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Estimation of the Effect of Kaolin Clay Addition on the Mechanical Properties of Foundry Moulding Sand Bonded with Grades 3 and 4 Nigerian Gum Arabic (Acacia Species)

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

[1]Department of Mechanical Engineering, Nigerian Defence Academy, P.M.B. 2109, Kaduna, Nigeria
[2]Department of Mechanical Engineering , Bayero University, Kano, Nigeria

Abstract: The foundry properties of moulding sand specimens bonded with composites made of grades 3 and 4 Nigerian acacia species (gum Arabic) with bentonite clay were appraised in a paper preceding this one. The success of the study prompted this research to find out the beneficial effects traditional binders like kaolin clay has on foundry sands bonded with each of these grades of Nigerian gum Arabic. The study involved mechanical property analyses of foundry sand specimens bonded with mixtures of each of the exudates of grades 3 and 4 Nigerian gum Arabic and quantities of refined kaolin. The experimental result that included moisture content, green/dry compressive strength, permeability, green hardness and shatter index values of mould specimens obtained using laboratory equipment of Ajaokuta Steel Company showed that kaolin addition substantially improved binding properties of green/dry mould bonded with the Nigerian grades 3 and 4 gum Arabic by an average of 30%/40% respectively. It lies in the fact that foundries in Nigerian that depended solely on imported binders would be availed with a local source of good sand binders from blends of materials that are abundantly available in the country thereby easing the problem of local foundry practice and better economics.

Key words: Gum Arabic · Kaolin clay · Foundry · Binder

INTRODUCTION

This research is one of the series aimed at creating enhanced industrial uses for gum Arabic, natural exudates that ooze from bark of trees called acacia species that is abundant in Nigeria. She grows four commercial grades; grade 1 (acacia Senegal), grade 2 (acacia Seyal), grade 3 (combretum) and grade 4 (neutral) [1]. Only grades 1 and 2 are preferred by European and American importers for emulsifiers, stabilizers and other applications in pharmaceutics, textile, lithographic printing, beverages and confectionaries [2]. Unfortunately Nigeria, the second largest world producer has no industrial use for it despite her import dependence for most needs including foundry inputs/outputs [3]. Kaolin clay a known binder is reported in deposits in 20 states of Nigeria [4].

Ademoh and Abdullahi [5] researched with grade 1 Nigerian acacia species exudates as foundry sand binders and found out that the material in powdered form with 2-3% moisture is suitable for non-ferrous, malleable and grey iron, but unsuitable for steel castings. The grade 2 species was studied and found suitable for non-ferrous castings at compositional range of 4.5-13% acacia exudates and 3% water [6]. Nigerian gum Arabic grade 3 was experimented with to bond moulding sand and found suitable for non-ferrous and grey iron castings at 6-9% composition [7]. 11.5-13% grade 4 acacia was also found suitable for binding light steel sand moulds [8]. The paper preceding this submitted for journal publication in India revealed the materials perform better when combined with bentonite clay as composite sand binder.

The main objectives of this study are to mix quantities of Nigerian kaolin clay with grades 3 and 4 Nigerian gum Arabic to bond moulding sand specimens; analyze specimens for properties like green and dry strength; permeability and hardness; shatter index and moisture content and to compare result with previous work with plain grades 3 and 4 gum Arabic binder as referred above and the standard in Table 1 [9].

EXPERIMENTAL PROCEDURES

The empirical values of the mechanical properties of mould specimens bonded with each of grades 3 and 4 of the Nigerian acacia exudates in combined mix with varying quantities of refined kaolin clay were experimentally measured. The tests included the moisture content; green and dry compressive strength; hardness, permeability and

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

Table 1: Satisfactory property range for sand casting [9]

Metal	Green Compressive Strength [KN|m^2]	Permeability No.	Dry Strength [KN|m^2]
Heavy Steel	70-85	130-300	1000-2000
Light Steel	70-85	125-200	400-1000
Heavy Grey iron	70-105	70-120	350-800
Aluminum	50-70	10-30	200-550
Brass and Bronze	55-85	15-40	200-860
Light Grey iron	50-85	20-50	200-550
Malleable Iron	45-55	20-60	210-550
Medium Grey Iron	70-105	40-80	350-800

shatter index. They are the most essential and the most measured properties as their values always give adequate information on other salient properties of foundry sand and the binder [10].

Known silica sand with 0.03% clay and of BS standard grain sieve size 40-72 was used to produce the specimens. The sand was washed and oven dried at 1100c to remove free water and then sieved to obtain the required grains. The gum Arabic sample was milled to smallest possible grain size to enable even particle distribution. The sand and quantities of each of grades 3 and 4 of Nigerian acacia exudates with measured kaolin clay as binder were thoroughly mixed in a roller mill for 10 minutes and then moulded into test specimens that measured 2 inches diameter by 2 inches height [11]. Each weighed 130 g after ramming with 6.5 Kg from 2 inches height [12]. Above tests were then carried out using foundry test equipment including universal strength machine, permeability, hardness, shatter index machine and quick moisture teller.

RESULTS AND DISCUSSION

The raw experimental results are presented in Table 2-5 and as processed into graphs in appendix A. Table 2 and 3 present result of analyses with kaolin clay at 1% and acacia varied from 1%-8% while Table 4 and 5 present that with kaolin clay varied from 1-6% and acacia fixed at 3%. The moisture test determined mould dampness; green/dry compressive strength measured ability of the sand mould to withstand the pressure of molten metal during pouring into sand mould; green hardness measured resistance against abrasion; permeability measured the porosity of mould and the ease of escape of gas to forestall defects; while shatter index measured mould collapsibility.

The result for the analyses of specimens bonded with 1-8% grade 3 Nigerian gum Arabic exudates mixed with 1% kaolin is presented in Table 2. Moisture decreased from 2.5 at 1% to 2 at 8% gum Arabic because as more binder needed more water to dissolve it and wet the clay and sand for reaction.

The green and dry compressive strength increased from 52/376 KN\m^2 at 1% acacia/1% kaolin to 102/436 KN\m^2 at 8% acacia/1% kaolin clay respectively.

These compared with 71/349 KN\m^2 for green/dry strength with 9% grade 3 acacia binder [7] showed that 1% added kaolin increased green/dry strength of grade 3 Nigerian gum Arabic bonded mould by about 45%/40%. By Table 1 standard a composite binder of 1% kaolin/1.0% grade 3 acacia is suitable for green and dry mould casting of aluminium, malleable and light grey iron; 1% kaolin/2.0% acacia for brass and bronze alloys; 1% kaolin/3.5% acacia for medium/heavy grey iron; and 1% kaolin/8.0% grade 3 acacia for light steel. Permeability, hardness and shatter index values are suitable for above range of applications and improved over moulds bonded with plain grade 3 acacia.

Green/dry compressive strength in Table 3 varied from 60/390KN\m2 at 1% acacia/1%kaolin to 120/502KN\m2 at 8% grade 4 acacia/1% kaolin. Earlier work by Ademoh and Abdullahi [8] using plain grade 4 acacia as binder, 9% binder gave 53/298KN\m^2 green/dry strength as compared with above result showed that 1% kaolin addition to grade 4 acacia bonded mould increased the green/dry strength by about 130%/66%. A consideration of the standard in Table 1 shows that a mixture of 1% kaolin/1.0% grade 4 acacia is suitable for green/dry casting aluminium, brass/bronze and light/grey/malleable iron; 1% kaolin clay/2% grade 4 acacia for dry casting of medium/heavy grey iron and light steel, 1% kaolin clay/3.5% grade 4 acacia for green/dry casting of medium/heavy grey iron and light steel; and 1% kaolin/8.0% grade 4 acacia for green casting of heavy steel with extra vents for adequate permeability. The hardness and shatter index for the tested moulds showed improvement over those bonded with plain grade 4 acacia and suitable for above specified castings. A cross comparison of result for composites of grade 4 acacia/kaolin with grade 3 acacia/kaolin showed that grade 4 acacia/kaolin is a better binder than grade 4 acacia/kaolin mix. Kaolin addition raised the materials suitability for binding non-ferrous and grey iron moulds to that of steel casting moulds.

The moisture content in Table 4 and 5 followed same pattern of decrease as that in Table 2 and 3 due to same reason. In Table 4, the green/dry strength increased from 36/334 KN\m^2 at 3% grade 3 acacia/0.5%kaolin clay to 54/364KN\m^2 at 3% acacia/3% kaolin clay. This compared with plain grade 3 acacia binder [7], 6% grade 3 acacia

Table 2: Measured Foundry Properties of River Niger Sand bonded with varying weights of Nigerian Gum Arabic Grade 3, 1% Kaolin and 3% water

Sample: Grade 3 mixed with Kaolin	A	B	C	D	E	F
Gum Arabic Content (%)	1.0	2.0	3.5	5.0	6.5	8.0
Moisture Content (%)	2.5	2.4	2.2	2.2	2.1	2.0
Green Strength (KN\m2)	52.0	56.0	72.0	84.0	94.0	102.0
Dry Strength (KN\m2)	376.0	378.0	380.0	400.0	412.0	436.0
Green Permeability (No)	178.0	161.1	160.0	153.8	150.3	140.4
Green Hardness (No)	55.0	57.0	59.0	62.0	64.0	62.0
Shatter Index (No)	82.0	80.0	73.0	70.0	62.0	58.0

Table 3: Measured Foundry Properties of River Niger Sand bonded with varying weights Nigerian Gum Arabic Grade 4, 1% Kaolin and 3% water

Sample: Grade 4 mixed with Kaolin	A	B	C	D	E	F
Gum Arabic Content (%)	1.0	2.0	3.5	5.0	6.5	8.0
Moisture Content (%)	2.6	2.5	2.4	2.2	2.0	2.0
Green Strength (KN\m2)	60.0	68.0	78.0	88.0	97.0	120.0
Dry Strength (KN\m2)	390.0	407.0	430.0	465.0	488.0	502.0
Green Permeability (No)	154.8	150.6	140.4	131.2	123.5	120.6
Green Hardness (No)	60.0	64.0	68.0	73.0	78.0	87.0
Shatter Index (No)	88.0	83.0	97.0	61.0	48.0	44.0

Table 4: Effect of Variation of Kaolin Clay content on Foundry Properties of Sand bonded with 3% Grade 3 Gum Arabic and 3% water

SAMPLE: 3% of Grade 3 with Varying Kaolin clay	A	B	C	D	E	F
Kaolin Clay Content (%)	0.5	1.0	1.5	2.0	2.5	3.0
Moisture Content (%)	2.7	2.6	2.5	2.4	2.1	2.0
Green Strength (KN\m2)	36.0	40.0	44.0	48.0	50.0	54.0
Dry Strength (KN\m2)	334.0	338.0	344.0	350.0	360.0	364.0
Green Permeability (No)	173.5	177.6	180.1	182.2	190.5	196.5
Green Hardness (No)	47.0	54.0	52.0	53.0	55.0	57.0
Shatter Index (No)	84.0	80.0	77.0	70.0	65.0	60.0

Table 5: Effect of Variation of Kaolin Clay content on Foundry Properties of River Niger Sand bonded with 3% Grade 4 Gum Arabic and 3% water

SAMPLE: 3% of Grade 4 with Varying Kaolin clay	A	B	C	D	E	F
Kaolin Clay Content (%)	0.5	1.0	1.5	2.0	2.5	3.0
Moisture Content (%)	2.6	2.6	2.4	2.2	2.1	2.0
Green Strength (KN\m2)	48.0	50.0	56.0	60.0	67.0	73.0
Dry Strength (KN\m2)	353.0	370.0	381.0	384.0	388.0	389.0
Green Permeability (No)	160.4	155.3	168.2	144.7	136.2	130.8
Green Hardness (No)	49.0	52.0	55.0	59.0	61.0	64.0
Shatter Index (No)	93.0	90.0	85.0	83.0	80.0	71.0

binder gave 62/320KN\m2 green/dry strength shows that green the strength decreased by 12% while dry strength increased by 13% over plain acacia bonded moulds. By the standard in Table 1 a mixed binder of 2% kaolin/3.0% Nigerian grade 3 acacia exudates is suitable for green/dry casting of malleable iron; 2.5% kaolin with 3.0% grade 3 acacia for aluminium and light grey iron; 3.0% kaolin with 3.0% grade 3 acacia for only green mould casting of brass, bronze medium and heavy grey iron. Permeability, hardness and shatter index as in Table 4 improved over plain gum Arabic bonded specimens and are suitable for above castings.

In Table 5 the green/dry compressive strength varied from 48/353KN\m2 at 3% acacia/0.5% kaolin to 73/3897KN\m2 at 3% grade 4 acacia/3% kaolin. This compared with plain grade 4 acacia binder [8] in which 6% binder gave 39/272KN\m2 green/dry strength showed 3% kaolin addition to 3% grade 4 acacia bonded mould increased the green/dry strength by about 50%/56%. By Table 1 standard a composite of 0.5% kaolin/3.0% grade 4 acacia is suitable for green/dry casting of malleable iron; 1.0% kaolin/3.0% grade 4 acacia for aluminium and light grey iron; 2.0% kaolin/3.0% grade 4 acacia for brass and bronze; and 3.0% kaolin/3.0% grade 4 acacia for medium/heavy iron and green mould casting of light steel. Permeability, hardness and shatter index are higher than plain grade 4 gum Arabic bonded specimens [8]. They are suitable for the specified castings. The composite of 3% grade 4 acacia/kaolin binds better than that of 3% grade 3 acacia/kaolin. Fixing kaolin at 1% with varied composition of gum Arabic gave higher benefits than otherwise.

CONCLUSIONS

The study showed that kaolin clay addition to each of grades 3 and 4 Nigerian gum Arabic greatly enhanced its mechanical binding properties. Based on this finding and abundance of the materials in Nigeria good binders can henceforth be produced for the country's foundries to replace exorbitant imported ones. Other foundries world over can also source for alternative high quality binders from the findings of this research.

APPENDIX: GRAPHICAL PLOTS OF THE EXPERIMENTAL RESULT

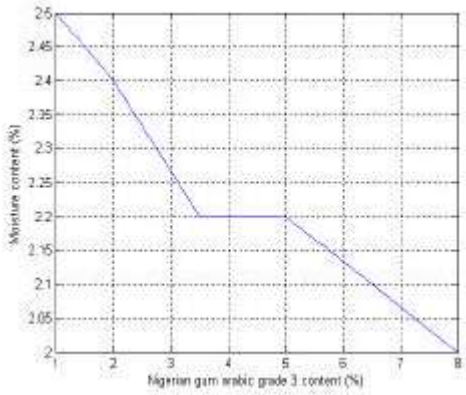

Fig. 1: Moisture content (%)) of Foundry sand moulds bonded with varying percentages of Powdered Gum Arabic grade 3 mixed with 1% of Kaolin Clay and 3% water

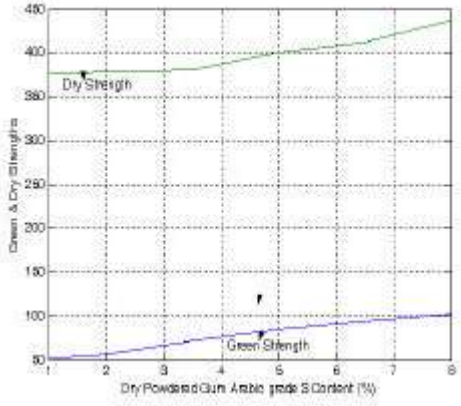

Fig. 2: Green and Dry Compressive strengths (KN\m^2) of Foundry sand moulds bonded with varying percentages of Powdered Gum Arabic grade 1 mixed with 1% of Kaolin Clay and 3% water

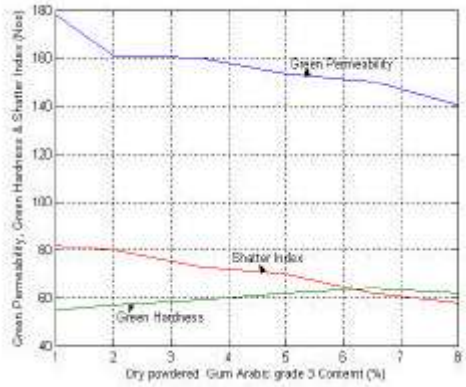

Fig. 3: Green Permeability No, Green Hardness No and Shatter index No of Foundry sand moulds bonded with varying percentages Gum Arabic grade 1 mixed with 1% of Kaolin Clay and 3% water

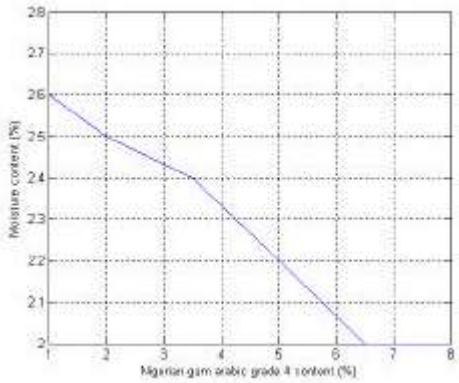

Fig. 4: Moisture content (%)of Foundry sand moulds bonded with varying percentages of Powdered Gum Arabic grade 4 mixed with 1% of Kaolin Clay and 3% water

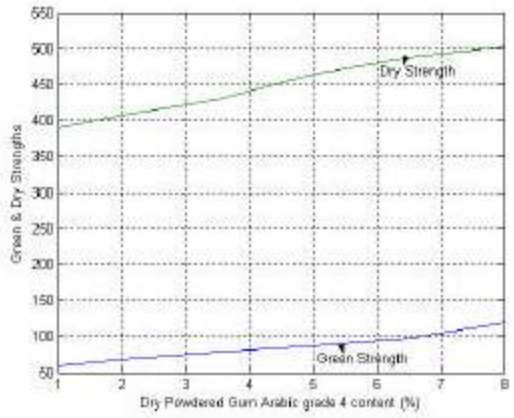

Fig. 5: Green and Dry Compressive strengths (KN\m^2) of Foundry sand moulds bonded with varying percentages of Powdered Gum Arabic grade 4 mixed with 1% of Kaolin Clay and 3% water

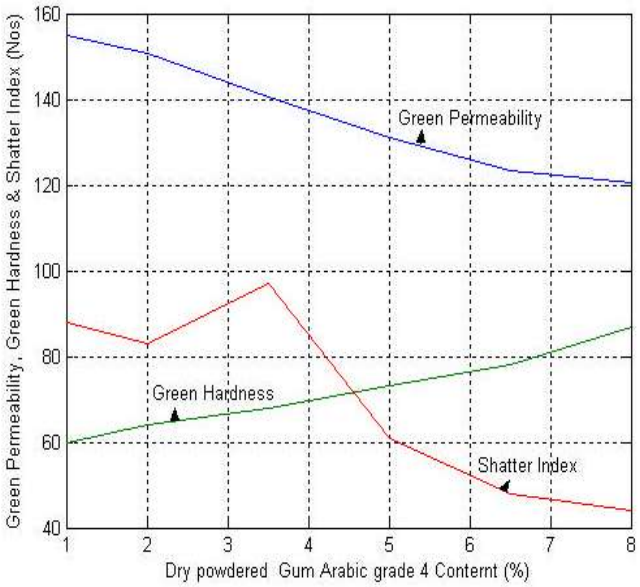

Fig. 6: Green Permeability No, Green Hardness No and Shatter index No of Foundry sand moulds bonded with varying percentages of Gum Arabic grade 4 mixed with 1% of Kaolin Clay and 3% water

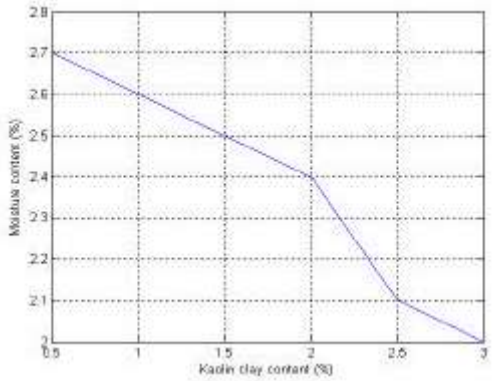

Fig. 7: Effect of Kaolin Clay Content on the Moisture content (%)of Foundry sand moulds bonded with 3% of Grade 3 Gum Arabic and 3% Water

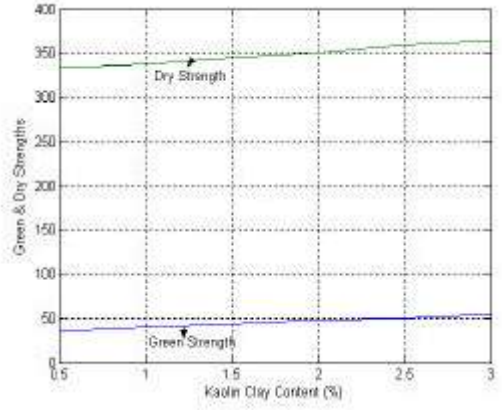

Fig. 8: Effect of Kaolin Clay Content on the Green and Dry Compressive strengths (KN\m^2) of Foundry sand moulds bonded with 3% of Grade 3 Gum Arabic and 3% Water

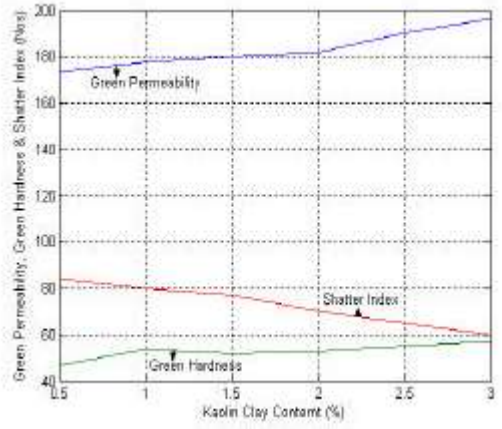

Fig. 9: Effect of Kaolin Clay Content on the Green Permeability No, Green Hardness No and Shatter index No of Foundry sand moulds bonded with 3% of Grade 3 Gum Arabic and 3% Water

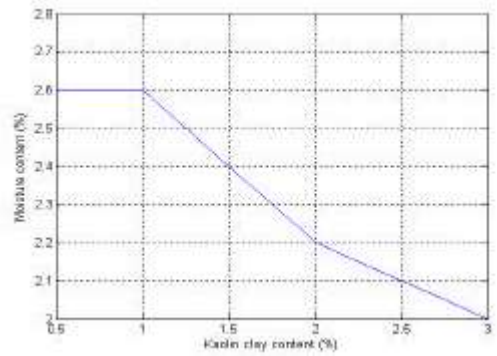

Fig. 10: Effect of Kaolin Clay Content on the Moisture content (%) of Foundry sand moulds bonded with 3% of Grade 4 Gum Arabic and 3% Water

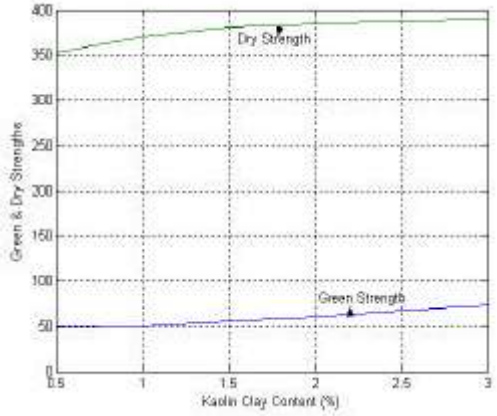

Fig. 11: Effect of Kaolin Clay Content on the Green and Dry Compressive strengths (KN\m^2) of Foundry sand moulds bonded with 3% of Grade 4 Gum Arabic and 3% Water

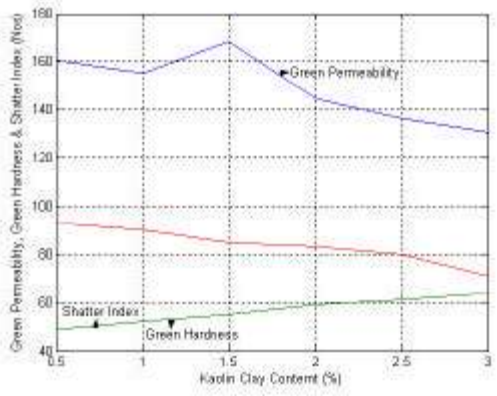

Fig. 12: Effect of Kaolin Clay Content on the Green Permeability No, Green Hardness No and Shatter index No of Foundry sand moulds bonded with 3% of Grade 4 Gum Arabic and 3% Water

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