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Foundry properties of moulding sand bonded with grades 3 and 4 Nigerian gum Arabic admixed with bentonite clay

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Abstract

Suitability of composites made of grades 3 and 4 Nigerian gum Arabic exudates mixed with bentonite clay as mould sand binder was investigated. The research involved foundry property analyses of mould specimens bonded with admixtures of each of grades 3 and 4 Nigerian gum Arabic and bentonite clay using foundry laboratory test equipment that included universal strength testing machine, permeability meter, hardness tester, shatter index machine and quick moisture teller in a well equipped foundry laboratory/workshop. The result when compared to foundry standard showed that combinations of 8% grade 3 gum Arabic with 1% bentonite was suitable as binder for sand moulds for casting light steel, grey iron and non-ferrous alloys. A composite of 8% grade 4 gum Arabic and 1% bentonite clay was suitable for binding green and dry sand moulds for grey iron and non-ferrous alloy castings. Bentonite addition to grades 3 and 4 gum Arabic bonded moulds generally improved the foundry properties of mould sand. Green strength was improved over the strength of mould bonded with plain gum Arabic by about 12.5%. Dry compressive strength was improved over strength of plain gum Arabic bonded sand moulds 20%. Moderate improvements of about 8% were also observed in permeability numbers of the composite bonded moulds.

Key words: Gum Arabic, bentonite clay, foundry, binder.

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1. Introduction

Nigeria produces four different grades of gum Arabic exudates in commercial quantities. These are the grade 1 (acacia Senegal), grade 2 (acacia Seyal), grade 3 (combretum) and grade 4 (neutral) [1]. Gum Arabic exudates is natural resin that contains arabin; semi solidified sticky fluid oozing from incision made on bark of trees called acacia species [2]. Fennema [3] described it as the complex variable compound mixture of arabino galactan oligosaccharide, polysaccharide glycoprotein that is less consistent than other hydrocolloids. Gum Arabic has not been put to serious industrial use in Nigeria, ranked as the second largest producer after Sudan. Based on the its extensive use in pharmaceutical, printing, beverage, textile and confectionary industries in importer countries [4]; gum Arabic has the potential of being used to solve the dependence of Nigerian foundries on processed foundry binders. Ademoh and Abdullahi [5] worked with grade 1 Nigerian gum Arabic as mould sand binder and found the material with 2-3% moisture suitable for non-ferrous, malleable and grey iron. Binders made with 6-9% of grade 3 gum Arabic and 3% moisture was suitable for sand mould for casting nonferrous and grey iron casting [6]. Binder composition of 11.5-13% grade 4 gum Arabic was found suitable for sand moulds for light steel casting [7]. Bentonite clay is of American origin and is used to mould foundry sand as colloidal clay binding agent [8]. It is one of the best sand binders due its good properties. It has Base Exchange value of 100, particle size diameter of less than one micron and is mainly composed of montmorillonite with refractoriness of 1,300°C [9]. Bentonite clay deposit is reported in some states of Nigeria [10]. Local availability of both bentonite clay and gum Arabic in Nigeria cheapens the use as combined binder. A careful blend of exudates and the clay as mixed organic/mineral foundry sand binder could give a high quality synthetic sand that is very suitable for selected casting applications.

This proposal constitutes the main aim of this research project. The objectives are to separately mix different compositions by weight of the exudates of grades 3

and 4 Nigerian acacia species with specified quantities of refined bentonite clay as composite binder for moulding sand specimen; to analyze the mould specimens for foundry properties like green/dry compressive strength; permeability and hardness; shatter index and moisture content and to compare result to foundry standard data in table 1 to ascertain its level of suitability. The table shows standards that are most basic and vital of all foundry mould sand properties as the values always give appropriate information of other essential properties [8]. The study targets determination of these important properties to ascertain suitability of the mixed binder. The significance of the research lies in the fact that foundries that relied on corrosive binders can source from blends of gum Arabic and bentonite clay for easier production.

2. Materials and Methods

Foundry properties of moulded sand bonded with each of grades 3 and 4 Nigerian gum Arabic exudate admixed with bentonite clay were experimentally measured on standard test specimen and equipment in a standard foundry laboratory. The properties measured included the moisture content; green and dry compressive strength, hardness, permeability and shatter index.

2.1. Research Materials and equipment: River Niger sand with 0.03% clay and of BS standard sieve size 40-72 mesh was used as base sand to produce mould specimens. The sand was collected from base of River Niger behind Ajaokuta Steel Complex within a kilometer range at five different spots after quartering down. Sand was mixed thoroughly and a representative sample taken. Each of grades 3 and 4 Nigerian gum Arabic was purchased in quantities of 5 Kg in gum Arabic market in Gombe, Nigeria. The experimental test equipment included laboratory sand mixer, sand rammer, universal strength test machine, permeability meter, hardness tester, drying oven, shatter machine and quick moisture teller.

2.2. Specimen Preparation and Test Procedure: The sand specimen was washed and oven dried at 110^0c to remove free water. A quantity was sieved with BS to obtain required grains of 40-70 mesh. The gum Arabic was milled into powder to obtain average grain size of 20-40 mesh to enable even particle distribution within mixes. The sand grains and quantities of each of grades 3 and 4 of Nigerian gum Arabic exudates with defined quantity of bentonite clay as the composite binder were thoroughly mixed in a roller mixer for 10 minutes and then moulded into specimens using a standard sand rammer that delivered a compaction blow of 6.5 Kg from a height of 50.4mm (2inches). Each specimen after three compaction blows measured 50.4mm (2inches) in diameter by 50.4mm (2inches) in height and was of an average weight of 130g [11]. Specimens were classified into those for green test and for dry test. The specimens, shaped as in figure 1 were then subjected to above listed foundry tests. A speedy moisture teller was used to quickly test and read the moisture content of test specimens. The instantaneous moisture content (in percentages) was read from instrument gauge.

For permeability test, standard air pressure of 9.8×10^2N\m^2 was passed through cylindrical specimen tube containing standard moulded green sand specimen placed in parameter of the permeability equipment and the time taken for 2000cm^3 of air to pass through specimen was read to determine permeability. The green and dry compressive strength tests were carried out with the universal strength machine. Steadily increasing compressive force was applied on test specimen until failure occurred and strength in KN\m^2 read instantaneously. The dry compressive specimens were first dried at 110°C for about one hour and then cooled down to room temperature before tests. A shatter test apparatus was used to measure shatter index as usual. The tests were in accordance with the American Foundry Men Society standards (AFS, 1989) as adopted in a research by Ademoh and Abdullahi [7].

3. Results and discussion

The result of the research is as presented in tables 2-5 and in graphical forms in appendix A. Tables 2 and 3 present the result of analyses with bentonite clay fixed at 1% and acacia content of the mix varied from 1%-8% while tables 4 and 5 present that of analyses with bentonite clay varied from 0.5-3% and gum Arabic content of the composite mix fixed at 3%. Moisture test determined dampness of mould specimen; green and dry compressive strength measured ability of sand mould to withstand pressure of molten metal during casting. Green hardness measured resistance of sand mould against abrasion. Green permeability measured ease of escape of evolved gas from mould to forestall defects. Shatter index measured collapsibility of sand mould after casting.

Result of property analyses of mould specimens bonded with 1-8% grade 3 Nigerian acacia exudates mixed with 1% bentonite clay is as presented in table 2. It shows that measured moisture decreased from 2.5% to 2% over as gum Arabic content of mixed binder increased from 1.0% to 8%. Moisture decreased with increasing binder because additional gum Arabic binder needed extra moisture to partially dissolve and wet the grains for effective bonding with sand. Measured green/dry compressive strength varied from 42/316KN\m^2 at 1% gum Arabic mixed with 1% bentonite clay to 94/378KN\m^2 at 8% gum Arabic combined with 1% bentonite clay. The result when compared with work of Ademoh and Abdullahi [7], 9% plain grade 3 gum Arabic bonded sand mould gave green/dry strength of 69/346 KN\m^2 . This shows 1% added bentonite increased green and dry strength by 30% and 10% respectively. In comparison with the foundry standard in table 1 a composite of 1% bentonite clay with 2.0% grade 3 gum Arabic is suitable for green/dry moulds for casting aluminium, brass\bronze, light and malleable iron. Composite of 1% bentonite clay with 5.0-6.5%% grade 3 gum Arabic is suitable green and dry sand moulds for casting medium/heavy grey iron. Mixed binders made up of 1% bentonite clay with 6.5-8.0% grade 3 gum Arabic is suitable for making only green sand moulds for casting light steel.

Fig. 1. A collection of some of the cylindrical test specimens

Table 1: Satisfactory property ranges for sand casting

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 & 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

Table 2: Measured foundry property of mould sand bonded with Nigerian gum Arabic grade 3, 1% bentonite clay and 3% water

SAMPLE: Grade 3 mixed with bentonite	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	2.4	2.2	2.1	2.0
Green Strength (KN\m^2)	42.0	64.0	72.0	78.0	90.0	94.0
Dry Strength (KN\m^2)	316.0	320.0	330.0	354.0	366.0	378.0
Green Permeability (No)	160.2	152.6	146.3	140.3	137.5	130.8
Green Hardness (No)	48.0	64.0	62.0	60.0	60.0	52.0
Shatter Index (No)	68.0	64.0	62.0	59.0	58.0	51.0

Table 3: Measured foundry property of mould sand bonded with Nigerian gum Arabic grade 4, 1% bentonite clay and 3% water

SAMPLE: Grade 4 mixed with bentonite	A	B	C	D	E	F
Gum Arabic Content (%)	1.0	2.0	3.5	5.0	6.5	8.0
Moisture Content (%)	2.8	2.7	2.5	2.3	2.2	2.2
Green Strength (KN\m^2)	52.0	60.0	68.0	71.0	75.0	81.0
Dry Strength (KN\m^2)	350.0	368.0	372.0	391.0	402.0	434.0
Green Permeability (No)	150.2	138.1	131.3	124.0	120.6	119.6
Green Hardness (No)	65.0	68.0	73.0	78.0	80.0	84.0
Shatter Index (No)	70.0	71.0	62.0	60.0	58.0	55.0

Table 4: Effect of variation of bentonite clay on foundry properties of mould sand bonded with 3% grade 3 acacia and 3% water

SAMPLE: 3% of Grade 3 with Varying bentonite	A	B	C	D	E	F
Bentonite Clay Content (%)	0.5	1.0	1.5	2.0	2.5	3.0
Moisture Content (%)	2.6	2.5	2.2	2.2	2.1	2.0
Green Strength (KN\m^2)	32.0	34.0	36.0	36.0	38.0	40.0
Dry Strength (KN\m^2)	298.0	300.0	306.0	312.0	318.0	322.0
Green Permeability (No)	188.0	179.2	170.6	164.0	160.6	156.5
Green Hardness (No)	54.0	56.0	58.0	59.0	60.0	62.0
Shatter Index (No)	85.0	80.0	73.0	70.0	68.0	65.0

Table 5: Effect of variation of bentonite clay on foundry properties of moulding sand bonded with 3% grade 4 acacia and 3% water.

SAMPLE: 3% of Grade 4 with Varying bentonite	A	B	C	D	E	F
Bentonite Clay Content (%)	0.5	1.0	1.5	2.0	2.5	3.0
Moisture Content (%)	2.4	2.4	2.2	2.1	2.0	1.9
Green Strength (KN\m^2)	47.0	54.0	59.0	62.0	66.0	70.0
Dry Strength (KN\m^2)	345.0	350.0	357.0	360.0	364.0	372.0
Green Permeability (No)	190.2	198.5	182.1	170.0	160.0	180.0
Green Hardness (No)	60.0	63.0	67.0	68.0	74.0	77.0
Shatter Index (No)	90.0	81.0	74.0	64.0	62.0	60.0

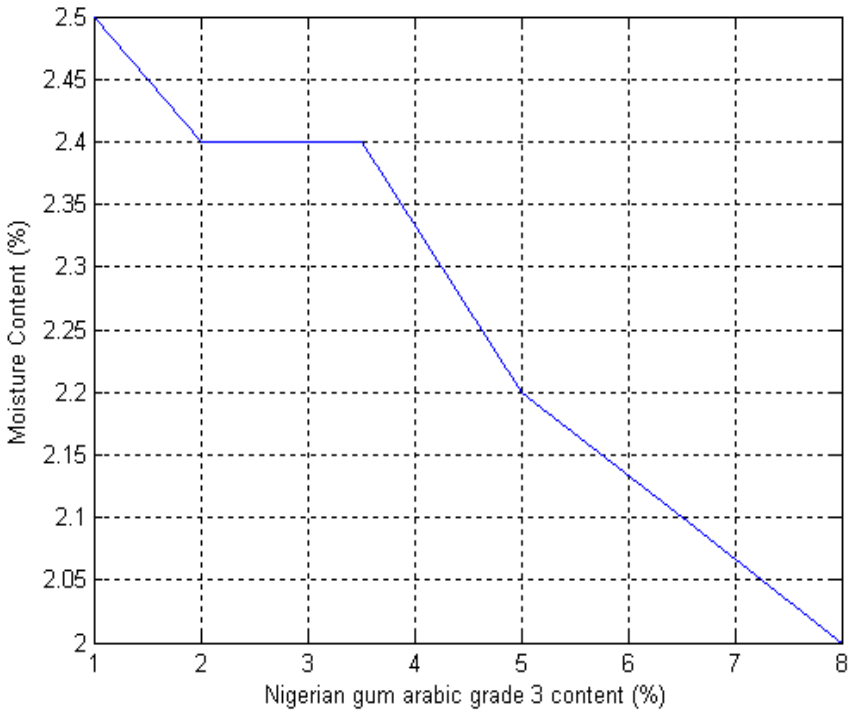

Fig. 2. Moisture conte4nt (%) of foundry sand moulds bonded with varying percentages of powdered Nigerian gum Arabic grade 3 mixed with 1% of bentonite clay and 3% water.

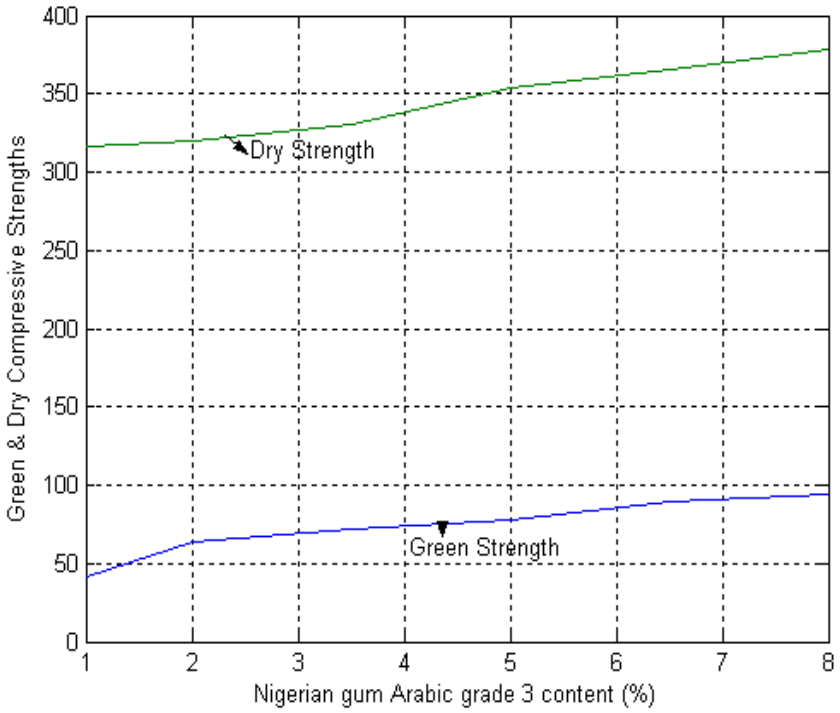

Fig. 3. Green and dry compressive strengths (KN\m^2) of foundry sand moulds bonded with varying percentages of powdered Nigerian gum Arabic grade 3 mixed with 1% bentonite clay and 3% water.

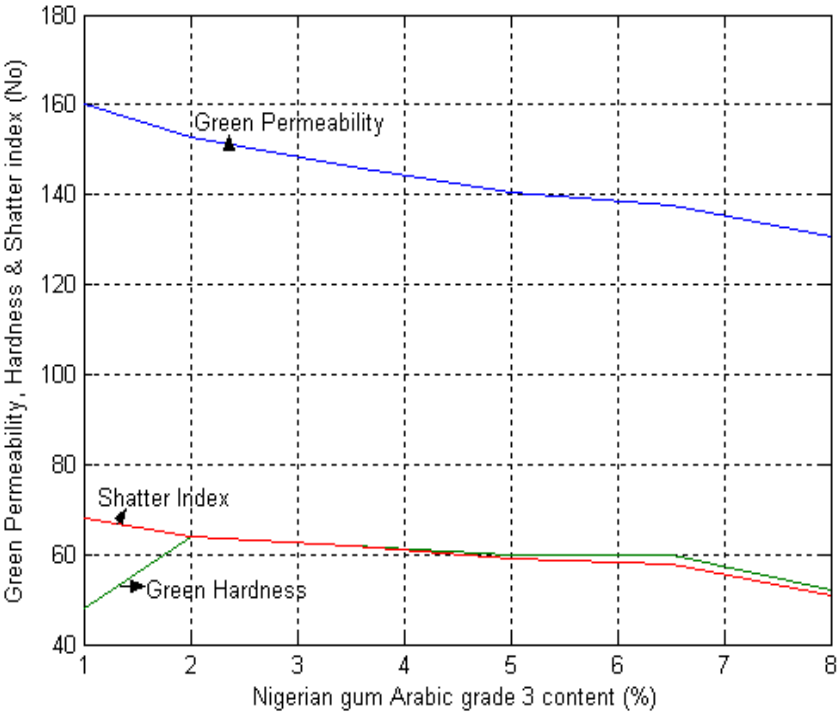

Fig. 4. Green permeability, green hardness and shatter index Nos of foundry sand moulds bonded with varying percentages of powdered Nigerian gum Arabic grade 3 mixed with 1% of bentonite clay and 3% water.

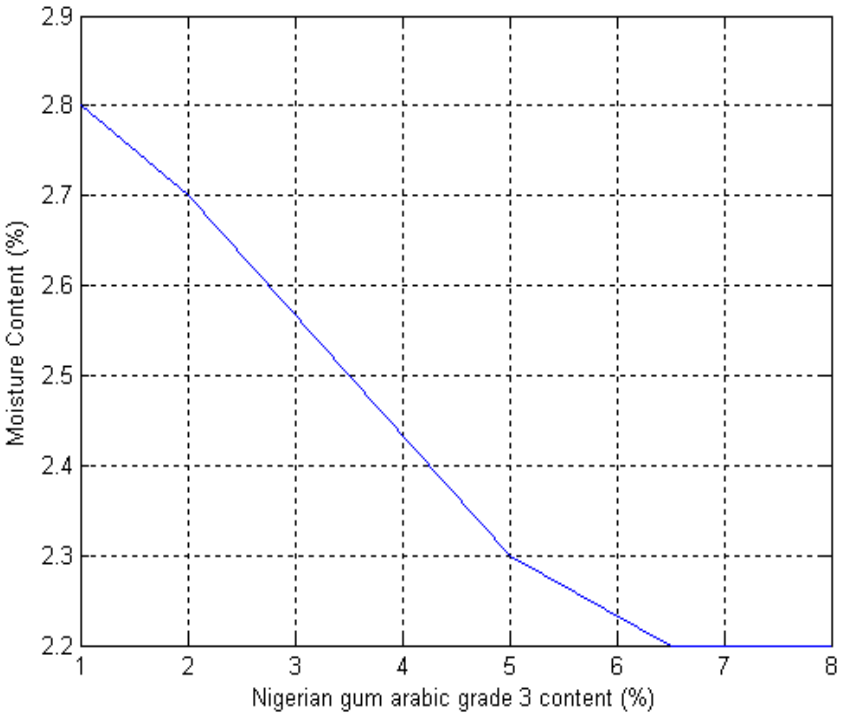

Fig. 5. Moisture content (%) of foundry sand moulds bonded with varying percentages of powdered Nigerian gum Arabic grade 4 mixed with 1% bentonite clay and 3% water.

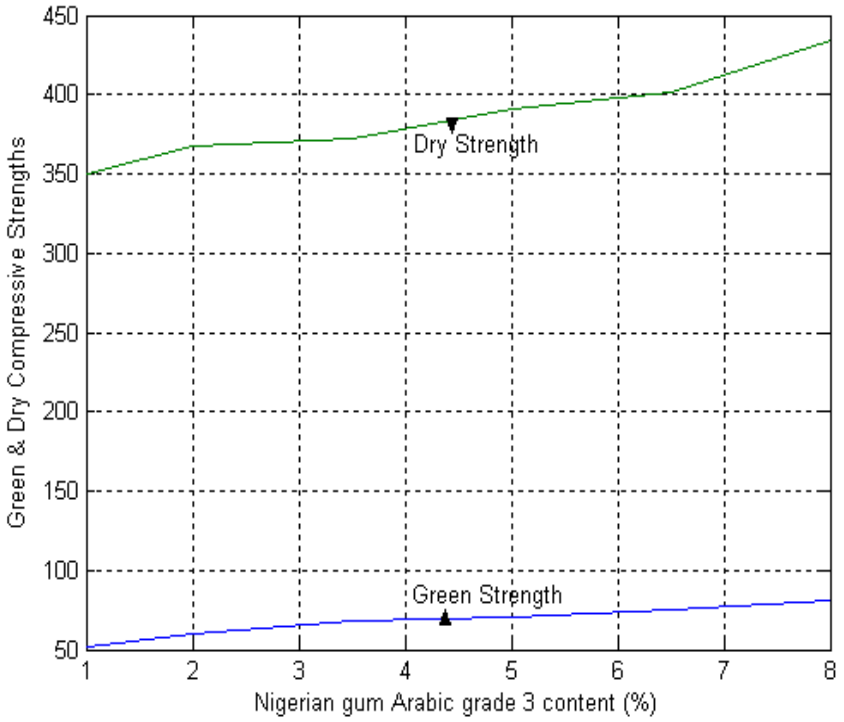

Fig. 6. Green and dry compressive strengths (KN\m^2) of foundry sand moulds bonded with varying percentages of Nigerian gum Arabic grade 4 mixed with 1% bentonite clay and 3% water.

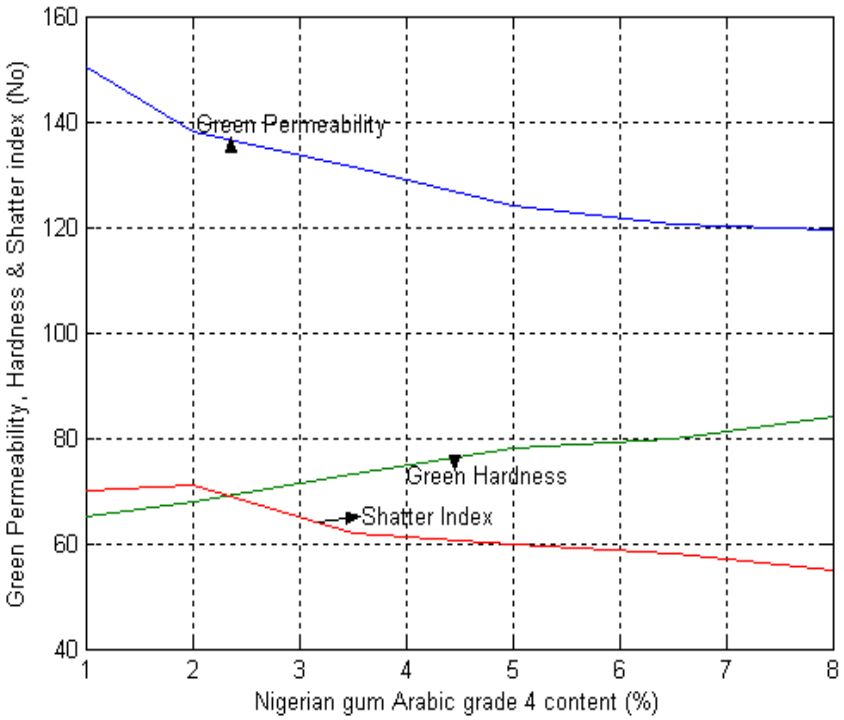

Fig. 7. Green permeability, green hardness and Shatter index Nos of foundry sand moulds bonded with varying percentages of powdered Nigerian gum Arabic grade 4 mixed with 1% bentonite clay and 3% water.

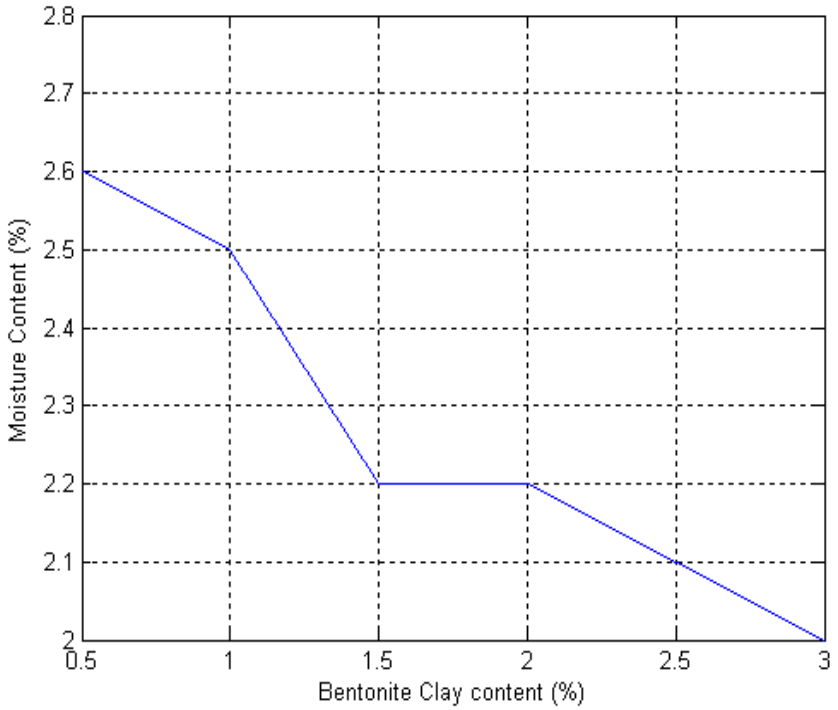

Fig. 8. Effect of bentonite clay content on the moisture content (%) of foundry sand moulds bonded with 3% of grade 3 Nigerian gum Arabic and 3% water.

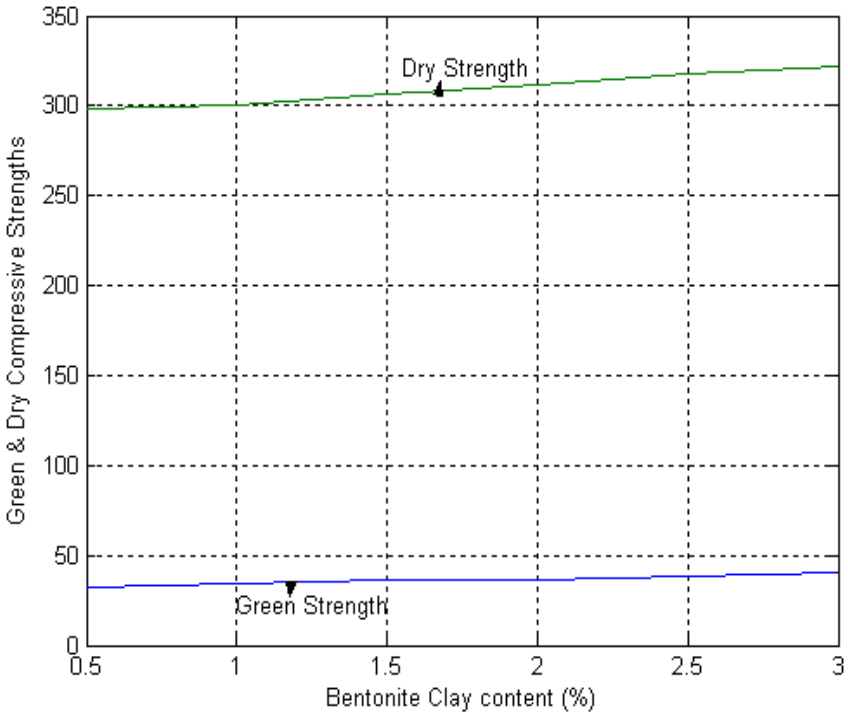

Fig. 9. Effect of bentonite clay content on the green and dry compressive strengths (KN\m^2) of foundry sand moulds bonded with 3% of grade 3 Nigerian gum Arabic and 3% Water.

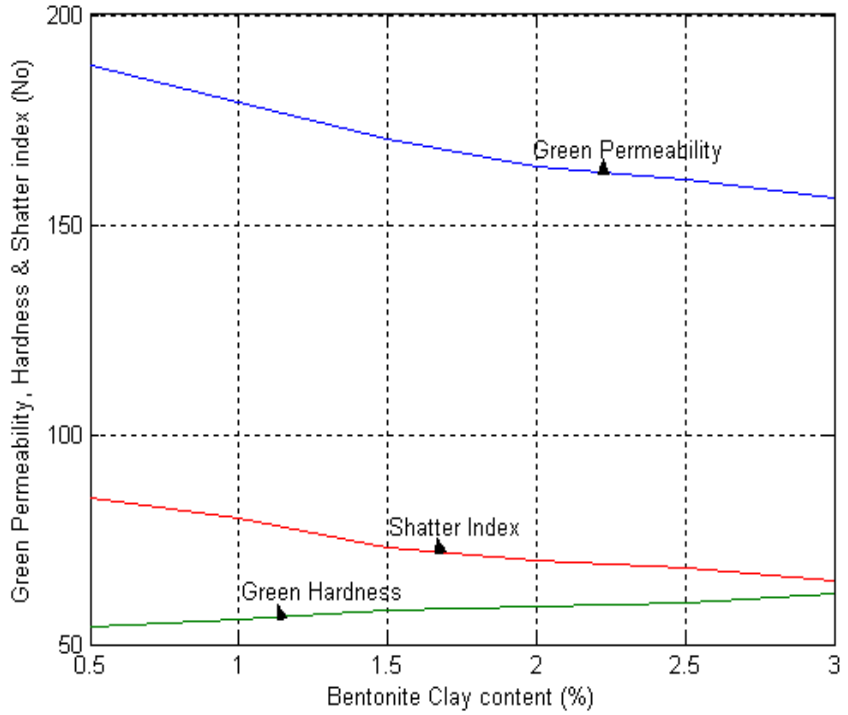

Fig. 10. Effect of bentonite clay content on the green permeability No, green hardness No and shatter index No of foundry sand moulds bonded with 3% grade 3 Nigerian gum Arabic and 3% water.

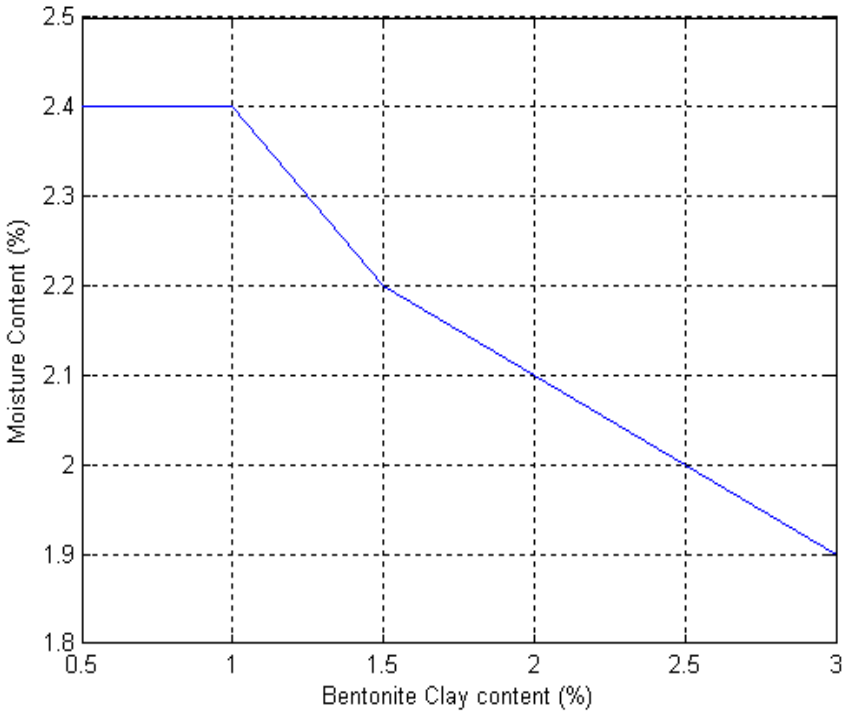

Fig. 11. Effect of bentonite clay content on the moisture content (%) of foundry sand moulds bonded with 3% of grade 4 Nigerian gum Arabic and 3% water.

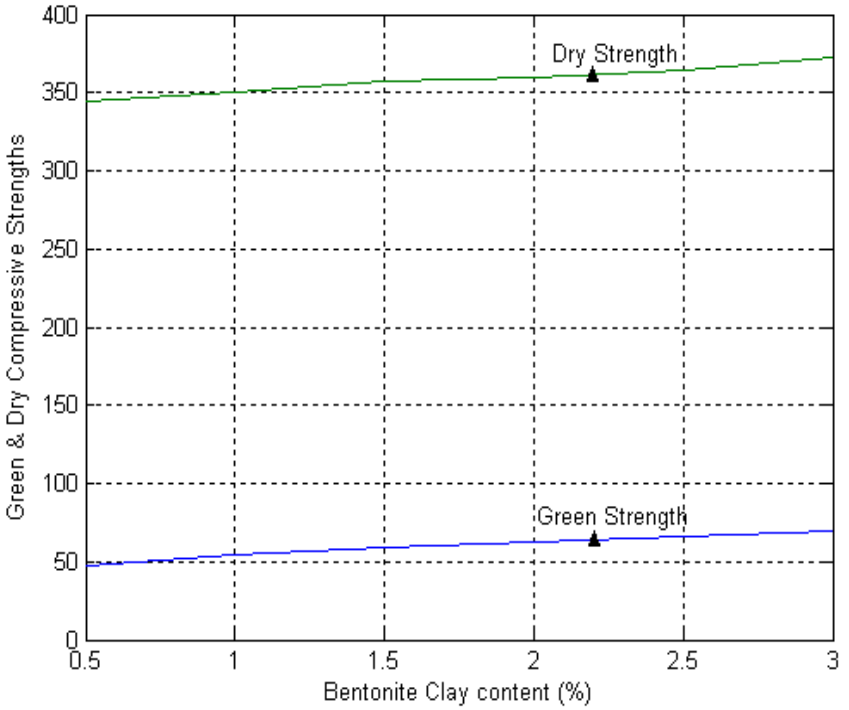

Fig. 12. Effect of bentonite clay content on the green and dry compressive strengths (KN\m^2) of foundry sand moulds bonded with 3% of grade 4 Nigerian gum Arabic and 3% water

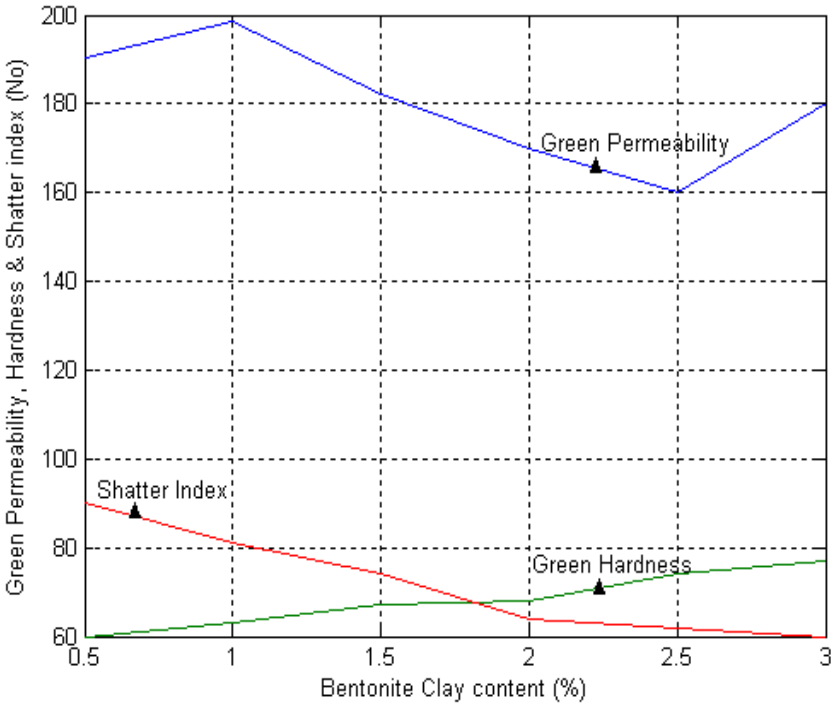

Fig. 13. Effect of bentonite clay content on the green permeability No, green hardness No and shatter index No of foundry sand moulds bonded with 3% grade 3 Nigerian gum Arabic.

The permeability, hardness and shatter index results in table 2 compared to the foundry standard in table 1 shows that the values are all suitable for applications defined above. In table 3, green and dry compressive strength varied from 52KN\m^2 and 350KN\m^2 respectively for moulds bonded with mixed binder made of 1% gum Arabic and 1% bentonite clay to 81 KN\m^2 and 434 KN\m^2 for sand moulds bonded with 8% grade 4 gum Arabic mixed with 1% bentonite clay. Ademoh and Abdullahi [7] worked with 9% plain grade 4 gum Arabic binder that gave 79 KN\m^2 green compressive strength and 387KN\m^2 dry strength; showing that 1% bentonite addition to grade 4 gum Arabic bonded sand mould increased both green strength and dry compressive strength by about 12.5%. When compared with foundry standard in table 1 composites of 1% bentonite with 1% grade 4 gum Arabic are suitable binders for green/dry moulds for casting aluminium, malleable/light grey iron. Composites of 1% bentonite and 2% grade 4 gum arabic for brass and bronze castings. Composite binders of 1% bentonite with 5-6.5% grade 4 gum Arabic is suitable for binding green and dry sand moulds for casting medium and heavy grey iron. Mixed binders made of 1% bentonite clay with 6.5-8% grade 4 gum Arabic is suitable for green/dry mould for casting steel. Green permeability, hardness and shatter index presented in the table when compared with foundry standard in table 1 showed that all the values therein are suitable for the above specified range of alloy castings. A cross comparison of the result shows that grade 4 gum Arabic with bentonite clay gave stronger bonds than composite binders made with grade 3 gum Arabic and bentonite clay by average of about 16.5% for dry moulds. Measured moisture content in tables 3 and 4 followed same pattern of decrease as explained above. In table 3, measured green/dry strength varied from 32 KN\m^2 and 298 KN\m^2 respectively for moulds bonded with composites of 3% grade 3 gum Arabic and 0.5%bentonite to 40 KN\m^2 and 322KN\m^2 for mould bonded with 3% gum Arabic 3%bentonite clay. This compared with the grade 3 gum Arabic binder where moulds bonded with 6% plain gum Arabic gave 36 KN\m^2 and 268KN\m^2 green and dry compressive strength respectively. This shows green and dry strength increased by about 12.5% and 20%respectively. In comparison with foundry standard in table 1 composites made of 1% bentonite with 3.0% grade 3 gum Arabic is suitable for binding dry mould for casting aluminium, brass/bronze, light grey/malleable iron but unsuitable for binding green mould for casting same alloys. Permeability, hardness and shatter index in table 4 show the values are suitable for above specified of applications. In table 5 the green and dry compressive strength of moulds bonded with 3% grade 4 gum Arabic and 0.5% bentonite clay varied from 47 KN\m^2 and 345 KN\m^2 respectively to 70 KN\m^2 and 372KN\m^2 for sand moulds bonded with 3% grade 4 gum Arabic 3% bentonite clay. This compared with 6% plain grade 4 gum Arabic bonded sand mould that gave green and dry compressive strengths of 70 KN\m^2 and 360 KN\m^2 shows that 3% bentonite clay addition to 3% grade 4 gum Arabic had no effect on the green strength but marginally increased dry strength. By foundry standard in table 1 composite binders of made up of 0.5% bentonite clay with 3.0% grade 4 gum Arabic is suitable for binding green and dry sand moulds for casting of malleable iron. Mixed binders made of 1.5% bentonite clay and 3.0% grade 4 gum Arabic for casting aluminium, brass, bronze and light grey iron. Mixed binder of 3.0% bentonite clay with 3.0% grade 4 gum arabic is suitable for green sand moulds for casting medium/heavy grey iron. Permeability, hardness and shatter index numbers in table 5 are suitable for the specified range

of castings. Consequently composites of grade 4 gum Arabic with bentonite clay gave about 3% stronger bonds than those made with grade 3 gum Arabic and bentonite clay.

Conclusion:

The research revealed that presence of bentonite clay in grades 3 and 4 Nigerian gum Arabic bonded sand moulds generally improved permeability, hardness and shatter index. Specifically, green and dry compressive strengths were improved over those of mould bonded plain gum Arabic bonded moulds by about 12.5% and 20% respectively. Thus the bentonite clay and gum Arabic composite binder is recommended for foundries in sand mould applications for selected ferrous and non-ferrous castings. With careful blending of these component materials which are non-toxic and non-corrosive to handling equipment will result to very effective and cheap binder alternatives that improves process economics.

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