

Determination of the Physio-Chemical Properties of Nigerian *Acacia* Species for Foundry Sand Binding Applications

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Abstract: Nigeria produces four grades of *Acacia* species in commercial quantities which are not used for local industrial applications but exported for foreign earnings. The grades 1 and 2 that are preferred by exporter countries are used in the pharmaceutical, confectionary, food, textile and beverage industries. Nigerian foundries use imported materials for binding their synthetic casting sands due to non development of locally available materials like *Acacia* species exudates. This research investigated physical and chemical properties of Nigerian *Acacia* species to determine its viability for binding sand. Standard experimental tests and equipment were used in laboratories of the National Research Institute for Chemical Technology and National Research Institute for Leather Technology, Zaria to determine the melting point, optical rotation, specific gravity, water solubility, PH, moisture/volatile matter, metal/sulphate ion content and macro-structural analyses of each grade of the Nigerian *Acacia* species. In comparison with foundry requirements it satisfies major physiochemical properties desired of good sand binders. The material can be investigated further for mechanical properties as potential high quality sand binder for Nigerian foundries.

Key words: *Acacia* species, physiochemical, properties, foundry and binders

INTRODUCTION

Bonding material is usually a constituent of synthetic foundry sand (Dietert, 1966). Binders are generally grouped as mineral materials, organic binders, inorganic binders or miscellaneous binders based on source and chemical composition (Hirst *et al.*, 1989). *Acacia* species exudate is a natural resin that contains arabin; a semi solidified sticky fluid oozing from incision made on bark of *Acacia* trees. Nigeria produces different grades of exudates and is ranked as second largest world producer after Sudan. She recorded an annual average production of 20,000 tones in 2005 (<http://www.nigeriaembassychina.com/eco/PRODUCE%F%20NIGERIA.htm>, 2007). The trees are used as potent weapon in the fight against land desertification and soil degradation in sahelian belt of the country without industrial uses.

According to Hirst *et al.* (1989) the major *Acacia* species is used for pharmaceutical, confectionary, food, textile and beverage production. From experiences of the uses it is believed that its physical and chemical properties may be compatible with those desired of sand binders in foundry. This would be very helpful to Nigeria where foundries use imported binders as the good ones are not locally available (Okeke and Sadjere, 1991). *Acacia* species (gum Arabic) is considered as the oldest and best known of natural gums traced back to 2650 BC, which is why it is called ancient ingredient of 21st century (Hirst *et al.*, 1989). Ayeni (2000) reported it as the most abundant of all natural *Acacia* exudates in Nigeria. Okatahi (1999) studied the characteristics and reported

that the average minimum and maximum temperatures that make *Acacia* trees thrive are 14°C and 40°C. Ominije (2003) found it useful as admixture in concrete mortar. Gary and Ryan (2002) reported that the trees grow more in Borno, Yobe, Sokoto, and Bauchi states of Nigeria.

Fennema (1996) described *Acacia* species exudates as complex variable compound mixtures of arabino galactan oligosaccharide, polysaccharide and glycoprotein that is less consistent than other hydrocolloids. Depending on source glycan components contain greater proportion L-arabi relative to D-galactose, D-galactose relative to L-arabinose (*Acacia* Senegal). It contains 4-0-methyl-D-glucuronic, less L-rhamnose and unsubstituted D-glucuronic acid containing lower molecular polysaccharide as major component with higher molecular hydroxyproline glycoprotein as minor component. As a mixture it varies significantly with source and the exact molecular structure is uncertain. However an infra red analysis of it by Ominije (2003) confirmed that it composes of polysaccharides. It has a flexible and compact conformation dissolving in water to low viscosity Newtonian fluid but in soluble in organic solvent. It has a low reactivity, an excellent emulsifying, and foam stabilizing adhesive properties and does not interfere with blended product due to its pale colouration, odourless, and tasteless properties (Fennema, 1996).

Nigerian grades of *Acacia* species: Four major commercial grades of gum Arabic are produced in commercial quantities in Nigeria (Osagie, 2002). These are as follows:

- *Acacia* Senegal (hard gum):-This is known as grade 1 and it is sourced mostly from Yobe and Borno states of Nigeria.
- *Acacia* Seyal (friable gum):-It is known as grade 2, sourced mostly from Bauchi and Jigawa states in Nigeria. It has a positive optical rotation.
- Combretum:-It is commercially called grade three, has a negative optical rotation and is sourced from the fourteen producer states of Nigeria.
- Neutral:-It is the fourth variety of gum Arabic. It does not have definite biological name but called neutral grade.

Industrial uses of *Acacia* species: It is used in powdered or oil for suspending sensitizer for hard coating on paper and masking agent in print. It combined with some sensitizer and pigment for print (<http://www.nigeriaembassychina.com/eco/PRODUCE%F%20NIGERIA.htm>, 2007). It is used in melting yarn chip processes to make yarn stronger and can be added to painting formula to fix pigments in fabrics to save cost. Of the gums used in textile none is as vastly used]. It acts as binder for pigments in watercolor and gouache paints and in the aluminum plate process. It is used in Plano graphic offset lithography; is mixed with water paint for brighter colors and is used for the preparation of basic, scented ink and black ink. Manufacturers mix it in injection mould for paraffin removal after production (Fennema, 1996). It is excellent in flavour fixation; is effective emulsifying and demulcenting characteristics. It is used for breaking surface tension inside soda and in witchcraft as better wear resistant option to chalk in protective circles (Hirst *et al.*, 1989). Gum Arabic is used in pharmaceuticals (calamine lotion, syrup and cod liver oil); confectionery (jujube, pastille, caramel, toffees, candies, beverages and cakes); food (buns, dry dietetic food and special food); cosmetic (lotion, cream and emulsion, cake, rouge and facial mask); and adhesive for paper and liquid gum for general office purposes (Fennema, 1996). A 40% aqueous solution was made into mucilage for office uses (<http://www.fiiroing/research.htm>, 2006). This review has not shown foundry use of gum Arabic in Nigeria creating gap that this work intends to fill to solve problem of binders for Nigerian foundries from *Acacia* species.

Desirable properties and attributes of sand binders: It is important to consider the attributes that make a material suitable for sand binding. For optimum performance Dietert (1966) suggested that sand binders should be in concentrated form and not settle out in drums or storage tank and should be in single package that is easy to handle. It should not impair the flowability of sand mixture, make patching easy and should be slow to air dry. Good sand binders should be easy to mix with sand and should lend it to being worked with dry or damp run of mine sand. It should cause minimum of cleaning of mixing equipment, should not stick to walls of mould or core boxes, should not drain to bottom of storage pile of

mixed sand and should lend itself to green strength control. A mould and binding materials should possess good warm strength, be easy to bake, should not be sensitive to atmosphere in oven and should be such that baked moulds and cores will free themselves easily from drier or core plate and should have low moisture absorption properties.

Based on these attributes as enumerated above, the main aim of the research is to evaluate physical and chemical properties of Nigerian *Acacia* species for its characteristics for binding foundry sands. The main objectives are to use well designed experimental techniques to determine physical and chemical properties of the different commercial grades of Nigerian *Acacia* species and analyzing in comparison with the desirable attributes binders to ascertain its usability for foundry applications. The significance of the research lies on the fact that it would open up a new field of investigative enquiry on actual efficacy of each grade of Nigerian gum Arabic for foundry application. This would lead to local source for binders in Nigeria and expanded industrial uses for Nigerian *Acacia* species, demand, economic potential in foreign earning and employment opportunity for Nigerians.

MATERIALS AND METHODS

The study was carried out in the laboratory of the Ajaokuta Steel Company Limited, Ajaokuta, Nigeria. The foundry laboratory and work shop equipment of the foundry of the integrated steel plant were used for the experimental analyses. Ajaokuta Steel Company is the largest integrated steel plant in Africa located along the western flank of the River Niger in Nigeria, West Africa. The Research experiments were carried out between 2007 and 2008.

The research included determination of the melting point, optical rotation, specific gravity, water solubility, PH, moisture/volatile matter, metal/sulphate ion and macro-structural compositions of each grade of Nigerian *Acacia* species. An open market survey was conducted for prices of each grade and compared with Nigerian price of imported binders for economic analysis. The melting point of each Nigerian *Acacia* species was determined at laboratory of National Research Institute for Chemical Technology, Zaria, with Stuart melting point equipment. Destro-rotary polarimeter equipment was used to determine optical rotation of samples of the material. Gas jar method was adopted to determine specific gravity in accordance with BS1377 method. The solubility at 30°C of each grade of gum Arabic was determined using the BS1377 method (Pearson, 1976).

A Kent EIL 7020 PH meter equipped with combined glass electrode was used to measure PH of 1% solution of each *Acacia* species in distilled water. Each gum Arabic was subjected to evaporation at 100°C-104°C in an oven for 30 minutes and reweighed for losses by gravimetric method (Pearson D., 1976). For chemical analysis each specimen of Nigerian *Acacia* species was ashed in

preparation for metal and sulphate ion analysis. 10g of each sample was oven dried at 102°C and later burnt in a crucible to carbonize and ashed at 450-500°C in a muffle furnace for 2 hours. Ash was digested with 1:1 of concentrated HCl and HNO₃ (20ml) till white fumes were evolved. 20cm³ digested ash was added and boiled for 10 minutes and filtered into a 100cm³ flask. The filter paper was rinsed several times and the volume made up to the mark. The solution was transferred into plastic containers for AAS analysis for metal ion. Sulphate (SO₄²⁻) ion was analyzed with HACH DR 2400 water spectrometric method (Pearson, 1976). Macro-examination was done with naked eyes to reveal the major physical features.

RESULTS AND DISCUSSION

The results are compared with standard attributes required of good binders as suggested by Diertert (1966). Grade 4 was most difficult to reduce to powder than other grades. Melting points in figure 1 show that grade 1 has the highest melting temperature followed by grade 2, grade 3 and then grade 4. Melting point averaged 178-210°C. This fell within the range of most organic foundry binders like vegetable drying oil used extensively to bind core. The value is suitable for foundry application as material fluidized at high temperature and held sand together into strongly bonded mould that can withstand casting pressure. Volatile matter is driven off to prevent gas entrapment in castings.

Optical rotation measured angle of diffraction of polarized light through the material as in figure 2. It is used to classify *Acacia* species. The four species have positive optical rotation. Grade 4 has the least rotation followed by grade 1, grade 2 and grade 3 with value more than 200% of other grades. Optical rotation inversely relates to specific gravity and adhesiveness. This means grade 4 should give higher bond strength than grades 1, 2 and 3 in that order. Grades 1 and 4 had a specific gravity of 1.10g/cm³ as in figure 3. Grades 2 and 3 have specific gravities 0.9g/cm³, 0.7g/cm³ respectively. These are high. Specific gravity is directly related to viscosity and adhesive property. Keeping all other factors constant, grades 1 and 4 would likely exhibit similar adhesive properties and give stronger bonds than grades 2 and 3. High specific gravity meant high adhesivity with sand.

The water solubility at 30°C of each Nigerian *Acacia* species was presented in figure 4. It showed the material has high solubility, forming clear solution in water. Gum Arabic is insoluble in organic solvent; water is its main solvent; an important attribute of binders making it versatile in application since main solvent is cheap, readily available and non-chemically based. In respect of cost and chemical hazard, it is more favored to other organic and inorganic binders. The result showed that grades 1 and 4 have equal solubility, followed by grades 3 and 2. Solubility relates directly with reactivity which

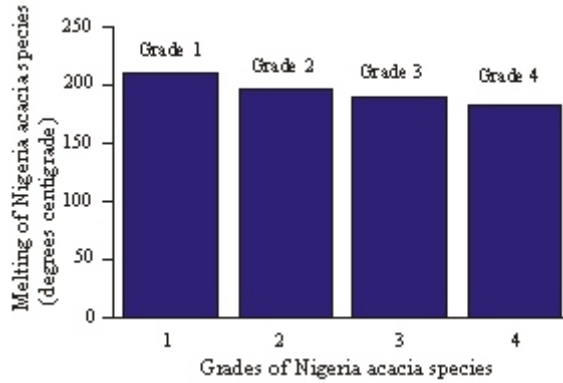


Fig 1: Melting/decomposition points of Nigerian acacia species

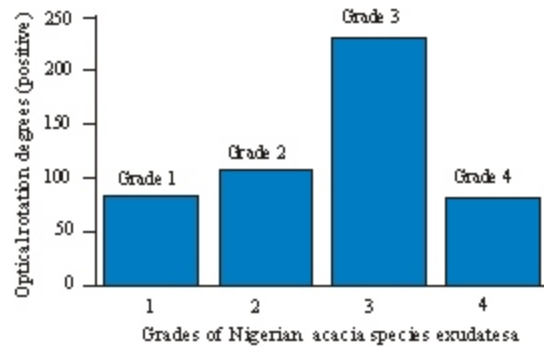


Fig 2: Optical rotation of each grade of Nigerian acacia species

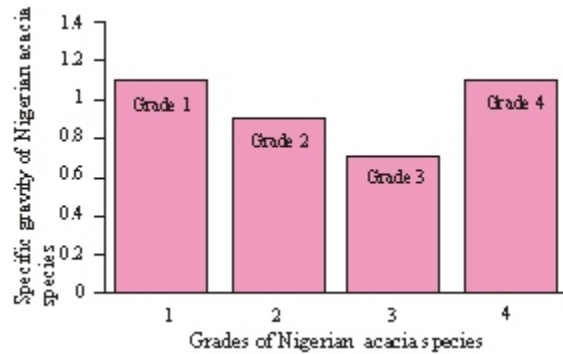


Fig 3: Specific gravity of Nigerian acacia species

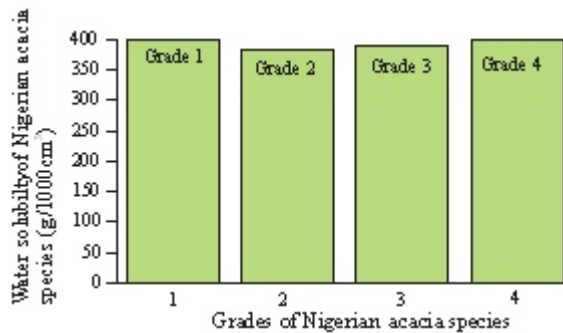


Fig 4: Water solubility of Nigerian acacia species in g/1000M³

Table 1: Chemical Composition of Gum Arabic

Gum Arabic Grade	Compositional Constituents (mg/L from a Solution of 100g/L)									
	K	Na	Mg	Ca	Mn	Cu	Zn	Fe	-SO ₄ ²⁻	
Grade 1	5.11	5.53	2.41	4.76	0.84	0.16	0.09	2.49	4.00	
Grade 2	3.71	3.59	1.42	4.02	0.33	0.16	0.03	1.41	1.00	
Grade 3	2.03	4.54	1.29	4.80	0.858	0.18	0.05	3.72	1.00	
Grade 4	2.66	3.64	1.67	1.60	0.24	0.27	0.39	1.48	1.00	

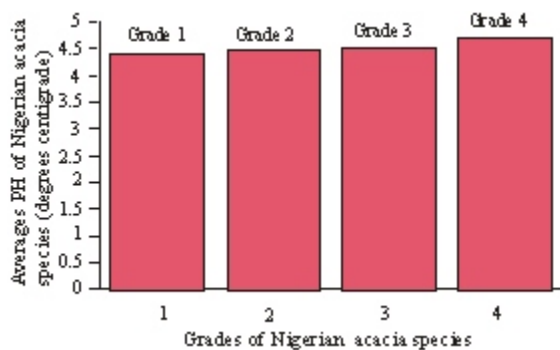


Fig 5: Average PH of Nigerian acacia species

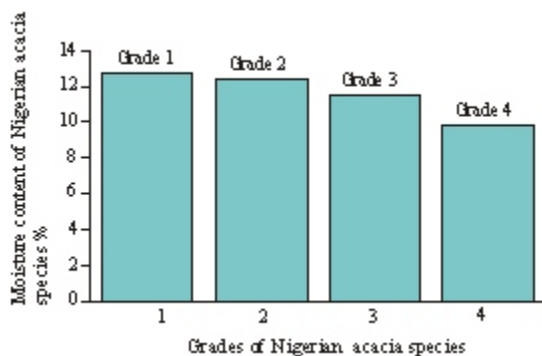


Fig 6: Moisture content of Nigerian acacia species (%)

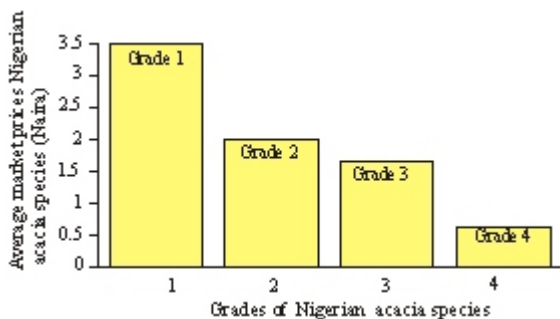


Fig 7: Average market prices of Nigerian acacia species (Naira)

determines bond strength. Grades 1 and 4 gum Arabic are better binders than 3 and 2. Figure 5 presented P H of *Acacia* species. Average P H ranged from 4.68 (grade 4) to 4.36 (grade 1). These are within weak acid range. Grade 4 is the least acidic, followed by grade 2, grade 3, and then grade 1 most acidic in the group. The low acidity makes it chemically human friendly and non corrosive to tools and equipment, satisfying another critical attribute of foundry binders.

Figure 6 presented moisture\volatile matter contents of the four types of *Acacia* exudates produced in Nigeria. Grade 4 had the lowest moisture and increased grade 1. Grade 1 had highest volatile matter. This suggests that in application grade 4 would evolve least gas at high temperature, making it the most preferred where casting defects (caused by gas evolution) must be avoided. On the other hand during storage, grade 4 needed the best protection from water absorption and deterioration as it had shortest shelf life. Generally, moisture contents of 10-13% are high. Adequate vents must be made in gum Arabic mould to prevent gas related defects casting. However this is not a detrimental factor as its low melting point will ensure all gasses are evolved before casting solidification.

The composition in Table 1 showed it contains three groups of element. They are group I (potassium and sodium), group II (magnesium and calcium) and alkaline earth metal (manganese, copper, zinc and iron) in the electrochemical series. They are most reactive in their groups. Their reactivity especially with oxygen favours strong bond with sand. Grade 1 *Acacia* species contains the highest weight of these elements (21.48) followed by grade 3 (17.65), grade 2 (14.54) and then grade 4 (14.52). Sulphate ion content is highest in grade 1 (4.0); other grades equal to unity. By the alkaline earth metal compositions (Mn, Cu, and Zn), grade 2 is the least toxic followed by grade 1 and then grade 4, grade 3 is most toxic though within foundry limit. Grade 1 was the most reactive grade 3, grade 2 and lastly grade 4. Its polysaccharide organic components render it very reactive as the multiple diradical groups (-COOH) present in it react with the base sand to give strong bonds.

The average prices of Nigeria gum Arabic are as presented in figure 7. They are annual averages due to fluctuation in price between peak harvest period when prices are highest and off peak period when prices are lowest in a year. Grade 1 is most the expensive followed by grade 2, grade 3, while grade 4 is the cheapest. These are competitive with imported synthetic binders that cost more than twice prices of Nigerian *Acacia* species grades 1 & 2. Grade 4 being cheapest, offers best economic prospect. The macro structure of each grade of *Acacia* species is as presented in plate 1a-d. Each has distinct appearance. Grade 1 has a clear light yellowish colour with averagely sized lumps. Grade 2 is dark yellowish and of bigger lump. Grade 3 is light brownish in smaller lump. Grade 4 is dark amber brown of large irregular shaped lumps. The structure satisfies packaging attribute of binders.



Plate 1a: Gum Arabic Grade 1 in the raw state



Plate 1b: Gum Arabic Grade 2 in the raw state



Plate 1c: Gum Arabic Grade 3 in the raw state



Plate 1d: Gum Arabic Grade 4 in the raw state

CONCLUSIONS

The study revealed that four different grades of *Acacia* species exudates are commercially available in

Nigeria. Grades 3 and 4 are of lower prices than imported foundry binders. The physiochemical properties of the material satisfied the attributes of good foundry sand binder. With good selection, industrial process and control, the Nigerian *Acacia* species exudates have great potentials for use in foundry as binders to replace imported ones. Further experimental studies on mechanical properties of the material will be done to determine the full potentials for foundry moulding and core sand binding applications for each grade of the material and communicated in subsequent papers.

REFERENCES

- Ayeni, N.A., 2000. Fractionalization and Studies of the physical properties of gum Arabic. Unpublished M.Sc. Thesis Department of Chemistry, Bayero University, Kano, pp: 56-63.
- Dietert, H.W., 1966. Foundry Core Practice. 3rd Edn., American Foundry Men's Society, Des Plaines, Inc., pp: 2-154.
- Fennema, O.R., 1996. Food Chemistry. 3rd Edn. Marcel Dekker Inc. New York. pp: 45-90.
- Gary, H. and R. Ryan, 2002. Best Practices, Markets, Training. Nigerian Gum Arabic Producer and Small Trader-A Workshop Workbook, Lagos.
- Hirst, E.L., J.K. Jones and F. Smith, 1989. Plant gums local vegetable oils. Ph.D Metallurgical Engineering and Mucilage, Advanced Carbohydrate Chemistry, pp: 243-250.
- Okatahi, S.S., 1999. Production of gum Arabic. Extension Bulletin No. 78, Published by N A E and Research Liaison Services, ABU Zaria.
- Okeke, I.B. and E.G. Sadjere, 1991. Technology of operating experience at DSC foundry. A Paper Presented at Nigerian Metallurgical Society Conference. July, 1991. Lagos, pp: 4-8.
- Ominiji, P.W., 2003. Gum Arabic as Admixture in Concrete. Unpublished Thesis (M. Eng Structures) Bayero University Kano.
- Osagie, C., 2002. Gum Arabic and Diversification of Nigerian Economy. Thisday Publishing Co. Limited. Lagos, Nigeria.
- Pearson, D., 1976. Chemical Analysis of Food. 7th Edn. Churchill Livingstone, Edinburgh London, pp: 12-98.