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Evaluation of the Mechanical Properties of Expendable Foundry Sand Cores Bonded with Composites Made of Kaolin Clay and Grades 1 and 4 Gum Arabic

Nuhu A. Ademoh

Department of Mechanical Engineering, Nigerian Defence Academy,
P.M.B 2109, Kaduna, Nigeria

Abstract: Defined quantities of grades 1 and 4 Nigerian gum Arabic were mixed with refined kaolin clay as composite binders for sand cores. Foundry mechanical properties like green compressive strength, permeability, shatter index and baked tensile strength tests were carried out on core specimens to ascertain degree of suitability of the composites for sand casting. The green compressive strength, permeability and shatter tests were carried out on cylindrically shaped specimens using standard universal strength machine, permeability meter and shatter machine. Tensile strength specimens shaped like the figure eight were oven baked at 200°C for 1-3 hours and cooled before tests. Core samples bonded with these composite binders were used for trial castings to ascertain its practical performance. The research showed that 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. On the other hand addition of gum Arabic to kaolin clay bonded cores improved green compressive strength by 15% and baked tensile strength by 17%, while it decreased shatter index and permeability by 6% and 5% respectively. Gum Arabic and kaolin clay composite binders gave cores that produced clean cast cavities which also collapsed easily after casting solidification.

Key words: Gum Arabic · Expendable cores · Kaolin clay

INTRODUCTION

Gum Arabic and kaolin clay are vegetable and mineral materials that are abundantly available in Nigeria which find no relevance in local metal manufacturing despite the dependence of Nigerian foundries on imports for critical inputs like sand binders and additives. The use of gum Arabic in foundry core production include the addition of 5% of it to 10% sugar and protein in a gelatinous mix derived from amino acid for binding expendable cores for casting [1]. In United Kingdom, it is used in hot box core process. It was combined with sugar, urea formaldehyde resin and boric acid to bind cores for casting [2]. Nuhu and Abdullahi worked with the four grades of Nigerian gum Arabic produced in commercial quantities for binding foundry mould sand and found them suitable for non-ferrous and ferrous castings at defined compositions [3]. Each of the grades 1 and 4 gum Arabic has been proved suitable for binding expendable cores baked at 180-220°C for 1-3 hours for casting of different alloys [4, 5]. The composites of Nigerian gum Arabic grades 1 and 2 with bentonite clay were found more suitable for binding mould sand than plain gum Arabic [6].

Based on these it is believed that combining gum Arabic with conventional binder like kaolin clay for core application would give better result than the plain material [7]. The aim and objectives of this paper is to mix each of grades 1 and 4 Nigerian gum Arabic exudates with defined quantities of refined kaolin clay as composite binder for specimen cores, to analyse the cores for mechanical properties including green permeability, shatter index, green compressive and tensile strength and to compare the result with existing foundry standard in Table 1 and with previous related works done under similar conditions so as to determine the suitability of the composites for foundry use. The significance of this work lies on the fact that its findings will reveal another source of cheap and locally available composite binders for Nigerian foundries leading better process economics.

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

Table 1: Desired mechanical property ranges of sand cores [8]

		Strength (KN/m^2)	
Alloy Casting	Permeability (No)	Green Compression	Baked Tensile
Class I iron/steel cores	130-150	3-6	700-1000
Class II iron/steel cores	100	5-10	500-700
Class III iron/steel cores	100	10-16	350-600
Class IV iron/steel cores	70	15-25	200-300
Class V iron/steel cores	70	20-35	80-150
Copper bronzes cores	90	3-5	400-600
Copper brasses cores	60	6-8	500-700
Intricate Aluminium cores	100	3-7	500-700
Non-intricate Aluminium cores	80	6-15	400-600
Magnesium cores	80	60-150	300-500

Experimental Methodology

Core Property Analyses: Cores are interior implants of casting moulds that are subjected to serious thermal expansion stress that can cause them to explode during casting solidification if the relevant properties are not properly controlled. For good process control, Titov and Stepanov [8] suggested that the ability of sand core to withstand the thermal stresses imposed on them in the form of tensile expansion by hot molten metal; gas permeability and ease of removal of burnt core sand from casting after solidification are critical properties that must be considered in assessment of a binder. These properties, usually determined as the green compressive strength, permeability, shatter index and baked tensile of cores were experimentally measured on specimens bonded with composites made from grades 1 and 4 gum Arabic and kaolin clay. Known silica sand with 0.3% clay was used to produce core specimens. The sand was oven dried at 110°C for 1 hour to remove free water, weighed and vibrated in a mechanical sieve for 30 minutes for grain classification [8].

Some quantity of the sieved sand of BS standard size 40-72 mesh was used to produce specimens. The gum Arabic sample was milled to the smallest possible particle size and mixed with defined quantities of kaolin clay to enable even particle distribution. The silica sand and the composite binders were mixed in a roller mill for 10 minutes and then moulded into test cores. Specimens for compressive strength, permeability and shatter were cylindrically shaped. Each measured 50mm diameter by 50mm height and weighed 130g after ramming with three blows each of 6.5Kg from a 50mm height [9]. Figure 1 shows some rammed specimens. Tensile test specimens were shaped as shown in Figure 1. They were moulded in a split core box and compacted with three blows each

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

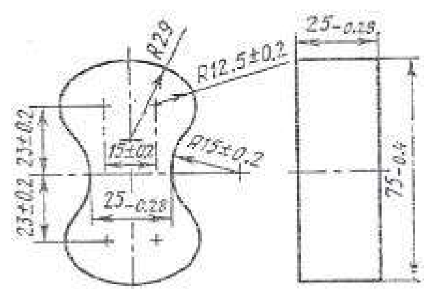

Fig. 2: Design shape of the core tensile strength test specimen (dimensions are all SI units).

weighing 6.5Kg from a height of 50mm by a standard rammer. After oven baking specimens at 200°C for 1-3 hours, they were cooled and tested with a universal strength machine equipped with attachments to grip them as shaped and a meter to instantaneously read the strength uf cores [8].

During the test a steadily increasing force in compression or tension was applied on compressive tensile strength specimen by a universal strength machine until failure occurred and strength was read. For permeability tests, a standard air pressure of 9.8x10^{2}N/m^2 was passed through sample tube placed in

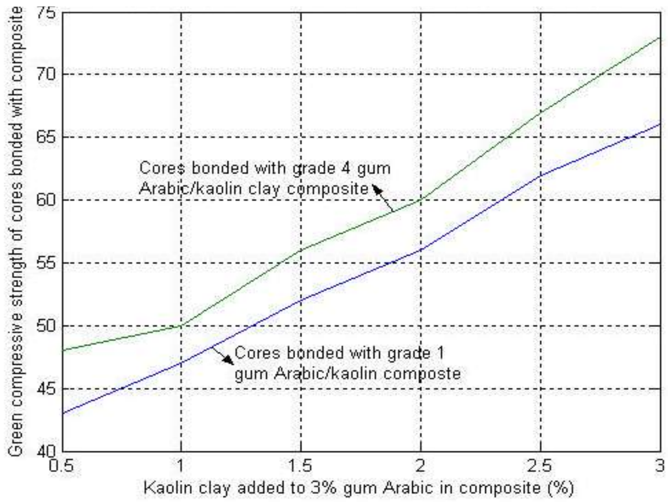

Fig. 3: Compressive strength (KN/m^2) of cores bonded with composites of kaolin and gum Arabic exudates

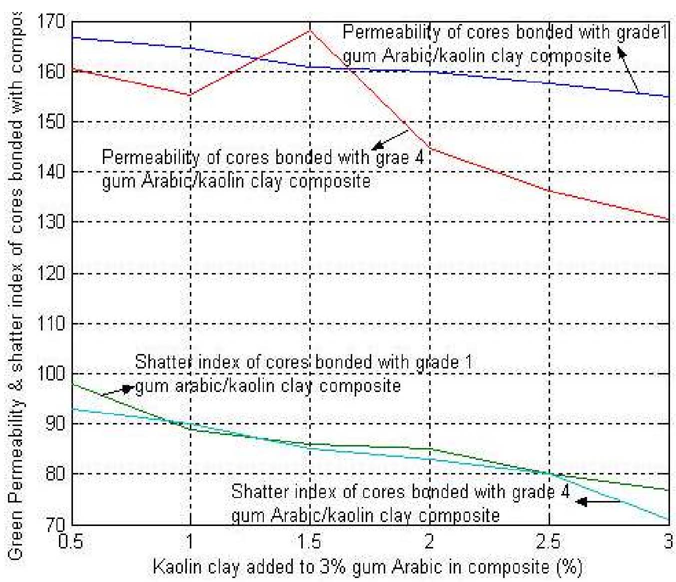

Fig. 4: Permeability and shatter index (No) of cores bonded with composite of kaolin clay and gum Arabic

Plate 1: Mould and Core Assembly

Plate 2: Casting process

its meter and after 2000cm^3 air had passed through, the permeability was read. For shatter test, specimens placed in container of shatter machine were pushed upwards over stripping post until it struck anvil, fell and shattered. Retained sand and over size were measured and used to instantaneously compute shatter index [9].

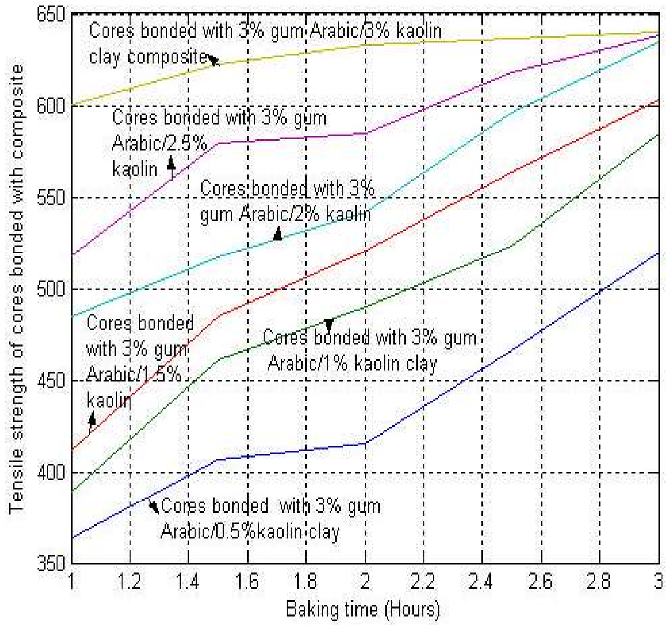

Fig. 5: Tensile strength values (KN/m^2) of cores bonded with varied amounts of kaolin clay with 3% grade 1 gum Arabic baked at 200°C for varying periods in hours

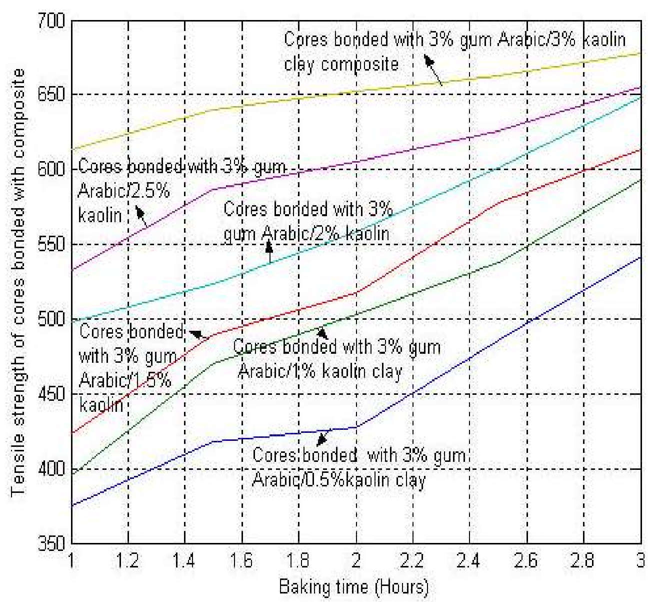

Fig. 6: Tensile strength values (KN/m^2) of cores bonded with varied amounts of kaolin clay with 3% grade 4 gum Arabic baked at 200°C for varying periods in hours

The raw experimental results were processed into graphs in Figure 3-6. Compressive strength measured bond strength in moist state. Permeability measured ease of gas escape from core. Shatter index measured core collapsibility. Tensile strength measured ability of cores to withstand thermally imposed rupture stress during casting.

Experimental Casting: Some experimental iron castings were made in sand moulds with core implants bonded with grades 1 and 4 gum Arabic and kaolin clay composites in a foundry to practically verify the results of the core property analyses done above. The baked sand core/mould assembly and casting process are as shown in Plates 1and 2. The moulds were oven dried at 120°C for

Plate 3: Experimental castings as shaken out from the sand moulds

Plate 4: A typical casting revealing cavity created by a core bonded with kaolin/gum Arabic grade 4 composite.

one hour while the cores were baked at 200°C for two hours before assembly. Molten cast iron was tapped from the induction furnace at 1400°C.

Presentation of Results: Figure 3 presents result of test for compressive strength; Figure 4 presents that of permeability and shatter index. Figure 5-6 present the result of tensile test of cores baked at 200°C for 1-3 hours. A trial casting shaken from mould is in Plate 3. Plate 4 reveals cleanliness of cavity created by core.

RESULTS AND DISCUSSION

In Figure 3 strength is observed to have varied from 44 KN/m^2 for cores bonded with 3% grade 1 gum Arabic with 0.5% kaolin clay to 65 KN/m^2 for cores bonded with 3% gum Arabic/3% kaolin clay. Those for cores with 3% gum Arabic grade 4 with 0.5% kaolin clay varied from 48 KN/m^2 to 73 KN/m^2 at 3% gum Arabic with 3% kaolin clay. This shows that gum Arabic grade 4 with kaolin composite gave stronger bond than the grade 1 gum Arabic with kaolin composite by about 11%. A comparison of result with foundry standard in Table 1 shows 3% that the grades 1 and 4 Nigerian gum Arabic with 0.5-3% kaolin clay composite binder is suitable for cores for casting all alloys except magnesium for which 2.5-3% grade 1 gum Arabic with 3%kaolin and 2-3% grade 4 gum Arabic with kaolin clay composites are suitable. When the result is compared with previous works that used plain grades 1 and 4 gum Arabic as core binders [4],[5] it shows that the addition of kaolin clay improved strength by about 8%. The composite had strength of about 15% higher than cores bonded with plain kaolin clay [10].

In Figure 4 the permeability for grade 1 gum Arabic/kaolin composite varied from 167 to 156 No. That of grade 4 gum Arabic with kaolin clay composite varied from 160 to 131 No. It showed that addition of kaolin clay improved permeability of gum Arabic bonded cores by about 18% due to creation of additional porosities by kaolin clay particles in mix as they caused discontinuities in sealed surface of cores by resinous gum Arabic. The permeability when compared with Table 1 shows the values are suitable for cores for all alloy casting. Shatter index varied from 98 to 77 and 93 to 71 No for gum Arabic grades 1 and 4 with kaolin clay composite bonded cores. The values are also suitable for all classes of sand cores. Permeability and shatter index were depressed by 6% and 5% respectively over the plain kaolin clay bonded cores.

Figures 5 and 6.present the results of tensile strength for core specimens bonded with 3% of each of grades 1 and 4 gum Arabic/0.5-3% kaolin composite and baked at 200°C for 1-3 hours The results when compared with standard in Table 1 shows that cores bonded with 3% grade 1 gum Arabic with 0.5% kaolin clay composite baked for 1.5 hours are suitable for casting magnesium, non-intricate aluminium, copper bronzes, class III-V iron and steel casting. Cores bonded with 3% grade 1 gum Arabic with 2-3% kaolin composite baked for 1.5-2.0 hours are suitable for copper brass, intricate aluminium and class I-II iron and steel casting. Similarly, sand bonded with 3% gum Arabic grade 4 with 0.5% kaolin clay composite baked at 200°C for 1.5 hours is suitable for magnesium, non-intricate aluminium, copper bronzes, classes III-V iron and steel cores. Sands bonded with 3% grade 1 gum Arabic with 2-3% kaolin clay composite baked for 1-1.5 hours are suitable for cores for copper brass, intricate aluminium, class I-II iron and steel castings.

The result of cores bonded with two composites of gum Arabic grade 1 with kaolin clay and grade 4 gum Arabic with kaolin clay shows that grade 4 gum Arabic/kaolin composite gave 2-4% higher baked tensile strength and shorter baking duration of about 1 hour than grade 1 gum Arabic/kaolin composite. This implies that grade 4 gum Arabic/kaolin mixes is more economical in heat energy cost than the grade 1 gum Arabic/kaolin. When result is compared with those of previous similar works [9],[10], addition of kaolin clay improved baked tensile strength of cores bonded with plain grades 1 and 4 Nigerian gum Arabic by about 11% and 15% for grades 1 and 4 gum Arabic/kaolin clay composites respectively. Presence of kaolin clay also pushed the baking period at which plain gum Arabic bonded cores got burnt leading to reduced strength from 2.5 hours to over 3 hours.

Some cast iron components made with cores bonded with the composite of grade 4 gum Arabic, plain grade 4 gum Arabic and plain kaolin clay just shaken out from sand moulds are as shown in plate 3. The component labelled as 3B in plate was made with plain grade 4 gum Arabic bonded core, that labelled as 1A was made with plain kaolin clay bonded core and that labelled as 2B was made with core bonded with grade 4 gum Arabic/kaolin clay composite. The casting made with core bonded with grade 4 gum Arabic/kaolin clay (2B) is extracted out as shown in plate 4 to clearly reveal the cavity left by core on shake out from the mould before fettling. The cleanliness of the cavity shows the efficacy of the composite for core application and the ease of collapsibility of core sand from casting cavity after solidification which is the expected result of a good binder.

CONCLUSIONS

From the foregoing it was observed that composite binders made from blends of Nigerian gum Arabic exudates and refined kaolin clay produce expendable sand cores with adequate mechanical properties for casting different alloys in foundry. The research showed that kaolin clay addition to gum Arabic bonded cores has beneficial effects on permeability; shatter index, green compressive and baked tensile strength. The presence of kaolin clay in 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. On the other hand the presence of gum Arabic in plain kaolin clay bonded cores improved green compressive strength by 15% and baked tensile strength by 17%, while it decreased shatter index and permeability by 6% and 5% respectively. The gum Arabic/kaolin clay composite binders gave cores that produced clean casting cavities and they collapsed easily after casting solidification. The research showed gum Arabic combined well with mineral material for core binding just as it did with other resins.

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