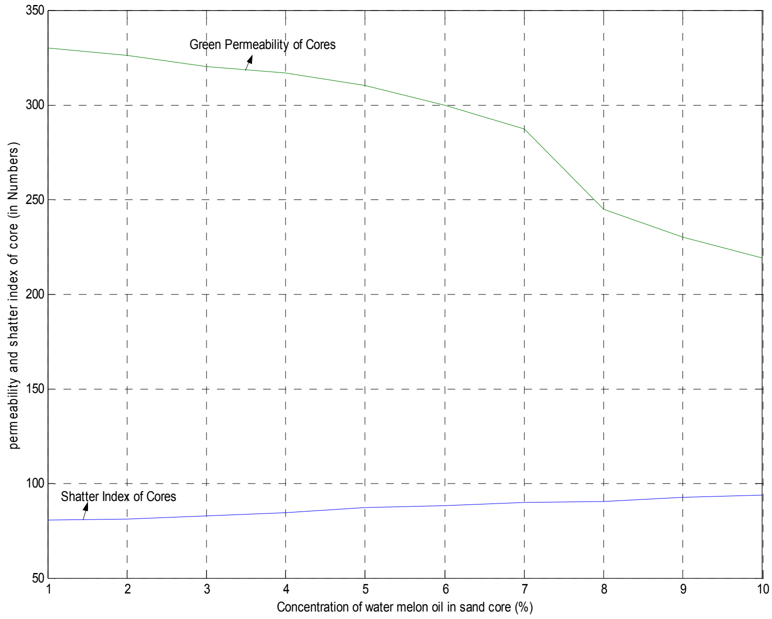

Figure 9:-Plots of permeability and shatter index (in Numbers) against increasing water melon oil binder content

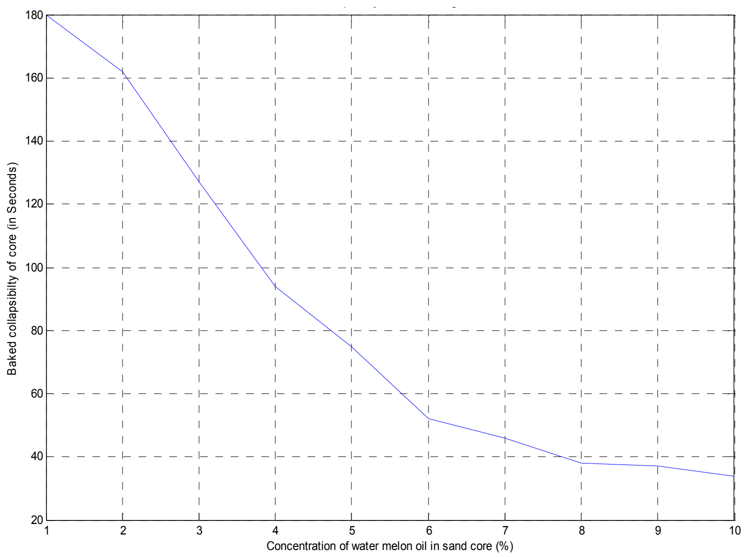

Figure 10:-Baked collapsibility (in Seconds) against increasing water melon oil binder content

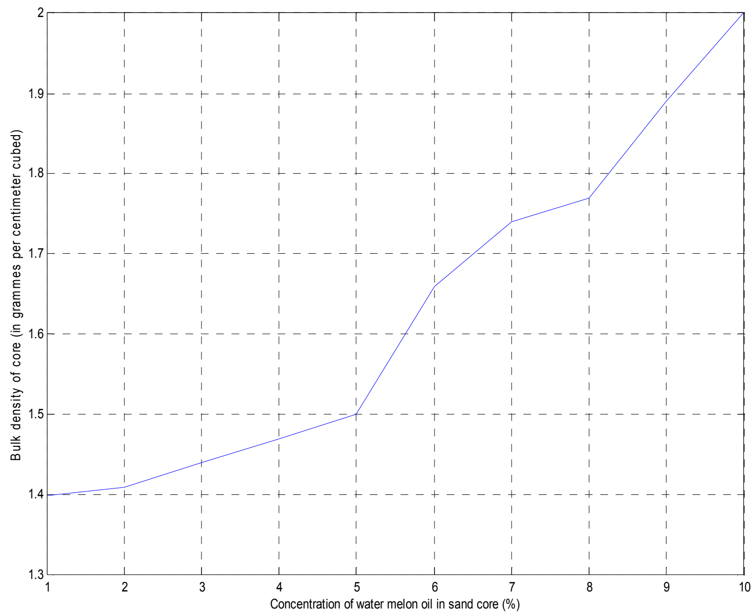

Figure 11:-Bulk density (in g/cm^3) against increasing water melon oil binder content

4.0 DISCUSSION OF RESULTS

The physiochemical constituents presented in table 1 indicated that water melon seed oil belongs to the type of foundry core oil classified by Stephens (1980) as drying oil based on its saponification value of 192 mgKOH/g (i. e. potassium hydroxide required for the complete hydrolysis of 1g oil). According to Middleton (1963) this type of vegetable oil draws its drying power from presence of acids or glycerides known as linoleic or linolenic with a chemical formula derived as: CH_3 (CH_2) 4OH = $CHCH_2CH$=CH (CH_2) 7COOH. The free fatty acid as analyzed shows the oil is composed of 62.3% linoleic acid with high iodine value of 121.8 mgI/g (i e. grams of iodine absorbed by 100g of fat or oil). According to West (1925) iodine value represents amount of unsaturated acid present in oil and its ability to absorb oxygen. Unsaturated free fatty acid break down to single or multiple chain diradicals (Aponbiede, 2000) of any of the configurations in figure 12 to react with oxygen of silica sand to bind cores with or without application of heat; explaining the mechanism of binding.

The linoleic acid break down di-radicals with straight single chains give cores with reasonably high tensile strengths due to the toughness induced in cores by high flexibility and ductility coupled with low multiple bonds of molecules of the parent oil. On the other hand, multiple chained linoleic acid break down di-radicals give hard cores with high compressive strength due to congestion and related resistance of branched chains to compression loads. In figure 3, the baked tensile strength increased non-linearly from 199kN/m^2 at 1.0% water melon seed oil to 358kN/m^2 at 10% binder content without dropping. This trend was explained by the binding mechanism as discussed above. Increase in water melon oil binder made more di-radicals produced from free fatty acids (linoleic) breakdown available for bond reaction with oxygen of silica sand. The high value of tensile strength at 1% oil content is due to the elevated temperature of baking cores that promoted reaction kinetics.

In figure 4, green compressive strength varied non-linearly from 23 kN/m^2 at 1% water melon oil to 61 kN/m^2 at 10% binder content. The values are much lower than those of figure 5 for cores baked at 200^{0}C which varied non-linearly from 333 kN/m^2 at 1% water melon oil to 527 kN/m^2 at 10% binder content. Figure 6 showed the three results presented in figures 3, 4 and 5 in one graph for cross comparison. It is very clear from this figure that temperature of processing this type of core mix greatly affects strength of the core as both baked tensile and compressive strengths were quite higher than green strength values. The wide differences observed were due to the high heat of baking that energized core mixtures for rapid and complete bond reaction at higher reaction kinetics catalyzed by the elevated temperature. As cores were baked at 200^{0}C the high heat energy increased reaction kinetics and promoted strong oil-sand bond. These high strengths gave cores bonded with this oil high hardness and resistance to moisture pick-up as stated by Stephens (1980) for oils with saponification exceeding 130. Water melon seed oil has saponification value of 192 as in table 1. It implies high hardness and stability of cores bonded with this oil. The advantage of this is that such cores can be stored for quite some time before usage without deterioration.

Development of baked strength is by the organic nature of core oil binder which is combustible as it was easily destroyed by heat (Mikhailov, 1989). At the baking temperature of 200°C it was possible that all water in core mix had been driven off. It could be suggested that water melon oil was solely responsible for binding neighbouring sand particles. It could be decided that the oil in core mix was the variable responsible for development of baked strength. In green sand, presence of moisture and other organic matter chemically impeded effective contact and bond between the active constituents of oil and sand; further accounting for weaker green strength. The strength result when compared with work of Ademoh (2011, 2012) showed cores bonded with 1-3% water melon oil gave green compressive strength suitable for aluminium, iron/steel, and copper alloys. Cores bonded with 10% oil were suitable for magnesium alloys. Sand bonded with 1% water melon oil and oven baked at 200^0C had adequate tensile strength for class V iron/steel cores. That bonded with 2-3% oil had sufficient tensile strength for casting class IV iron/steel. Cores bonded with 9% oil had adequate tensile strength for magnesium alloys. Those made with 10% water melon oil had sufficient tensile strength for class III iron/steel casting. Sand bonded with oil in compositional range experimented with however had insufficient baked tensile strength values for casting aluminium and copper alloy.

Higher than 10% water melon seed oil used would be quite expensive for core production coupled with associated health hazards due to massive generation of fumes observed during oven baking of such cores at the preliminary stages of this research work. Green permeability of tested specimens in figure 7 gradually decreased from 330 Numbers at 1% water melon oil to 219 Number at 10% binder content. This followed a natural pattern that as the oil binder increased there was stronger sand-oil bond as explained above. It resulted into closer contact of the two molecules of the core mix. This intimacy reduced the porous spaces between core particles and in turn reduced ease of air passage through core causing decrease in permeability with increased binder. Shatter index in figure 8 increased non-linearly with increased oil binder. Figure 9 showed the results in figures 7 and 8 in combined plot for comparison. The trend therein occurred because the stronger a core the higher it resisted air passage and shatter as increased strength observed with increased binder caused higher intermolecular compactness. In comparison with work of Ademoh (2011), the range of shatter index and permeability presented in the results are adequate for all categories of alloy castings.

In figure 10, baked collapsibility of core decreased with increased oil binder. This occurred because at experimental temperature of 600°C; well above the boiling point (69^0C) and flash point (189^0C) at which collapsibility was measured, most of the oil might had already burnt off, making it easier for cores to readily collapse. According to Dietert (1966), collapsibility within the range of 60-120 seconds is regarded as fast with consequence of production of undesired cracks and warpage in casting. Collapsibility greater than 180 seconds is regarded as slow. Based on this, the collapsibility presented in figure 9 showed that above 3% water melon seed oil binder contents, cores possessed fast collapsibility and castings made with such cores would suffer from cracks and warpage defects. Bulk density increased with increased water melon oil content in figure 11. As constant ramming was applied with sand rammer, this outcome implied that content of available oil binder rather than the ramming action alone produced the variation in density. Increased oil produced more reaction di-radicals from its linoleic acid for stronger bond reaction that resulted to more compact cores.

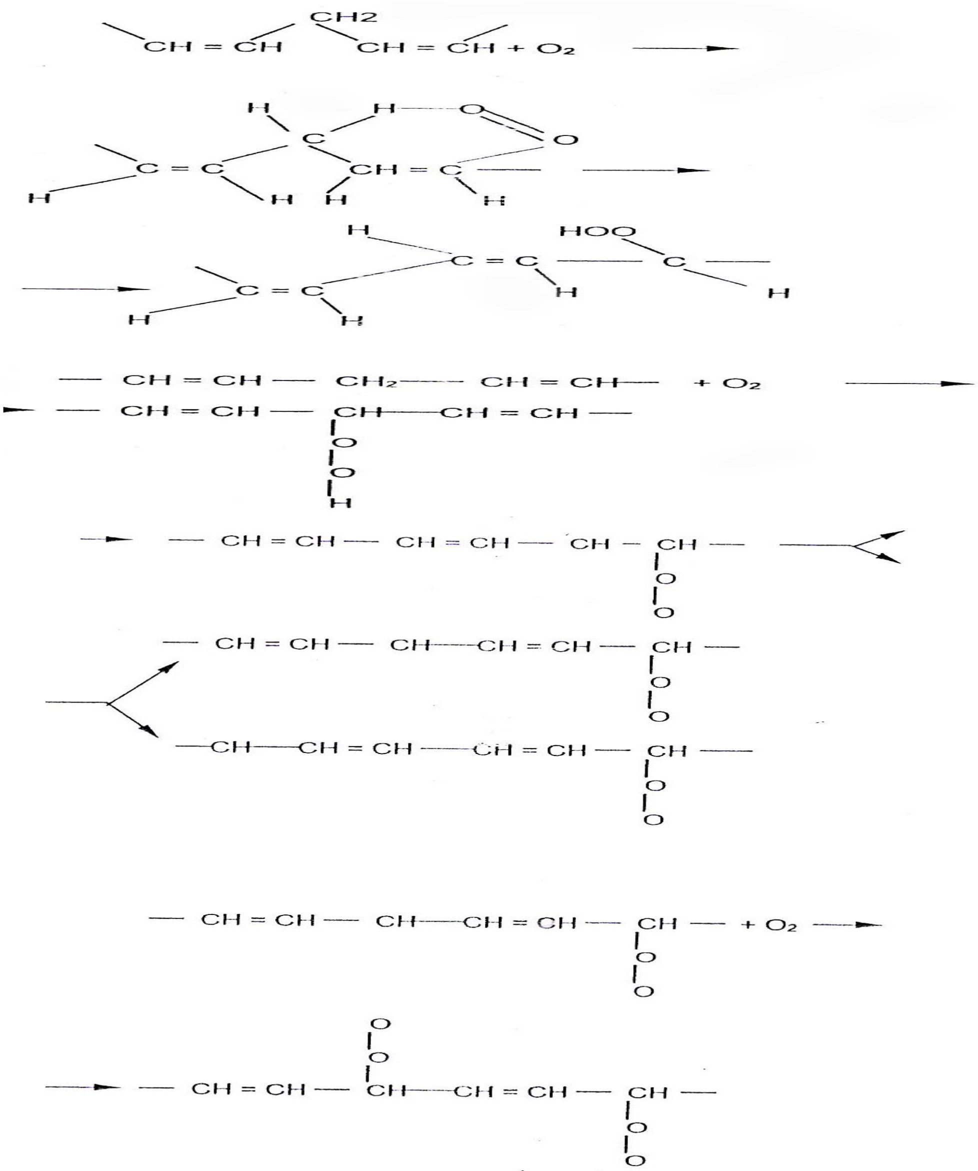

Figure 12:-Different configurations of di-radicals formed from linoleic acid break down

5.0 CONCLUSIONS

The established through the results of the experiments that water melon seed oil has good potentials for binding sand cores mostly for non complicated iron and steel castings. Based on limitations of tensile strength and baked collapsibility values, the most useful composition is core sand mix with 1-3% water melon oil. Cores however, exhibited excellent green compressive strength, permeability and shatter index characteristic. Result of green compressive, permeability and shatter index of specimens were very satisfactory for all alloys but the limiting factors of baked tensile strength and collapsibility narrowed diversified uses of cores bonded by the oil. Suitable property enhancement additives could be investigated to widen the core application of the oil for other foundry alloys.

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