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Full Length Research Paper

Effect of kaolin clay addition on mechanical properties of foundry sand moulds bonded with grades 1 and 2 Nigerian acacia species

Nuhu A. Ademoh

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

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The research studied effects of addition of kaolin clay on mechanical properties of sand moulds bonded with grades 1 and 2 Nigerian acacia species exudates. The properties included green and dry compressive strength; permeability and hardness; shatter index and the moisture content. Green and dry sand mould specimens bonded with composite mixtures of kaolin clay and each of grades 1 and 2 acacia exudates were subjected to the property tests using the universal strength and shatter index machines; permeability meter; hardness tester and moisture teller in foundry laboratory of Ajaokuta Steel Company Limited. The result when compared to previous works showed that addition of kaolin clay to acacia exudates improved green and dry strength of sand moulds over those bonded with plain grades 1 and 2 Nigerian acacia by about 25 and 40%; and moulds bonded with plain kaolin clay by about 54 and 11% respectively. It increased green permeability by about 15% and hardness by about 10%. The significance of the research lies in the fact that foundries would be availed with an alternative source of good sand binder from a blend of vegetable and mineral material, reducing total dependence on earth mineral that causes environmental degradation from mining. It would further promote reforestation through acacia tree plantations which would reduce ozone layer depletion and global warming for beneficial global climate change.

Key words: Nigerian acacia species, exudates, kaolin clay, sand, binder.

INTRODUCTION

Kaolinite clay includes siliceous clay composed of Kaolin, also called China clay. It is made up of hydrated alumino-silicate that is also the constituent of many plastic and fire clays .Its particle and refractoriness are up to 20 microns and 1,650°C respectively. It is a major clay when all uses are considered and has been used in foundry as a traditional binder for sand moulds (Griffiths, 1982). Kaolin clay deposit is reported in more than 20 out of the 36 states of Nigeria (Sawyerr, 2008). There is however no processing plant to refine the mineral into concentrates of required quality for foundry use. Acacia species exudate is a natural resin that contains arabin; a semi solidified sticky fluid oozing from incision made on the bark of trees called acacia species (Fennema, 1996). Nigeria produces four grades of acacia species in commercial quantities; which according to Osagie (2002) include grade 1 (acacia Senegal), grade 2 (acacia Seyal), grade 3 (combretum) and grade 4 (neutral). Acacia exudates are the complex variable mixtures of arabino galactan oligosaccharide, polysaccharide glycoprotein (Fennema, 1996). Ademoh and Abdullahi (2008[1]) 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 alloy, malleable and grey iron, but unsuitable for steel casting moulds. Grade 2 acacia found suitable for non-ferrous casting at compositional range of 4.5 - 13% exudates with 3% moisture content (Ademoh and Abdullahi, 2008[2]). Nuhu Ademoh (2008) evaluated the foundry properties of the river Niger sand behind the Ajaokuta Steel Company Limited, Nigeria, and found it suitable for non ferrous casting moulds when bonded with Kaolin or bentonite clay.

Previous works that used composite mould binders of acacia species and other materials include 5 - 10% acacia used as an organic additive in the preparation of nano-composite binders for sand mould obtained by

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

surface modification of colloidal inorganic particles with one or more silanes and a radical (Schmidt et al., 2002). In the patent entitled "mould and method for casting metals and refractory composition for use therein" mixed resins of phenol formaldehyde, urea formaldehyde and acdrylic with gum Arabic are used to bind aluminium containing microsperes of 40% alumina for moulds for ingot, sleeve and board casting (Gough, 1997). Refractory heat-insulating compositions containing hollow alumino-silica microspheres for use in casting moulds are bonded with combinations of phenol-formaldehyde, urea-formaldehyde and acrylic resins, gum, sulphite lye and a carbohydrate or a colloidal oxide (Gough, 1999).

Based on these previous studies this research is designed to admix each of the grades 1 and 2 Nigerian acacia species and kaolin clay as a special binder for moulding sand. This would particularly solve the problem of non-availability of indigenous binders in Nigeria and other developing economies. The objectives are to separately impregnate mould specimens bonded with each of the grades 1 and 2 acacia exudates with quantities of kaolin clay; analyze specimen for mechanical properties including green and dry compressive strength; green permeability and hardness; shatter index and moisture content and compare the result with previous work and foundry standard in table 1.1 (Dietert, 1966; Titov and Stepanov, 1982) to ascertain the effect of kaolin clay addition on the binding properties of Nigerian acacia species grades 1 and 2.

MATERIALS AND METHODS

The research experimentally measured the empirical values of the mechanical properties of mould specimens bonded with separate mixtures grades 1 and 2 Nigerian acacia exudates and quantities of kaolin clay. Properties investigated included the moisture content; green and dry compressive strength; hardness, green permeability and shatter index. They are most essential and therefore most measured in foundry (Dietert, 1966). Titov and Stepanov (1982) showed that their values always give adequate information on other salient properties of good foundry sand and active binder. Umar and Bashir (2007) used some of these properties for the development of an optimum mix of moulding material for casting using Challawa river sand with clay as binder.

River Niger bed sand was used to produce specimens. Sand sample was taken such that shovels full were taken from different points (surface and interior) along 0.5 Km distance of river Niger behind Ajaokuta Steel plant. It was mixed and 500Kg sample taken after quartering down to ensure a true representation of parent material. Sand was washed and oven dried at 110^{0}c to remove free water. The sand lot was weighed and transferred to the mechanical sieve and vibrated for 30 minutes for grain size distribution (Busby and Stancliffe, 1997). A quantity of sieved sand of BS standard grain size 40 - 72 was used to produce mould specimen. The grades1 and 2 acacia exudates were milled to smallest possible grain size to enable even particle distribution.

The sand and each of grades1 and 2 of Nigerian acacia exudates with some kaolin clay were thoroughly mixed in roller mill for 10 minutes before moulding into specimen. Each specimen measured 2inches diameter by 2inches height and weighed about 130 g after ramming with three compaction blows of 6.5Kg from 2inches height (American Foundry men Society, 1989). Specimens were then subjected to above mechanical property tests using quick moisture teller, universal strength, hardness and shatter index test machines and permeability meter in foundry laboratory of Ajaokuta Steel Company Limited, Nigeria.

Small sand sample of a known mass was compressed between prongs of teller and instantaneous reading of moisture content made from the gauge. Steadily increasing compressive force was applied on mould specimen until failure just occurred and green compressive strength (KN/m^2) read instantaneously. Dry compressive specimens were first oven dried at 110^{0}C for an hour and cooled to room temperature before test. Standard air pressure of 9.8 x 10^{2}N/m^2 was passed through the permeability sample tube containing mould sand specimen placed in meter and after 2000 cm^3 of air had passed through it permeability was read. A half-inch diameter ball loaded with spring loads of 330g/175g at hardness reading of 100/50 was applied to test specimen. Hardness was read by pulling instrument slowly across specimen face with sufficient force. Shatter specimen placed in the container of shatter machine was pushed upwards over stripping post until it struck anvil, fell and shattered. Retained sand and over size were measured and then used to compute the shatter index in numbers. Nuhu Ademoh (2008) used these procedures to evaluate foundry properties of river Niger sand behind Ajaokuta Steel Company Limited.

DISCUSSION

The green and dry compressive strength increased from 46/364KN/m^2 at 1% acacia\1% kaolin to 81/460KN/m^2 at 8% acacia\1% kaolin. These compared to 71/349KN/m^2 for green\dry strength with 9% plain grade 1 acacia as binder (Ademoh and Abdullahi, 2008[1]) showed that 1% kaolin clay addition to grade 1 acacia bonded sand

Table 2. Measured foundry properties of sand bonded with varying weights of Nigerian gum Arabic grade 1, 1% kaolin and 3% water.

Properties	Gum Arabic Content (%)					
	1.0	**2.0**	**3.5**	**5.0**	**6.5**	**8.0**
Moisture Content (%)	2.5	2.3	2.2	2.1	2.0	2.0
Green Strength (KN/m^2)	46.0	52.0	61.0	72.0	76.0	81.0
Dry Strength (KN/m^2)	364.0	378.0	386.0	398.0	422.0	460.0
Green Permeability (No)	167.7	156.6	143.5	132.6	130.5	129.6
Green Hardness (No)	50.0	52.0	55.0	60.0	62.0	64.0
Shatter Index (No)	90.0	85.0	72.0	63.0	50.0	46.0

Table 3. Measured foundry properties of sand bonded with varying weights of Nigerian gum Arabic grade 2, 1% kaolin and 3% water.

Properties	Gum arabic content (%)					
	1.0	2.0	3.5	5.0	6.5	8.0
Moisture Content (%)	2.6	2.5	2.3	2.2	2.1	2.0
Green Strength (KN/m^2)	41.0	47.0	56.0	62.0	71.0	75.0
Dry Strength (KN/m^2)	362.0	374.0	383.0	401.0	418.0	434.0
Green Permeability (No)	185.0	171.5	162.9	158.1	156.3	156.0
Green Hardness (No)	55.0	58.0	62.0	65.0	68.0	69.0
Shatter Index (No)	75.0	72.0	70.0	65.0	60.0	57.0

moulds increased green and dry strength by about 13 and 32% respectively. By Table 1 a mixed binder of 1% kaolin and 1.0% grade 1 acacia is suitable for malleable iron moulds; 1% kaolin with 2.0% acacia for aluminium, brass, bronze and light grey iron; 1% kaolin with 5.0% acacia for heavy grey iron and 1% kaolin with 8.0% acacia for light steel. Permeability, hardness and shatter index improved over moulds bonded with acacia grade 1 (Ademoh and Abdullahi, 2008). In comparison with Table 1 these values are suitable for above specified range of uses.

Tables 2 presented the result for specimen bonded with 1 - 8% grade 1 Nigerian acacia exudates mixed with 1% kaolin clay. Moisture content decreased from 2.5% at 1 to 2% at 8% acacia because as more powdered binder was added more water was absorbed to partially dissolve it and wet the clay and sand to create the right bonding reaction environment.

The green and dry compressive strength in table 3 varied from 41/362KN/m^2 at 1% acacia\1%kaolin clay to 75/434KN/m^2 at 8% grade 2\1% kaolin. In an earlier work by Ademoh and Abdullahi (2008[2]) 9% plain grade 2 acacia binder gave 53/298KN/m^2 green/dry strength. In comparison with this shows addition of 1% kaolin clay to grade 2 acacia increased green strength of sand mould by about 40% and dry strength by about 60%. A consideration of the standard in Table 1 shows that the mixed binder of 1% kaolin and 2.0% grade 2 acacia is suitable for green\dry casting of malleable iron; 1% kaolin with 3.5% grade 2 acacia for aluminium, brass, bronze and light grey iron; while 1% kaolin with 8.0% grade 2 is suitable for grey iron and light steel. Permeability, hardness and shatter index improved over those of sand mould bonded with plain grade 2 acacia (Ademoh and Abdullahi 2008[2]). By table 1 the values are suitable for specified uses. A cross comparison of composites of the grade 1 acacia\kaolin to grade 2 acacia\kaolin shows the grade 1 acacia mix is better than grade 2.

The result of this work when compared with that of Nuhu Ademoh (2008) that used plain grades 1 and 2 Nigerian acacia to bind river Niger sand showed that with similar sand grain distribution of adequate refractory, 3% binder made up of kaolin clay and grade 1 acacia raised the green strength of sand moulds by about 63%, dry strength by 12%, permeability by 20% and shatter index by 20% but lowered hardness by 15%. It raised green strength of grade 2 acacia bonded moulds by about 45%, dry strength by 10%, permeability by 25% and shatter index by 40% but lowered hardness by 3%. In comparison with work of Adamu and Bashir (2007) that required 20% clay content to bind Challawa river sand this work is much more economical in binder consumption. Also in comparison with works of Gough (1997), Schmidt et al. (2002) and Gough (1999) that used acacia to support organic resins to bind sand mould this work showed that acacia can be used as main sand binder supported by clay.

Moisture content in Tables 4 and 5 followed same pattern of decrease as that in Tables 4 and 5 due to similar reason. In Table 4, green\dry strength increased from

Table 4. Effect of the variation of kaolin clay on foundry properties of sand bonded with 3% grade 1 gum Arabic and 3% water.

Properties	Kaolin clay Content (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Moisture Content (%)	2.5	2.5	2.3	2.2	2.1	2.0
Green Strength (KN/m^2)	44.0	48.0	52.0	58.0	62.0	76.0
Dry Strength (KN/m^2)	340.0	368.0	377.0	392.0	416.0	427.0
Green Permeability (No)	166.5	164.5	160.8	159.9	157.7	155.0
Green Hardness (No)	48.0	49.0	50.0	51.0	53.0	54.0
Shatter Index (No)	98.0	89.0	86.0	85.0	80.0	77.0

Table 5. Effect of the variation of kaolin clay on foundry properties of sand bonded with 3% grade 2 gum Arabic and 3% water.

Properties	Kaolin clay Content (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Moisture Content (%)	2.4	2.3	2.1	2.1	2.0	2.0
Green Strength (KN/m^2)	36.0	42.0	48.0	50.0	55.0	62.0
Dry Strength (KN/m^2)	324.0	335.0	343.0	354.0	365.0	397.0
Green Permeability (No)	183.3	186.4	187.0	193.5	190.5	198.8
Green Hardness (No)	45.0	53.0	55.0	59.0	59.0	60.0
Shatter Index (No)	79.0	75.0	65.0	62.0	60.0	57.0

44/340KN/m^2 at 3% grade 1 acacia\0.5%kaolin clay to 76/427KN/m^2 at 3% acacia\3% kaolin clay. This compared with plain grade 1 acacia binder in which 6% gave 62/320KN/m^2 green/dry strength implied green/dry strength increased by 14%\30% over plain acacia bonded mould due to kaolin addition. By table 1 a binder of 1% kaolin clay with 3.0% grade 1 acacia is suitable for green\dry mould for malleable iron casting; 1.5% kaolin with 3.0% grade 1 for aluminium and light grey iron; 2.0% kaolin with 3.0% grade 1 for brass and bronze while 3.0% kaolin with 3.0% grade 1 for medium/heavy grey iron and light steel sand moulds. Permeability, hardness and shatter index as in Table 4 showed much improvement over those of plain acacia bonded specimens.

In Table 5, the green\dry compressive strength varied from 36/324KN/m^2 at 3% acacia\0.5% kaolin to 62/397KN/m^2 at 3% grade 2 acacia \3% kaolin. This compared with 6% grade 2 acacia binder which gave 39/272KN/m^2 green\dry strength showed that 3% kaolin addition to 3% grade 2 acacia increased green strength of sand mould by about 60% and dry strength by 53%. By Table 1, composite binders made of 0.5% kaolin with 3.0% grade 2 acacia exudates is suitable for dry moulds for aluminium, brass, bronze, light grey and malleable iron; 2.0% kaolin clay with 3.0% grade 2 acacia is suitable for both green and dry casting moulds for above alloys and 2.0% kaolin clay with 3.0% grade 2 for only green moulds for iron. Green permeability, hardness and shatter index values are higher than those of plain grade 2 bonded moulds and are suitable for above castings. Thus composite of 3% acacia grade 1 with kaolin is better binder than with grade 2. The hydrated and plastic aluminosilicate component of added kaolin clay is responsible for the improvements in binding properties.

RESULTS

The results are as presented in Table 2 - 5. Tables 2 and 3 present the result of analyses with kaolin clay fixed at 1% and acacia in the mix varied from 1 - 8%, Tables 4 and 5 present that with kaolin clay varied from 1 - 6% and acacia fixed at 3%. Moisture test determined degree of dampness of mould. Green and dry compressive strength measured the ability of sand mould to withstand pressure of molten metal during casting. Hardness measured the resistance of mould against abrasion. Permeability measured the porosity of mould and ease of escape of gas from mould. Shatter index measured mould collapsibility.

Conclusions

The research revealed that addition of kaolin clay substantially improved the mechanical properties of sand moulds bonded with the grades 1 and 2 Nigerian acacia species exudates. It increased green and dry strength by about 25 and 40%; 15 and 10% in permeability and shatter index respectively over moulds bonded with plain acacia. Kaolin clay and acacia combination as binder also gave better result than plain kaolin clay bonded moulds as green strength averagely increased by about 54%, dry strength by 11%, permeability by 22.5%, shatter index by 30% and hardness decreased by 9%. The effects of addition of kaolin clay on properties of grades 3 and 4 acacia bonded moulds would be investigated in the next paper and findings would be communicated.

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