Natural Honey and Nigerian Gum Arabic as Composite Binder for Expendable Foundry Cores

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Abstract

Potentials of foundry sand core binders made with composites of Nigerian gum Arabic and natural honey were investigated. Core specimens made with silica base sand bonded with composites of each of four grades of Nigerian gum Arabic and honey were classified and tested for tensile and compressive strength; permeability and shatter index to ascertain binder efficacy. Tensile strength specimens shaped like figure number eight were oven baked at 180°C and 200°C; cooled to room temperature and tested with universal strength machine. Cylindrically shaped permeability and shatter index specimens were tested with permeability meter and shatter machine. Results showed that cores baked at 200°C attained higher strength at shorter baking periods than those baked at 180°C. Honey improved tensile strength by 15%, 17%, 16% and 17% over the plain gum Arabic grades 1, 2, 3, 4 bonded cores, respectively. It improved compressive strength by 7%; permeability and shatter index by 2%. Composites cores of 3% gum Arabic grade 2 - 4 with 0.5% honey baked at 200°C were suitable for magnesium, copper bronze, non-intricate aluminium, classes III, IV, V iron and steel castings. Cores made with composites of 1.5 - 3% honey and 3% gum Arabic grade 1 - 4 were suitable for intricate aluminium, copper brass, class II - V iron and steel castings.

Keywords: *Gum Arabic, foundry cores, natural honey.*

1. Introduction

Gum Arabic (acacia species) is plant gum produced mostly in the sahel region of Africa including northern Nigeria, where four different commercial grades of the gum are produced (Osagie 2002). Natural honey is a sweet food made by bees using nectar from flowers. The variety produced by honey bees (genus *Apis*) is one most commonly referred to and it is type of honey collected by beekeepers and consumed by humans. This edible species of honey is material of interest to this study as honey produced by other bees and insects is uncommon and has distinctly different properties that make its collection and use too expensive to foundry industry. Natural honey, though not reported as major export commodity from gum Arabic belt of Africa, it is produced in large quantities for domestic consumption (Wikipedia 2011).

Nigerian gum Arabic was analyzed to be mostly composed of polysaccharides, with a PH of 4-6, minimal chemical contaminants and other physico-chemical properties that make it very suitable for foundry binding application. Moreover, it isn’t toxic to human and non-corrosive on handling equipment when compared to chemical sand binders; thus it less is problematic in use by foundries in less developed economies (Ademoh and Abdullahi 2009a). Grades 1, 2, 3 and 4 of it was each investigated in different studies and found suitable for binding foundry cores for both steel and non-ferrous alloys at specified compositions and baking treatment (Ademoh and Abdullahi 2008a, 2008b, 2009b, 2010). Selected vegetable oil like neem, linseed and soybean oil were investigated as composites with Nigerian gum Arabic for core uses. They each produced marginal effect on plain gum Arabic bonded cores due to low their chemical reactivity and solubility with gum Arabic (Ademoh 2009; Ademoh 2010).

Natural honey is a pure agro-based material with PH of 3.2 - 4.5. Its relatively acidic pH level with its low water activity of 0.6 prevent growth of many bacteria and other microorganisms which makes it non-toxic and non-corrosive to human being and process equipment (Krell 1996). Honey like gum Arabic is mixture of sugars and other compounds (Wikipedia 2011). With respect to carbohydrates, honey is mainly fructose (about 38.5%) and glucose (about 31.0%), making it similar to synthetically produced inverted sugar syrup which is approximately 48% fructose, 47% glucose, and 5% sucrose. Honey remaining carbohydrates include maltose, sucrose and other complex carbohydrates. The specific composition of any batch of honey depends on type flowers available to bees that produced it. Typical honey analysis consists of fructose (38.2%); glucose (31.3%); maltose (7.1%); sucrose (1.3%); water (17.2%); higher sugars (1.5%); ash (0.2%) and others undetermined (3.2%). Its glycemic index ranges from 31 to 78, depending on variety. It contains tiny amounts of several compounds which function as antioxidants, like chrysin, pinobanksin, vitamin C, catalase and pinocembrin (Root and Root 2005).

Honey has ability to absorb moisture content from the air directly. This hygroscopic phenomenon depends on relative humidity of environment as it tends to absorb more water in this manner than individual sugars would allow on their own, that may be due to other ingredients which it contains (Gheldof *et al*. 2002). Its deoxidizing ability and high water affinity are properties that are believed to be beneficial to gum Arabic bonded core sand as honey would attract high moisture content of gum Arabic and deoxidize silica of sand in multiple reactions that will promote stronger particulate bonds. The aim of this research is to determine foundry property enhancement ability of natural honey on sand cores bonded with Nigerian gum Arabic. The objectives of the study are to use composites made with each of four commercial grades of Nigeria gum Arabic and natural honey as binders for core specimens; analyze them for foundry properties like green compressive strength, permeability and baked tensile strength; and compare results with the standard in Table 1 (Titov and Stepanov 1982) and past related work so as to ascertain efficacy of the binder.

Table 1. Foundry property ranges of cores for different alloys castings.

Cores for type of alloy castings	Perme-ability (No)	Strength (KN/m^2)	
		Comp-ression	Baked Tensile
Class I iron/steel	130-150	3-6	700-1000
Class II iron/steel	100	5-10	500-700
Class III iron/steel	100	10-16	350-600
Class IV iron/steel	70	15-25	200-300
Class V iron/steel	70	20-35	80-150
Copper bronzes Copper brasses	90 60	3-5 6-8	400-600 500-700
Intricate Aluminium Non-intricate Aluminium	100 80	3-7 6-15	500-700 400-600
Magnesium cores	80	60-150	300-500

2. Experimental Method

The properties investigated included the permeability, shatter index, compressive and baked tensile strength of standard core specimens. Experiments were carried out in a standard foundry laboratory under standard environmental conditions in Nigeria. Green compressive strength measured strength of cores in moist state. Permeability measured ease of gas escape from cores. Shatter index measured core collapsibility after casting. Tensile strength measured ability of core to withstand thermal stress during casting. These vital foundry properties are known to give other salient information of a sand core and its binder (Titov and Stepanov 1982).

2.1 Experimental raw materials and equipment*:-*The raw materials used included water; silica sand with 3% clay, 4litres of natural honey and 5 kg of each of grades 1,2, 3 and 4 Nigerian gum Arabic pre-sorted and powdered to BS sieve size 30-50 mesh; all obtained from local markets in Nigeria. Test equipment included standard permeability meter, shatter machine and universal strength testing machine; all sourced from foundry workshop of a steel plant in Nigeria.

2.2 Test specimen preparation: - The raw silica base sand was washed, oven dried at 110°C, classified with BS sieve and the grain within the particle size of 40-72 mesh was obtained for the work. Varied quantities of grades 1, 2, 3 and 4 Nigerian gum Arabic, natural honey (used as purchased), treated silica sand and water were measured with a digital scale and mixed thoroughly in a roller mill for about 10 minutes. The mixture was moulded into cores specimens and classified for tests. Specimens for green compressive strength, permeability and shatter tests were cylindrical in shape. Each measured 50 mm diameter, 50 mm in height and weighed 130 g after compacting with three blows of 6.5 kg from a height of 50 mm. A collection of some specimen is as shown in Fig. 1. The tensile strength specimens were shaped like figure number eight as dimensioned in Fig. 2. They were moulded in a set of split core box and compacted with a standard rammer with three blows each of 6.5 kg from a height of 50 mm. They were grouped, oven baked at 150-200°C for 1-3 hours and oven cooled in desiccators before the test. These procedures were in accordance with AFS standard (AFS 1989) as adopted by Ademoh (2010).

Fig. 1. Samples of test specimens for green compressive strength, permeability and shatter index.

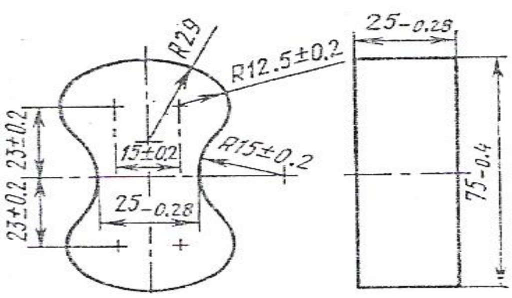

Fig. 2. Shape of core tensile strength test specimen (dimensions are in millimetres).

2.3 Specimen Tests:- Standard universal strength test machine equipped with a meter to instantaneously read strength (in KN/m^2) with proper specimen gripping attachment was used for green compression and tensile strength tests (Titov and Stepanov 1982). During test, a steadily increasing compressive/tensile force was applied on specimen by the machine until failure occurred and strength instantaneously read from gauge. For permeability, standard air pressure of $9.8x10^2N/m^2$ was made to pass through the sample tube placed in permeability meter and after 2,000 cm^3 air passed through the specimen, the permeability (No) was read instantaneously from its gauge. For shatter index, a specimen placed in machine container was pushed upward over stripping post until it struck anvil, fell and shattered. The retained and the oversize particles were measured and used to automatically compute shatter index of cores (AFS 1989).

3. Presentation of Results

The research results are presented in Figs. 3-10. Figures 3-7 present the result of baked tensile strength test for cores bonded with composites of gum Arabic and honey baked at 180°C and 200°C for 1-3 hours. Figure 8 presents result of green compressive strength test. Figure 9 presents result of permeability and Fig. 10 that of shatter test.

4. Discussion of Results

Figure 3 showed that tensile strength increased with natural honey and increase in baking period. The gum Arabic component of mixed binder melted at 200-210°C while honey got melted at 40-50°C (Ademoh and Abdullahi 2009a; Wikipedia 2011). Above 50°C honey melted, became fluid and reacted with silica sand and gum Arabic to provide strong bond, though gum Arabic wasn’t fluid enough to engage in serious bond reaction. At 180°C, baking temperature of core, gum Arabic was close to its melting point making it more reactive to create strong bonds, even though some components of the honey could have deteriorated at this baking temperature far above its melting point.

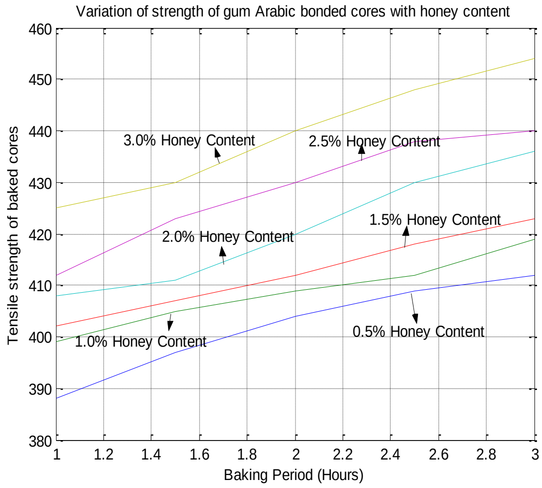

Fig. 3. Tensile strength (in KN/m^2) of cores bonded with 3% grade 1 gum Arabic and varying honey content baked at 180^{o}C for 1-3 hours.

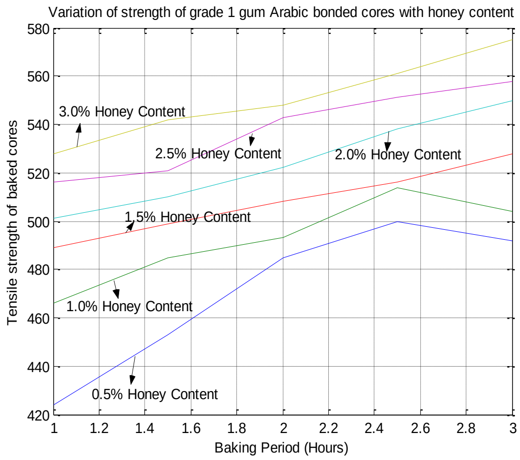

Fig. 4. Tensile strength (in KN/m^2) of cores bonded with 3% grade 1 gum Arabic and varying honey content baked at 200^{o}C for 1-3 hours.

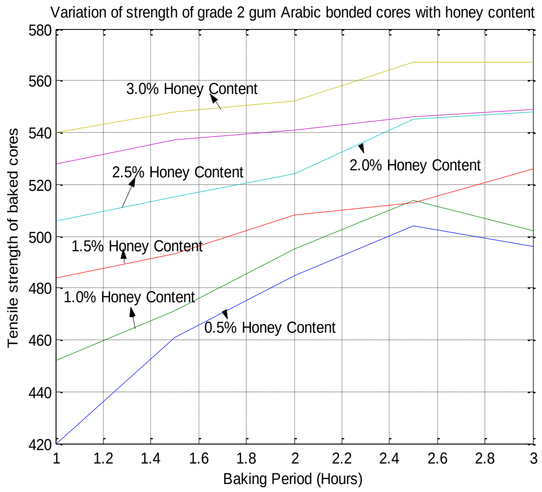

Fig. 5. Tensile strength (in KN/m^2) of cores bonded with 3% grade 2 gum Arabic and varying honey content baked at 200^{o}C for 1-3 hours.

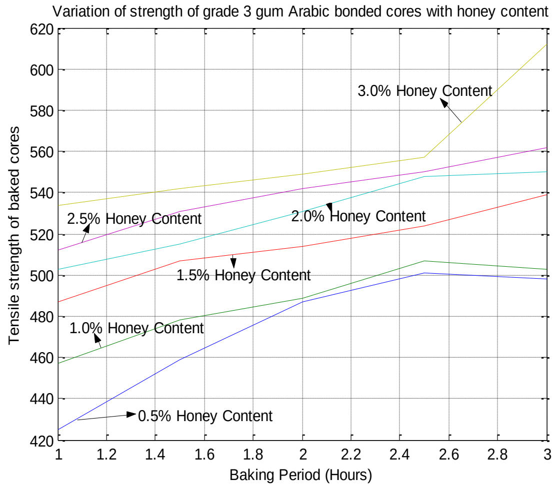

Fig. 6. Tensile strength (in KN/m^2) of cores bonded with 3% grade 3 gum Arabic and varying honey content baked at 200^{o}C for 1-3 hours.

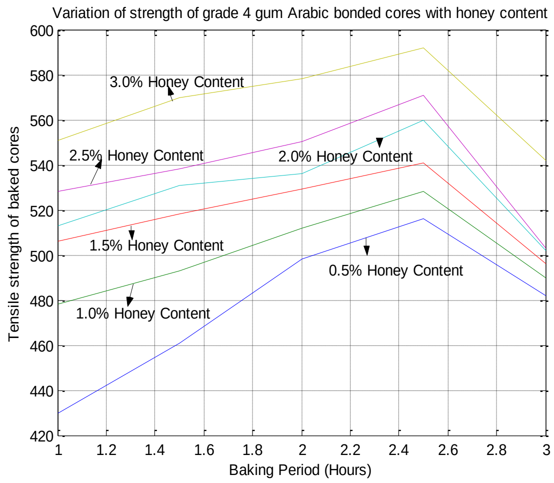

Fig. 7. Tensile strength (in KN/m^2) of cores bonded with 3% grade 4 gum Arabic and varying honey content baked at 200^{o}C for 1-3 hours.

Tensile strength increased with increased baking time because longer soaking provided more time for core sand components to react together. Increased bond strength occurred with increased honey content of binder. Its addition attracted more reaction agents for strong bond. According to Gheldof *et al.* (2002), antioxidant constituents in honey help clean up oxygen free radicals in the core mixture as shown in the following reaction, called the glucose oxidase reaction:

$C_6H_{12}O_6 + H_2O + O_2 \rightarrow C_6H_{12}O_7 + H_2O_2$.

Glucose was provided by honey; water molecule was from moisture of core mix and gum Arabic; and oxygen came from silica of sand. This reaction strengthened and ensured effective core bond. The result as compared with standard in Table 1 shows that a composite of 3% gum Arabic and 0.5 - 1.0% natural honey baked at 180°C for 1 hour is suitable for binding core for sand casting magnesium and classes III, IV, V iron and steel alloy. Composites made of 3% gum Arabic and 0.5-1% honey baked for 2 - 3 hours or 3% gum Arabic and 1.5-3% honey baked at 180°C for 1 hour are suitable for binding sand for non-intricate aluminium and copper bronze alloy casting. A statistical average of 15% increase in the strength was shown by this composite binder over plain gum Arabic bonded core in a related study by Ademoh and Abdullahi (2009b). Figure 4 presented the result of cores baked at 200°C. The tensile strength increased with increased honey in binder and the baking period due to above similar reasons. However, as baking temperature was within the melting range of grade 1 gum Arabic, higher tensile strength was attained in shorter baking time due to the faster reaction. In comparison with Table 1, composite of 3% gum Arabic with 0.5% honey baked for 1 hour is suitable for cores for casting non-intricate aluminium, copper bronze, magnesium and class III - V iron and steel alloys. Cores bonded with 0.5% honey and 3% gum Arabic baked for 2½ hours and those with 2-3% honey and 3% gum Arabic baked at 200°C for 1 hour is suitable for casting copper brass, class II iron and steel.

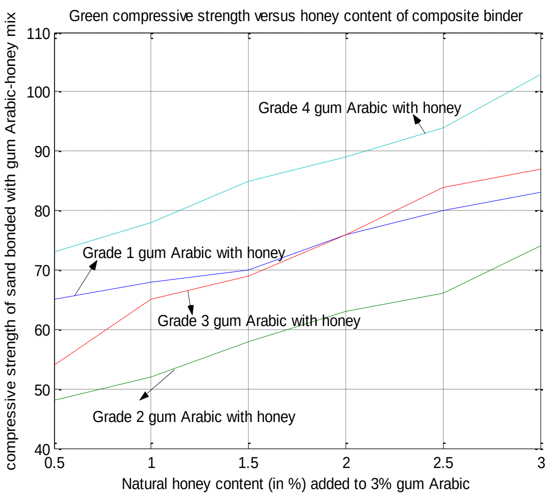

Fig. 8. Effect of variation of honey content (in %) on green compressive strength (KN/m^2) of core bonded with 3% grades 1, 2, 3 and 4 gum Arabic.

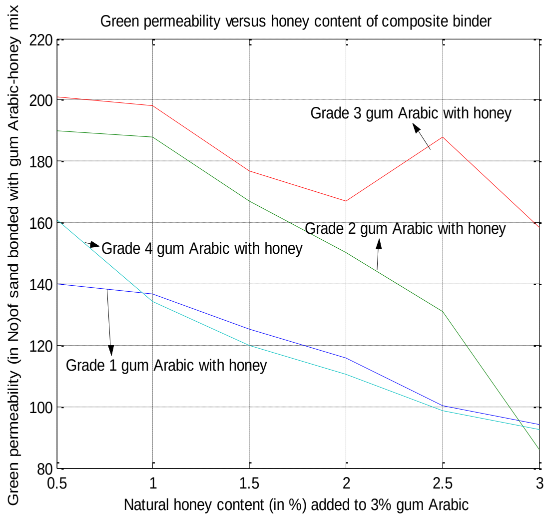

Fig. 9. Effect of variation of honey content (in %) on green permeability (No) of cores bonded with 3% grades 1, 2, 3 and 4 Nigerian gum Arabic.

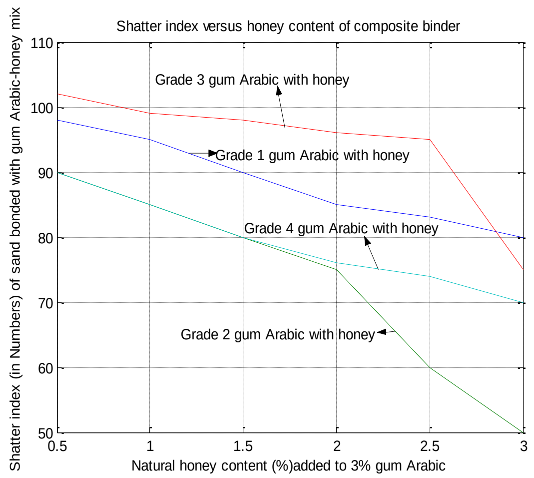

Fig. 10. Effect of variation of honey content (in %) on shatter index (No) of cores bonded with 3% grades 1, 2, 3 and 4 Nigerian gum Arabic.

In Fig. 5, tensile strength increased with increase in natural honey content and increased baking time of 1-3 hours for cores with 1.5-3% honey but dropped from 2½ hours for cores with 0.5 - 1% honey. Gum Arabic grade 2 melted at 190-194°C. Long holding of core at the baking temperature of 200°C lead to burning of some active binder agents at lower content of honey; an effect that was compensated with higher presence in 1.5-3% honey bonded core. Result showed that due to lower melting point cores quickly attained higher strength at short baking time. Composites of 3% gum Arabic grade 2 with 0.5% honey is suitable for binding cores for magnesium, non-intricate aluminium, copper bronze, classes III, IV, V iron and steel alloy. Cores bonded with 0.5% honey and 3% gum Arabic grade 2 baked for 2½ hours and that bonded with 2-3% honey and 3% gum Arabic grade 2 baked for 1 hour is suitable for casting copper brass and class II iron and steel alloy just like cores bonded with honey and gum Arabic grade 1 exudates baked at 200°C but at slightly lower strength. Figure 6 that presented result of gum Arabic grade 3 and honey bonded sand cores showed similar trend with those bonded with gum Arabic grade 2 and honey. The low melting point of gum Arabic grade 3 (184-188°C) aided cores attain similar tensile strength as those bonded with gum Arabic grade 1 exudates and honey at shorter baking time. The range of usability of this group of composite is similar to that made with gum Arabic grade 2 with minor variation in strength. When compared with previous work with plain gum Arabic grades 2 and 3 core (Ademoh and Abdullahi 2008a, 2010), it showed a statistical average increase of 17% and 16% with addition of honey.

In Fig. 7 baked core tensile strength increased with increasing honey and baking time from 1-2 hours. It generally dropped at 2½ hours as gum Arabic grade 4 melted at 178-182°C and baking cores at 200°C for long periods caused deterioration that higher honey content (most of which had burnt off at temperature in excess of 70°C) could not compensate. This shows high sensitivity of tensile strength to baking temperature and also that optimum core treatment shouldn't exceed acceptable range stated above. Honey caused about 17% increase in strength and its composite is more economical than cores made with gum Arabic grades 1, 2 and 3 and honey as they required shorter baking period to attain similar tensile strength. The green compressive strengths presented in Fig. 8 when compared with the standard in Table 1 showed that values are within suitable range for cores bonded with composites for alloys discussed above. The result when compared with the cores bonded with plain gum Arabic showed average marginal improvement of about 7%. Increased green bond strength was possible due to higher viscosity and surface tension offered by the honey as regards that of ordinary moisture in gum Arabic in mix.

Figures 9 and 10 presented the results of permeability and shatter index test. Values showed marginal improvement averaging at about 2% over the plain gum Arabic bonded cores. They fall within acceptable standard for cores bonded with composites specified for the casting applications described above when compared with the foundry standard in Table 1. The shatter index and permeability properties of these cores would be expected to substantially improve after baking as the volatile matter in honey and gum Arabic are driven off at elevated temperature of baking leaving more vents for easier gas escape and improved collapsibility. According to Martos *et al*. (2000), excessive heat has detrimental effects on some constituents of natural honey like endospores and yeast. Heating honey to 37°C causes loss of nearly 200 components, some of which are antibacterial materials. Heating it up to 40 °C destroys invertase, an important enzyme. At 50°C, honey sugars caramelize. Generally any large temperature heating causes decay (Prescott *et al*. 1999). Nigerian gum Arabic contains more than 10% volatile matter driven off at high temperature (Ademoh and Abdullahi 2009a). Properties of the two constituents of binder ensures that contaminants and volatile material that may be detrimental are to high quality casting are removed by high temperature baking to give good and accurate cores that withstand long storage with decay.

5. Conclusion

Natural honey was effectively combined as composite with Nigerian gum Arabic for core binding for ferrous and non ferrous castings. Both materials are polysaccharides and posses volatile fractions that are easily vapourized off to give clean and accurate cores that do not quickly depreciate during storage. The study synthesized binders from composite of simple natural materials subjected to simple easy and oven baking process as alternative materials to hazardous chemical binders that are not only expensive to developing foundries but are also more difficult to handle and apply as they require sophisticated skills and equipment.

6. References

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