International Journal of the Physical Sciences Vol. 5(5), pp. 557-563, May 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 © 2010 Academic Journals

Full Length Research Paper

Evaluation of the tensile strength of foundry cores made with hybridized binder composed of Neem oil and Nigerian gum arabic

Nuhu A. Ademoh

Department of Mechanical Engineering, Nigerian Defence Academy, P. M. B 2109, Kaduna, Nigeria.
E-mail: nuhuadam@yahoo.com.

Accepted 13 January, 2010

Defined quantities of the vegetable oil extracted from the seed of neem tree were mixed with each of four commercial grades of Nigerian gum arabic exudates as hybrid binders for foundry sand cores. The cores which were made with silica sand were classified and oven baked at 200°C for 1 - 3 h, oven cooled and then tested for tensile strength using standard universal strength machine to ascertain their level of suitability for industrial casting. The specimens for tensile strength were shaped like figure eight. The result showed that grade 2 gum arabic hybrids with Neem oil offered best economic advantage as it attained required tensile strength after the shortest period of baking. It was followed by the grade 4, grade 1 and then grade 3 gum arabic based hybrids with neem oil in that order. The benefit of hybridizing Nigerian gum arabic exudates with neem oil was more pronounced when cores were baked at about the melting temperature of the grade of gum arabic involved. Baking cores below the melting point marginally improved bond strength while baking them at temperatures well above melting point depressed tensile strength.

Key words: Neem oil, gum arabic, hybrid binder, tensile strength.

INTRODUCTION

The popular core binders used in most modern foundries use very robust self setting methods that include instant-taneous hardening techniques such as fast curing with gaseous and catalytic agents. Most of these current organic binders are predominantly based around phenol formaldehyde resins which though provide exceptional performance in respect of process robustness, easy breakdown and removal of the core sand after casting but are however environmentally not friendly. They are composed of corrosive acids or volatile organic compounds whose thermal breakdown products give out very foul and pungent odours and waste streams that are hazardous to health of users (Busby, 1992).

Moreover these binder systems are too sophisticated and expensive for foundries in developing countries that have abundant natural raw materials but without needed advanced technologies for proper use of the resources. There is therefore a need for development of environmentally friendly binder systems based around organic, inorganic or hybrid derivatives that would offer substantial advantages in terms of occupational health safety and other environmental issues.

The processes involved in use of such binders should be simpler for easy adoption by foundries in developing economies like Nigeria to enable the industry contribute its quota to national growth. This paper is a continuation of a research series aimed at developing high quality foundry sand binder system based around Nigerian gum Arabic exudates.

It is a known clean, non-toxic and environmentally friendly vegetable material obtained from plant trees called acacia species. The objective of the paper is to determine the proper compositional mixes of neem oil with each of the four commercial grades of Nigerian gum arabic as hybrid binders for foundry core specimens on the basis of their baked tensile strengths. The significance of the work is that the process is based on simple oven baking of cores using blends of vegetable binders with no health threats to users. Each of the grades 1, 2 and 4 gum arabic was proved suitable for binding expendable cores baked at 180 - 220°C for 1 - 3 h in separate previous studies. Generally, the result showed that each was suitable for cores for casting non-ferrous, iron and steel alloys (Ademoh and Abdullahi, 2008; Ademoh and

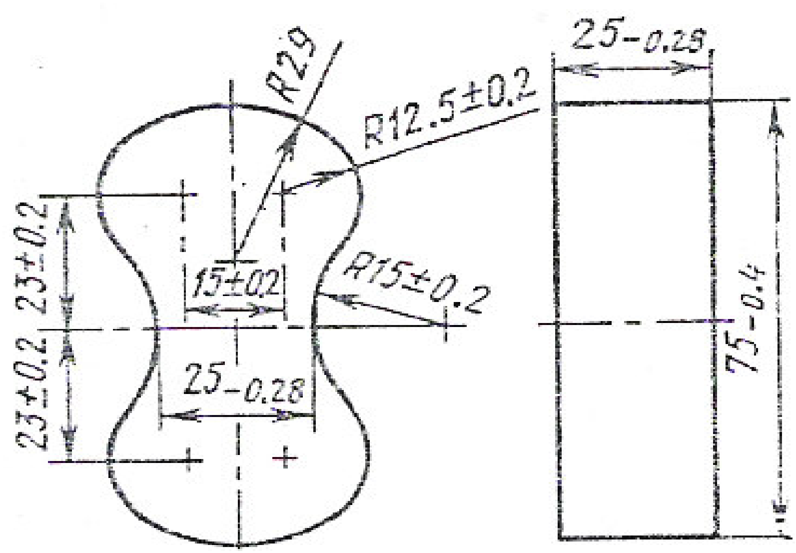

Figure 1. Design shape of the cores for tensile strength test analysis (dimensions are in millimetres).

Abdullahi, 2009). Processes that used gum arabic combined with sugar, urea formaldehyde resin and boric acid to bind core for casting.

This binder and the one that added 5% gum arabic to 10% sugar and protein in a gelatinous mix derived from amino acid are typical uses of gum arabic as core binders (Siak June-sang et al, 1994) that require inno-vative reviews like this work to make them more user and equipment friendly by excluding the acids and toxic resins in the formulations. Neem oil belongs to group of binders called drying oil, though its use in cores is not popular (Aponbiede, 2000). Neem tree the seed of which the oil is extracted is very common in gum arabic producer countries making it an easily available raw material.

MATERIALS AND METHODS

The tensile strength of core specimens bonded with blends of each grade of Nigerian gum arabic with neen tree seed oil was measured with a standard universal strength test machine in a foundry laboratory. Baked tensile strength is a vital mechanical property that measures ability of cores to withstand the thermal expansion stresses during pouring in and solidification of molten metal.

It is the most critical of all core properties in metal casting and solidification because as cores are interior implants within mould cavities, cores are usually subjected to severe thermal conditions and are highly prone to high temperature induced failures that can in turn cause casting defects (Busby, 1993). Thus a serious consideration of core tensile strength ensures good production control in castings.

Research raw materials

The experimental raw materials included purified water; silica sand washed, oven dried at 110℃ and classified with BS sieve of size range 40 - 72 mesh with 3% clay (Busby, 1993). Raw neem oil was milled from neem tree seed in Kaduna town. About 100 gram of each of the four commercial grades of pre-sorted Nigerian gum arabic exudates was sourced from Bauchi and Yobe States of Nigeria.

The acacia exudates are composed mainly of polysac-charides (Ademoh and Abdullahi, 2008). The neem oil was sent for chemical analysis at the National Institute of Chemical Research, Zaria, Nigeria. It was found to contain unsaturated fatty acids made up of 41% oleic acid, 20% linoleic acid, 20% stearic acid and 18% palmitic acid as its major active ingredients.

Test specimen preparation

Measured quantities of silica sand, each grade of Nigerian gum arabic exudates; neem oil and water using a digital scale were mixed in a roller mill for 10 min and moulded into test cores in accordance with experimental schedules in Figure 2 - 6. The specimens for tensile strength test were in accordance with standard foundry practice shaped like figure number eight dimensioned as shown in Figure 1 (Titov and Stepanov, 1982).

Each gum arabic sample was decontaminated and powdered to BS sieve size of 30 - 50 mesh before it was added to sand mix. The core specimens were bonded with hybridized mixes made of 3% of each of four commercial grades of Nigerian gum arabic and 0.5 -3% varied weights of neem oil. They were oven baked at 200℃ for 1 - 3 h and then oven cooled to room temperature before the tests.

Core specimen testing

Each specimen was moulded in a split core box and compacted with three blows each weighing 6.5 kg from a height of 50 mm in a standard rammer in compliance with American Foundry Men Society (1989).

During the test, each specimen was gripped with the attachment of the universal strength testing machine and a steadily increasing tensile force was applied by machine until failure occurred and strength read instantaneously. The raw results were processed into graphical plots as shown in Figures 2 - 6, analysed and compared with the standard foundry test data in Table 1.

Table 1. Desired tensile strength property ranges of sand cores (Busby, 1993).

Type of alloy casting applications	Baked tensile strength (KN/m^2)
Class I iron/steel cores	700 - 1000
Class II iron/steel cores	500 - 700
Class III iron/steel cores	350 - 600
Class IV iron/steel cores	200 - 300
Class V iron/steel cores	80 -150
Copper bronzes cores	400 - 600
Copper brasses cores	500 - 700
Intricate Aluminium cores	500 - 700
Non-intricate Aluminium cores	400 - 600
Magnesium cores	300 - 500

RESULTS

The results were processed into graphs as presented in Figures 2 - 6. Figure 2 presents result of cores bonded with grade 1 gum arabic hybridized with neem oil baked at 180°C for 1 - 3 h. Figure 3 presents result of cores bonded with grade 1 gum arabic based hybrids, Figure 4 is that of cores bonded with grade 2 gum arabic/Neem oil hybrid, Figure 5 presents that bonded with grade 3 gum arabic/Neem oil hybrid and Figure 6 is that of cores bonded with grade 4 gum arabic/Neem oil hybrid all baked at 200°C for 1 - 3 h.

DISCUSSION

Tensile strength increased with increasing neem oil content and baking period in Figure 2. The longer soaking at baking temperature enabled more sand and binder molecules to acquire higher reaction energies needed for strong bonding. The increasing neem oil also provided more binder molecules that reacted with more sand grain for higher bond strengths. Strength increased without dropping because baking temperature is below melting point of gum arabic grade 1 (about 210°C) (Ademoh and Abdullahi, 2008) above which burning of some of its molecules and reduction of strength could have occurred.

The temperature was not excessive to have caused burning of neem oil. Gum arabic is insoluble in organic solvents like neem oil. Therefore each component of the hybrid binder reacted separately with silica sand to form bonds as the combination could not react into different chemical binders. The result when compared with Table 1 shows that the hybrid of 3% grade 1 gum arabic and 0.5% neem oil baked at 180°C for 1½ h is suitable for class III - IV iron/steel, copper bronzes, non-intricate aluminium and magnesium cores. Sands bonded with hybrids of 3% grade 1 gum Arabic with 1½ - 3% neem oil and baked for 2 h are suitable for class II iron/steel, copper brass and intricate aluminium cores. When compared previous work that bonded core with same amounts of gum Arabic grade 1 under similar conditions (Ademoh and Abdullahi, 2009) neem oil caused 3 - 4% tensile strength increase. This is because neem oil as vegetable oil (Aponbiede, 2000) has more unsatisfied valence electrons and diradicals as multiple double bonded molecules than single double bonded molecules of polysaccharides of gum Arabic. Oleic, linoleic and stearic acids in neem oil are unsaturated fatty acids that posses two or more double bonds per molecule unlike saturated fatty acids whose radicals are linked by single bonds. Presence of these multiple radicals in gum Arabic bonded cores promoted formation of multiple bonds with oxygen of silica sand by cross linking peroxy radicals into polyperoxides. This enhances tensile strength. The unstable neem oil radicals coupled with its less dense crystals can result into cross bonding between carbon of oil and oxygen of sand to form hydroperoxides that further improved strength. These reactions were facilitated by elevated baking temperature, however the polygonal crystal structure of gum Arabic polysaccharides made its bond with sand harder to brake and more tenacious than the bond of neem oil to sand.

Tensile strength also increased with increase in neem oil in the hybrid binder and baking period in Figure 3 due to similar reasons as above. In comparison with standard in Table 1, the result shows that hybrids made of 3% grade 1 gum Arabic with 0.5% neem oil baked at 200°C for 1 - ½ h is suitable for class III - IV iron/steel, copper bronze, non-intricate aluminium and magnesium cores. Those of 3% gum Arabic with 2 - 3% neem oil baked for 1 h are suitable for class II iron/steel, brass and intricate aluminium cores. Figure 3 compared with Figure 2 shows that strength is higher for cores baked at 200°C than at 180°C because of higher molecular mobility brought by higher heat/reaction energy available to sand and binder at 200°C that is closer to melting point of grade 1 gum arabic (Ademoh and Abdullahi, 2008). Tensile strength is about 8% higher than that obtained in a previous study

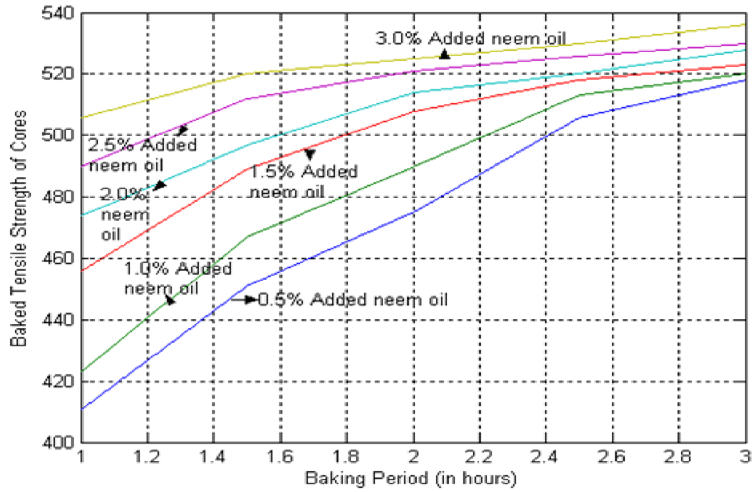

Figure 2. Tensile strength (in KN/m^2) of cores bonded with hybridized mix made of 3% grade 1 gum arabic and varying quantities of neem oil baked at 180℃ for 1 - 3 h.

with cores bonded with same amount of grade 1 gum Arabic baked at 2000c for 1 - 3h (Ademoh and Abdullahi, 2009).

In Figure 4 tensile strength followed similar pattern as Figures 2 and 3. Grade 2 gum arabic melts at about 200°C, the temperature at which the cores were baked. As a class 3 core binder it became very reactive, held sand grains together to form strong bonds on cooling to room temperature. The neem oil component of hybrid also acquired heat energy that promoted its reaction with interior sand. Tensile strength did not drop as none of the binder constituents was burnt while cores were baked. By comparing this result with Table 1, it is observed that hybrids made of 3% gum arabic grade 2 with 0.5% neem oil baked for 1 h are suitable for class III - IV iron/steel, copper bronze, non-intricate aluminium and magnesium cores. Sands bonded with hybrids made up of 3% gum arabic with 2 - 3% neem oil baked for 1 h are suitable for class II iron/steel, brass and intricate aluminium cores like those bonded with grade 1 gum arabic hybridized with neem oil. This result shows about 14% increase in strength over that of a similar work with plain grade 2 gum arabic.

The result in Figure 5 when compared with foundry standard in Table 1 shows that hybrid binders made of 3% grade 3 gum arabic and 0.5% neem oil baked at 200℃ for 1 h are suitable for class III - IV iron/steel, copper bronze, non-intricate aluminium and magnesium cores while those made of 3% gum arabic grade 3 with 1.5 - 3% neem oil baked for 1½ h are suitable for class II iron/steel, brass and intricate aluminium cores. Tensile strength rose with increased baking period up to 2½ h at which it gradually dropped at each composition of hybrid binder. Reduction in bond strength could only be accounted for by a reduction of chemical reactivity between sand and binder constituents or by burning of some binder. Gum arabic grade 3 melts at about 190℃ (Ademoh and Abdullahi, 2008). Holding the sand mix at baking temperature (over 10℃ above melting point) for too long caused some of its molecules to burn. Moreover at this baking temperature unburnt gum arabic is totally fluid. As it is nonreactive with organic oil its sintering type of bond reaction with sand is reduced by neem oil that prevents some of it from wetting the sand surface for effective bond formation. In comparison with previous work with plain Nigerian gum arabic grade 3 under similar conditions (Ademoh and Abdullahi, 2009) neem oil hybridization with the material decreased tensile strength by about 3.5% drastically at 2.0 h instead of 2½ hours of baking. This shows the effects that caused sudden reduction of bond strength are more pronounced here than Figure 5. This is because grade 4 gum Arabic melts at below 180℃ (Ademoh and Abdullahi, 2008) making cores bonded with its hybrid with neem oil baked at 200°C to burn at shorter baking duration than cores bonded with grades 1, 2 and 3 gum Arabic based hybridized binder with neem oil. However, the result when compared with Table 1 shows that hybrid made of 3% gum Arabic grade 4 with 0.5% neem oil baked at 200℃ for 1 h is suitable for class III - IV iron/steel, copper bronze, non-intricate aluminium and magnesium cores. Hybrids of 3% Nigerian gum Arabic grade 4 with 2.0 - 3% neem oil and baked at 200℃ for 1 h are suitable for class II iron/steel, copper brass and intricate aluminium cores. This result shows 11.5% decrease in baked tensile strength of cores over that obtained for cores bonded with plain gum Arabic grade 4 (Ademoh and Abdullahi, 2008).

A cross comparison of Figures 2, 3, 4, 5 and 6 shows

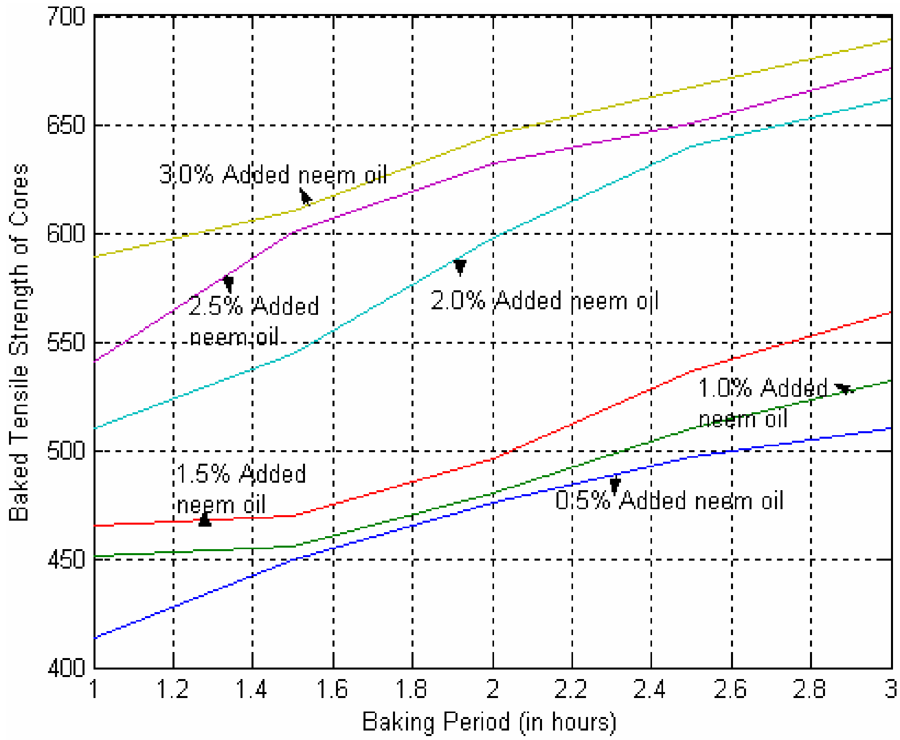

Figure 3. Tensile strength (in KN/m^2) of cores bonded with hybridized mix made of 3% grade 1 gum Arabic and varying quantities of neem oil baked at 200℃ for 1 - 3 h.

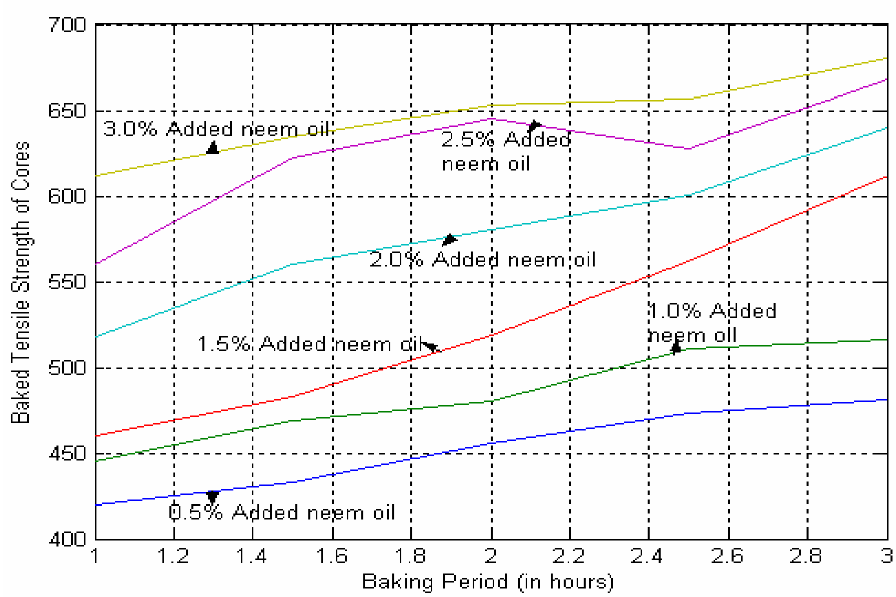

Figure 4. Tensile strength (in KN/m^2) of cores bonded with hybridized mix made of 3% grade 2 gum Arabic and varying quantities of neem oil baked at 200℃ for 1 - 3 h.

that the range of suitability of the hybrids in terms of neem oil content and baking duration of 1 - 1½ h are closely similar. When sand cores were baked at 200℃ neem oil improved tensile strength of cores bonded with grades 1 and 2 gum Arabic based hybrid binder with neem oil, grade 2 being more enhanced. On the other

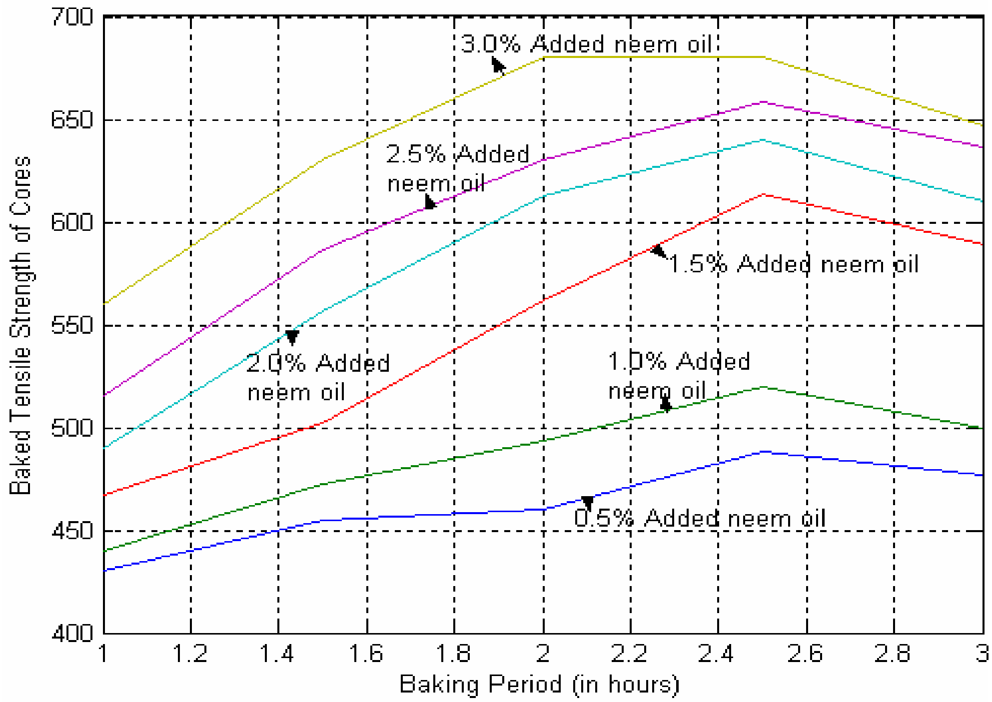

Figure 5. Tensile strength (in KN/m^2) of cores bonded with hybridized mix made of 3% grade 3 gum Arabic and varying quantities of neem oil baked at 200°C for 1 - 3 h.

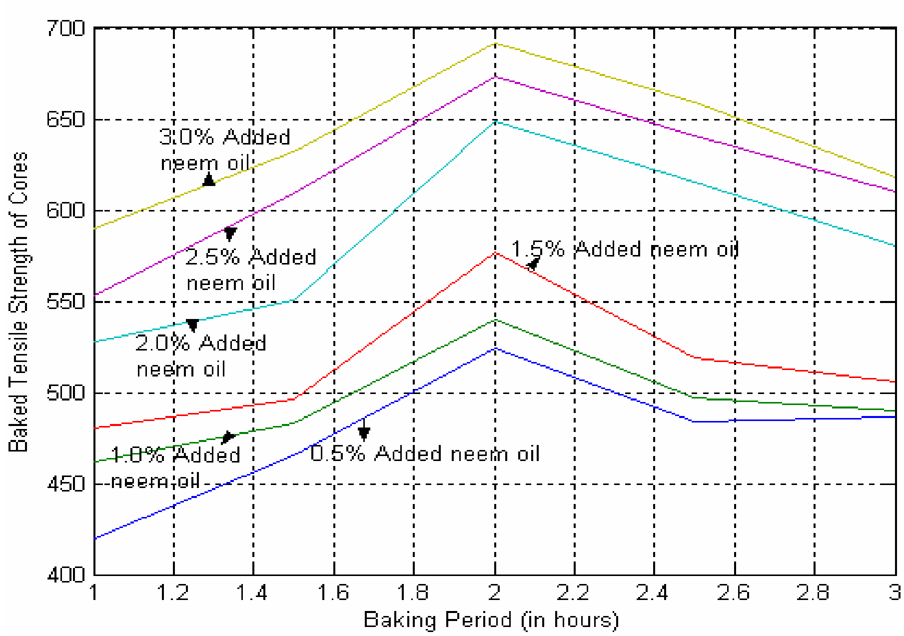

Figure 6. Tensile strength (in KN/m^2) of cores bonded with hybridized mix made of 3% grade 4 gum Arabic and varying quantities of neem oil baked at 200°C for 1 - 3 h.

hand it depressed tensile strength of cores bonded with grades 3 and 4 gum Arabic based hybrid binder with neem oil, grade 4 was more depressed. Grade 2 gum Arabic hybrids with neem oil offered best economic advantage as it attained required tensile strength after the shortest period of baking at 200℃. It was followed by grade 4, grade 1 and grade 3 gum Arabic based hybrid in that order. If the cores were baked at 210°C only the cores bonded with grade 1 gum Arabic hybridized with neem oil may retain sufficient strength as its melting point above which it start to burn off was not exceeded. However cores bonded with other grades with melting points less than 200℃ will burn and result to weakening of tensile strength (Ademoh and Abdullahi, 2008). The neem oil component of hybrid binder would severely burn off and weaken strength as 210℃ is well above its vapourization point of 170℃.

Conclusion

The benefits of mixing neem oil with Nigerian gum Arabic as hybrid binder is more pronounced when cores are baked at about the melting temperature of grade of gum Arabic involved. Baking below melting point marginally improves bond strength while baking at well above melting point and holding for long depresses tensile strength of cores.

REFERENCES

Ademoh NA, Abdullahi AT (2008). “Evaluation of the mechanical properties of expendable foundry sand cores bonded with Nigerian gum Arabic grade 4”. Middle East J. Sci. Res. IDOSI Publications. 3(3): 126-133.

Ademoh NA, Abdullahi AT (2009). Assessment of the efficacy of grade 2 Nigerian acacia species exudates for binding foundry sand cores”. Nig. J. Eng. Ahmadu Bello University, Zaria. 15(2): 121-126.

Ademoh NA, Abdullahi AT (2009). Evaluation of the effective baking conditions for grade 3 Nigerian acacia species bonded foundry sand cores”. © Maxwell Scientific Organization. ISSN: 2040-7467.

Ademoh NA, Abdullahi AT (2008). Determination of physico-chemical properties of Nigerian acacia species for binding foundry sand. Res. J. Appl. Sci. Eng. Technol. © Maxwell Scientific Organization. 1(3): 107-111, ISSN: 2040-7467

Ademoh NA, Abdullahi AT (2009). Production of expendable foundry sand cores using grade 1 Nigerian acacia exudates”. Niger. J. Eng. Ahmadu Bello University, Zaria, (accepted for publication).

American Foundry Men Society (1989). “Mould and Core test Handbook”. 2nd edition Procedure 113: 74-78.

Aponbiede O (2000). “Development of oil cores using local vegetable oils”. Ph. D degree dissertation in Metallurgical Engineering, ABU Zaria, Nigeria. pp 4-11.

Busby AD (1992). Phenolic ester process-the past, present and future”, The American Foundry men’s Society Congress, Chicago, AFS Transactions 93-172. pp. 621-633.

Busby AD (1993). “Recent development in binder tech.” Institute of British Foundry men, 9th annual conference, Castion York foundry men. pp. 13-38.

Siak June-sang, Schreck RM Shah Kush (1994). USA Patent 5320157 (14th June,)- “Expendable core for casting processes”.

Titov ND, Stepanov YU (1982). “Foundry practice”. Translated by Ivanov P.S. Mir Publishers Moscow. pp 49-101.