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Evaluation of the Mechanical Properties of Expendable Sand Cores Bonded with the Nigerian Gum Arabic Grade 4

[1]Nuhu Ali Ademoh and [2]Ahmed Tijani abdullahi

[1]Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna, Nigeria
[2]Department of Mechanical Engineering, Bayero University, Kano, Nigeria

Abstract: Nigerian gum Arabic grade 4 (acacia species) was used to bind foundry sand cores and analyzed for mechanical properties including baked tensile and green compressive strength; permeability and shatter index using universal strength machine, permeability meter and shatter test machine respectively to ascertain their suitability for sand casting. Tensile strength specimens were shaped like figure eight baked at 160, 180, 200 and 220°C for 1-3 h were oven cooled and tested. Compressive strength, permeability and shatter specimens were cylindrically shaped and tested in the green state. Results were compared with foundry standard. It was found that mechanical properties of sand bonded sand bonded with 4.5% acacia baked at 160°C for 1-2.0 h are suitable for bronze, non intricate aluminium, magnesium and classes III, IV, V iron/steel cores. Those of 4.5% acacia bonded sand baked at 180°C for 1.0-1.5 h are suitable for magnesium, brass, intricate aluminium, classes II and III iron/steel cores. The mechanical properties of sand bonded 6-13% Nigerian acacia grade 4 baked at 200°C for 2.0 h are suitable for class I iron and steel cores except the permeability that must be improved with the use of coarse sand.

Key words: Grade 4 · Gum Arabic · Cores · Mechanical properties

INTRODUCTION

The materials and methods used for core production in most modern foundries are too complex and expensive for easy adoption for local use by the plants in developing countries. This has compelled countries like Nigeria to depend on expensive imports for binders and synthetic sands [1]. This disabled the rapid growth of foundries in Nigeria that could have led to her overall technological advancement and economic emancipation as witnessed in recently developed Asian economies called the Asian Tigers [2]. This research is one of the critical efforts required to urgently solve the problem non indigenous sources of good and affordable binders for foundries through the use of gum Arabic produced in abundance of four different grades in commercial quantities in Nigeria.

Ademoh and Abdullahi researched with grade 4 of the four commercial grades of Nigerian gum Arabic and found that 11.5-13% of the material with 2-3% moisture is suitable for binding sand mould for light steel [3]. The study was conducted after investigation of physiochemical properties of Nigerian acacia gum proved the material suitable for binding foundry sand [4]. Gum Arabic is natural resin that contains arabin; semi-solidified sticky fluid that oozes from incision made on bark of acacia trees [5]. The use of gum Arabic in foundry include addition of 5% of acacia gum to 10% sugar and protein in a gelatinous mix derived from amino acid for binding expendable cores for sand casting [6]. In United Kingdom, it is used in hot box process. Acacia gum also combined with sugar, urea formaldehyde resin and boric acid to bind foundry cores [7].

The aim research is to evaluate the mechanical properties of oven baked sand cores bonded with the Nigerian acacia species exudates grade 4 as sole binder to ascertain the level of usability of such cores in foundry. The main objectives are to produce acacia species grade 4 bonded sand cores oven baked at 160°C, 180°C 200°C and 220°C for 1-3 h, test them for tensile strength; test the green core sand mix for mechanical properties such as compressive strength, permeability and shatter index and to compare result with standard in Table 1 [8], to ascertain the suitability for castings.

Corresponding Author: Nuhu A. Ademoh, Department of Mechanical Engineering, Nigerian Defence Academy, P.M.B 2109, Kaduna, Nigeria

MATERIALS AND METHODS

The green compressive and the baked tensile strength; green permeability and shatter properties of cores bonded with grade 4 Nigerian gum Arabic (acacia species) were measured with standard equipment consisting universal strength machine, permeability meter and shatter index machine in foundry laboratory of Ajaokuta Steel Company Limited, Nigeria. These mechanical properties were suggested by Titov and Stepanov [8]; Dietert [9] as the main determinants for suitability of sand cores and binders for casting. Known silica sand sample with clay content of 0.3% was used to produce the core test specimens. Sand was dried at 110°C to remove free water, weighed and transferred to a mechanical sieve and vibrated for 30 minutes for grain size distribution [10].

A quantity of sieved sand of BS standard grain size 40-72 was taken and used to produce specimen. Grade 4 Nigerian acacia species exudates was milled to smallest possible grain size to enable even particle distribution within mix for enhanced bonding reaction. Sand and measured grade 4 acacia exudates were thoroughly mixed in a roller for 10 minutes and then moulded to specimens in accordance with test schedule. Compressive strength, permeability and shatter index specimens were cylindrically shaped, measuring 2 inches diameter by 2 inches height and weighed 130g after ramming with three blows of 6.5 Kg [11].

The tensile strength specimens were shaped as the figure eight dimensioned as shown in Fig. 1. The specimen was moulded in split core box and compacted with three dropping blows weighing 6.5 Kg from a height of 2 inches from the rammer. After oven baking specimens at 180°C, 200°C and 220°C for 1 to 3 h, they were oven cooled and tested with universal strength equipped with attachment to grip the specimens as shaped and a meter that reads strength instantaneously [11]. A steadily increasing force in compression or tension was applied on either a compressive or tensile strength specimen by the universal strength machine until failure occurred and strength read. For permeability, standard air pressure of $9.8x10^2 N/m^2$ was passed through specimen in sample tube placed in meter and after $2000cm^3$ air had passed through it, permeability was read [10]. Shatter specimen placed in the container of test machine was pushed upwards over stripping post until it struck the anvil, fell and shattered. Retained sand/over size was collected, measured and used to compute shatter index. The results are presented as graphs in Fig. 2-7.

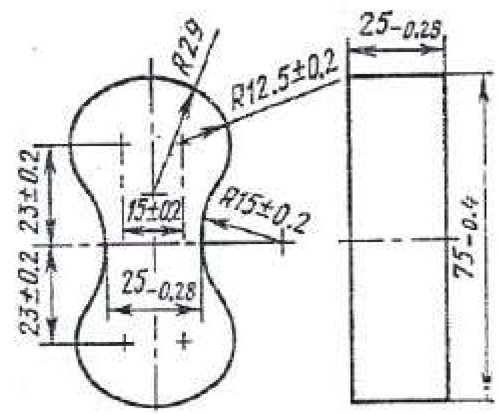

Fig. 1: Design shape of the core tensile strength test specimen

RESULTS

The results are presented in Fig. 2-7. Figure 2 presents the result of green compressive strength test, Fig. 3 presents results of permeability and shatter index test and Fig. 4-7 present results of tensile strength tests after baking at 160°C,180°C, 200°C and 220°C for 1-3 h and then oven cooling. Results were compared with the established foundry standard in Table 1 [8] to draw up proper conclusion on the research. Compressive and tensile strength measured ability of core to withstand compressive and tensile stress loads during casting. Adequate tensile strength prevents cores enclosed by hot molten metal within mould cavities from exploding due to thermal expansion stresses.

DISCUSSION

Figure 2 presented the green compressive strength test result of cores bonded with grade 4 Nigerian gum Arabic. It shows that green compressive strength increased with increasing acacia binder from 9 KN/m^2 at 3% to 92 (KN/m^2) at 13% gum. Increased binder promoted more bond reaction between loose sand particles and raised strength. In comparison with Table 1, sand bonded with 3-13% gum Arabic is suitable for brass, bronze, aluminium and class I and II iron and steel cores while sand bonded with 4.5-13% Nigerian gum Arabic grade 4 is suitable for magnesium, class III, IV and V iron and steel cores.

Figure 3 presented results of permeability and shatter index tests. Permeability decreased with increasing gum Arabic from 160.8 to 87.4 No. This is because additional binder caused more compaction of sand grains resulting

GRAPHICAL PLOTS OF THE EXPERIMENTAL RESULTS

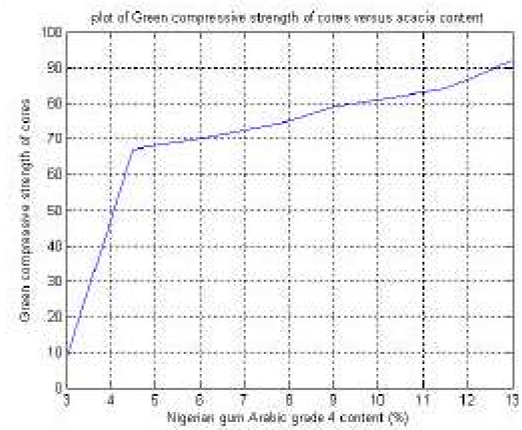

Fig. 2: Green compressive strengths (KN/m^2) of foundry sand cores bonded with varying percentages grade 4 Nigerian gum Arabic

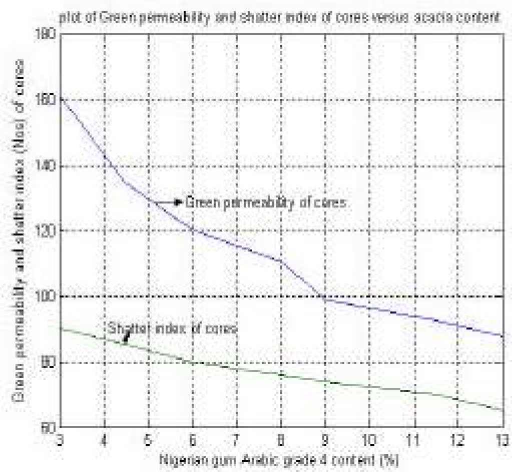

Fig. 3: Green Permeability and shatter index (No) of foundry sand cores bonded with varying percentages grade 4 Nigerian gum Arabic

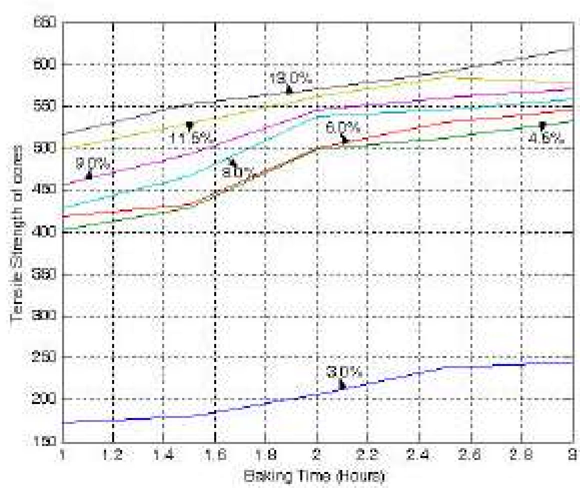

Fig. 4: Tensile Strength (KN/m^2) of sand cores bonded with varying percentages grade 4 Nigerian gum Arabic with 3% water and baked at 160°C for varying periods in hours

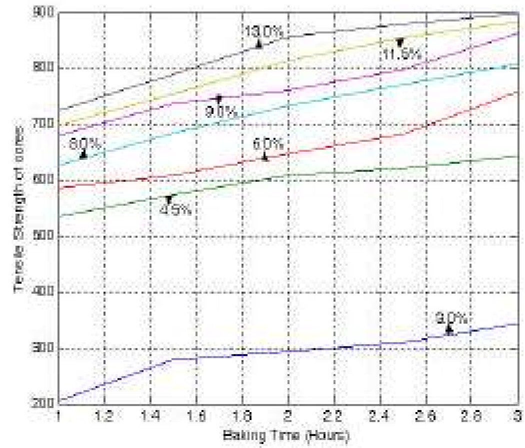

Fig. 5: Tensile Strength (KN/m^2) of sand cores bonded with varying percentages grade 4 Nigerian gum Arabic with 3% water and baked at 180°C for varying periods in hours

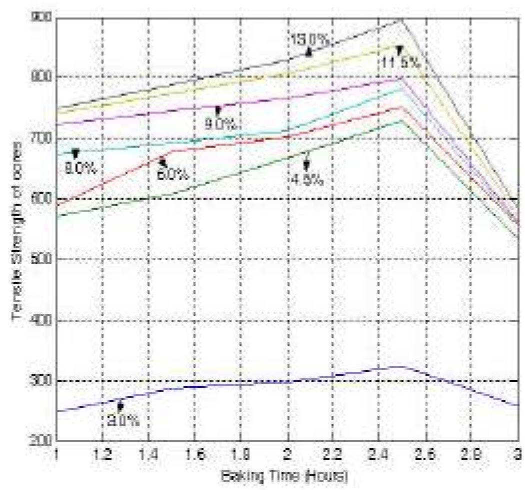

Fig. 6: Tensile Strength Values (KN/m^2) of cores bonded with varying percentages of grade 4 Nigerian gum Arabic with 3% water content and baked at 200°C for varying periods in hours

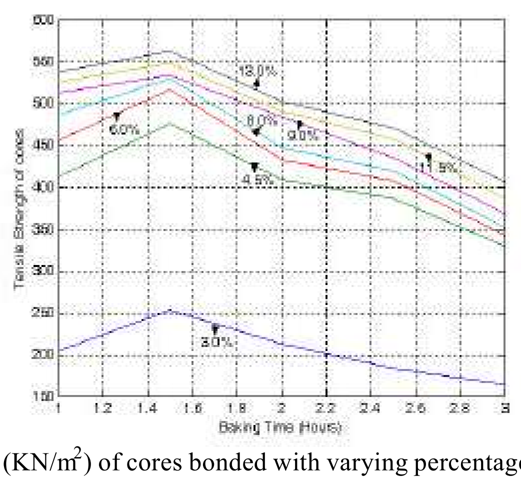

Fig. 7: Tensile Strength Values (KN/m^2) of cores bonded with varying percentages of grade 4 Nigerian gum Arabic with 3% water content and baked at 220°C for varying periods in hours

to reduction porosity and gas escape from cores. In comparison with Table 1, permeability at 3-4.5% acacia gum is suitable for class I iron/steel core; at 3-8% is suitable for bronze, intricate aluminium, class II and III iron/steel cores; and at 3-13% acacia is suitable for magnesium, brass, class IV and V iron and steel cores. Shatter index result in Fig. 3 is also suitable for above listed applications.

Figure 4, 5, 6 and 7 presented the result of tensile strength analyses for core baked at 160°C, 180°C, 200°C and 220°C for 1 to 3 h, respectively. Results in Fig. 4 for cores baked at 160°C compared with standard in Table 1 shows that sand bonded with 3.0% acacia grade 4 baked for 1.0 h is suitable for class V iron and steel cores and that baked for 2-3 h is suitable for class IV iron and steel cores. Sand bonded with 4.5% acacia baked for 1-2.0 h is suitable for bronze, non intricate aluminium, magnesium and classes III, IV, V iron/steel cores while sand with 11.5-13% acacia baked for 1.5-2.0 h is suitable for brass, intricate aluminium and class II iron/steel cores. The peak tensile strength was not reached at 160°C in Fig. 4 because as a class three type of binder that melts to bind sand and harden on cooling, the melting point (178-182°C) [4] for display of this wasn't attained. Tensile strength increased with baking time because of longer bond reaction period available.

Figure 5 presented result of cores baked at 180°C. Tensile strength increased with gum Arabic without sloping. At 180°C (within melting range of gum Arabic grade 4) the interior and exterior parts of cores are still acquiring heat to melt become fluid and form strong bonds on being cooled. In comparison with Table 1, sand bonded with 3.0% acacia baked for 1.0-1.5 h and 2.5-3.0 h are suitable for classes IV and V iron/steel and magnesium cores respectively. 4.5% acacia bonded sand baked for 1.0-1.5 h is suitable for magnesium, copper, aluminium, class II and III iron/steel cores; and that with 8-9% gum Arabic baked for 2.0-3.0 h is suitable for class I iron and steel cores.

The result of cores baked at 200°C is presented Fig. 6. Tensile strength increased with increase in binder and baking time up to just above 2 h. 200°C is 18-22°C above melting range of grade 4 and at 1-2 h of baking cores acquired sufficient heat to melt, became fluid and formed strong bonds. Holding cores above this period caused some acacia binder to burn off resulting to weakening of strength. In comparison with Table 1, sand bonded with 3.0% acacia baked at 200°C for 1.0 and 2.5 h are suitable for classes IV and V iron/steel and magnesium cores respectively. 4.5% acacia bonded sand baked for 1.0-1.5 h is suitable for copper, aluminium, classes II and III iron/steel cores and 6-13% acacia sand baked for 2.0 h for class I iron/steel cores.

Figure 6 presented the result of cores baked at 220°C for 1 to 3 h. Tensile strength increased marginally with baking time up to 1.5 h from when it decreased rapidly because above melting range of grade 4 gum Arabic it began to burn off and weakened strength due to over baking. Cores bonded with the material are therefore not suggested to be baked at or above this temperature.

CONCLUSIONS

Based on above results and discussions core sands bonded with grade 4 gum Arabic possess adequate mechanical properties different metal alloy castings in foundry. A consideration of all the mechanical properties measured shows that sand bonded with 4.5% acacia baked at 160°C for 1-2.0 h is suitable for bronze, non-intricate aluminium, magnesium and classes III, IV, V iron/steel cores. 4.5% acacia bonded sand baked at 180°C for 1.0-1.5 h is suitable for magnesium, brass, intricate aluminium, classes II and III iron/steel cores. Sand bonded 6-13% Nigerian acacia grade 4 baked at 200°C for 2.0 h is suitable for class I iron and steel cores but with improved green permeability. In comparison with other core processes reviewed [6], [7], [9], [11] this work produced good cores using simpler organic material and method.

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