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Evaluation of Mechanical Properties of Aluminium Casting using Sand Deposits in Niger State, Nigeria

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ABSTRACT
Mechanical properties of aluminium casting using sands from Gidan Mangoro, Tagwai Dam, Tungan Mallam, Wuya and Zungeru in Niger State of Nigeria was evaluated according to the American Foundry Society (AFS) standard. Tensile, Hardness and Metallographic tests were carried out on the aluminium cast specimens produced from the five different sand samples. The results obtained for the aluminium alloy cast compared favourably with standard values. Hence the sand deposits can be used for casting of aluminium products.

Keywords: S*and Casting; Tensile strength; Aluminium;*

INTRODUCTION

Sand casting, otherwise known as sand moulded casting, is a metal casting process whereby sand is used as the mould material. It is relatively cheap and sufficiently refractory for steel foundry use. Khan (2005) identifies sand casting as the most widely used casting process in the casting industry, worldwide. Abolarin *et al* (2010) share the view in stating that sand is the major moulding material used in casting all over the world and it is used for the production of all types of metals casts both ferrous and nonferrous metals. In explaining the reason for the high utilization of sand casting, Aweda and Jimoh (2009) noted the particle size of sand which is packed finely and tightly together provides an excellent surface for the mould. A large variety of moulding materials is used in foundries for manufacturing of moulds and cores. They include moulding sand, system sand or backing sand, facing sand, parting sand, and core sand. The choice of moulding materials is based on their processing properties. The properties that are generally required in moulding materials are; Refractoriness, Permeability, Green Strength, Dry Strength, Hot Strength, Collapsibility, Bala and Khan (2013). The much desired development of Nigeria can only be achieved through industrialization and the back bone of any industrialized country is very much dependent on its production capacity from the availability of raw materials to the technology utilized in transforming the raw materials to finished products. Nigerian economy over the years has continue to depend on oil as the major source of revenue neglecting other sectors that would boost its industrial and economic development, Abolarin *et al* (2004). The abundance of mineral deposits all over Nigeria is greatly underutilized, sand being one of them. Asuquo *et al* (2013) in investigating the nature and quality of Zircon sand from Jos Plateau State and sand samples from Idah, Kogi State for foundry application, noted that Nigeria is blessed with large quantity of natural resources that have numerous applications which can be used in producing expensive High Performance Engineering equipment, which are not being utilized to the optimum.

Nigeria is aiming to be among the twenty most developed nations by the year 2020, this can only be achieved through rapid industrialization and this cannot be achieved without sufficient production that would serve the country and even provide for export to other nations. Sheidi (2012) noted that the production of castings is necessary for the development of every nation, as almost all human aspect is reliant upon casting of equipment in construction, transportation, petroleum, mining, farming, and in water supply. Nuhu (2008) noted the significance of Ajaokuta steel rolling company situated in Kogi state operating at full capacity will draw a large number of ancillary and small to heavy industries to the region that require large foundry plants for the spare and completely knocked down parts.

Niger state with a land mass of 99,000 km^2 situated in central Nigeria and also the largest state in terms of land mass in Nigeria has tremendous potential in the casting industry if only it would be harnessed properly. The growing desire for increase in local content in the production industries and the quest for rapid industrialization in Nigeria necessitates that more and more local materials be sought to replace imported materials. Shuaibu (2014) investigated the properties of sand collected from Gidan Mangoro, Tagwai Dam, Tungan Mallam, Wuya and Zungeru of Niger state and found that the sand deposit could be used for casting purposes and other foundry applications. This paper presents mechanical properties of aluminium casting using the moulding sands of Gidan Mangoro, Tagwai Dam, Tungan Mallam, Wuya and Zungeru.

1. METHODOLOGY

Sand samples were collected from each of the location and used to produce moulds in its natural state i.e without the addition of bentonite and other additives because the sand samples were observed to have high clay content to act as binder. Wooden patterns of rectangular shape (length = 150mm, breadth = 30mm height = 6mm) and cylindrical shape of diameter 30mm and height 150mm were made. The rectangular pattern was used to produce cast for hardness test and microstructure analysis, while the cylindrical pattern was used to produce cast for tensile test. The aluminium alloy AA6063 (Al-Si-Mg) used for the experiment was obtained from the Nigerian Aluminium Extrusion Company, Lagos. The chemical composition of the aluminium alloy is presented in Table 1.

1.1. Melting and Casting Processes

The alloy of aluminium was melted using a fuel-fired crucible furnace. The molten alloy was thoroughly stirred and slag removed at a pouring temperature of 680°C. Melting of the aluminium alloy took an hour and fifteen minutes. A ladle was used to scoop the molten metal and poured into the sand mould and allowed to solidify and cool. The solidified cast was then removed from the mould.

1.2. Tensile Test Procedure

Tensile test was carried out using the Universal Testing Machine at the Strength and Materials Laboratory, Ahmadu Bello University, Zaria, Nigeria. The aluminium cast was machined to ASTM E-8 standard size in dimension for tensile strength testing of gauge length of 30mm, Ayoola *et al* (2012). The test piece was inserted into the jaws of the universal testing machine and gripped firmly.

Table 1: Chemical Composition AA6063

Alloying Element	Al	Si	P	Ca	Ti	V	Cr	Mg	Mn	Fe	Ni	Cu	Zn	Pb	As	Sn
Percentage Composition	87.45	10.87	0.2	0.05	0.019	0.12	0.068	0.20	0.29	0.27	0.007	0.034	0.015	0.007	0.06	0.34

Tensile force was then applied gradually using 5kN load, the loading was applied continually at steady rate until the aluminium cast fractured and failed as shown in Plate I. The maximum load before fracture was read and recorded.

The fractured test piece was removed from the universal testing machine. The fractured parts were put together to enable the determination of the increase in length as well as the necking diameter for the calculation of elongation and reduction in area.

Plate I: Alumiunm Cast Samples after Tensile Tests

1.3. Hardness Test Procedure

Hardness test is carried out to ascertain the level or degree of resistance of material to wear, cutting, crushing when the material is under loading. Hardness test was carried out at the foundry laboratory in Federal Institute Industrial Research Oshodi, Nigeria using a Brinnel Hardness testing machine. The aluminium specimen was placed in position under the testing machine. The test was carried out using a 10mm diameter steel ball. The test piece was then brought into contact with the steel ball with the gradual application of force. The loading was done until a clear indention was made. After the indention had been made, the load was removed and the steel ball removed from the top of the aluminium cast test piece leaving an indention on the cast as shown in Plate II. The diameter of the indention was measured using a Venier calliper and the force applied was recorded.

Plate II: Aluminium Cast Samples showing Indention of Hardness Tests

1.4. Metallographic Test Procedure

The microstructure or metallographic test was carried out at the Metallurgical and Materials Engineering Laboratory of University of Lagos, Nigeria. The cast aluminium test piece was cut and polished to a good smooth surface using a Belt Grinder (B.G-20) with fine grades of abrasive papers to ensure better surface finish. The aluminium test specimen was then washed in warm water, rinsed thoroughly and allowed to dry. Etching was done using a chemical reagent of 0.5 % hydrofluoric acid after which it was allowed to dry before placing the specimen under the microscope to view and record the microstructure of the surface at a magnification of x400µm.

2. RESULTS AND DISCUSSIONS

3.1. Mechanical Test Results

The mechanical tests results for the aluminium casts from the five different sands samples tested include, tensile strength, hardness, elongation and reduction in cross sectional area are presented in Tables 2 to 6.

Table 2: Mechanical Tests Results of Aluminium Cast Sample Using Gidan Mangoro Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.25	4.17	6.00	5.85	4.94	132.45	4.54	5.59	128.44	44.14
2	30	31.25	4.17	6.00	5.82	5.91	116.32				
3	30	31.58	5.27	6.00	5.82	5.91	136.55				

Table 2 presents the mechanical test results of Gidan Mongoro aluminium cast sample. The average ultimate tensile stress of 128.44 N/mm^2, average percentage elongation of 4.54 %, also an average reduction area of 5.59 % and Brinell hardness number of 44.14.

Table 3: Mechanical Tests Results of Aluminium Cast Sample Using Tagwai Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.25	4.17	6.00	5.85	4.94	120.23	4.54	5.26	118.81	39.34
2	30	31.25	4.17	6.00	5.85	4.94	124.32				
3	30	31.58	5.27	6.00	5.82	5.91	111.89				

Table 3 presents the mechanical test results of Tagwai Dam aluminium cast sample. The average tensile stress of 118.81 N/mm^2, average percentage elongation of 4.54 %, also an average reduction area of 5.26 % and Brinell hardness number of 39.34.

Table 4 presents the mechanical test results of Tungan Mallam aluminium cast sample. The average tensile stress of 129.26 N/mm^2, average percentage elongation of 4.90 %, also an average reduction area of 4.94 % and Brinell hardness number of 42.26.

Table 4: Mechanical Tests Results of Aluminium Cast Sample Using Tungan Mallam Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.58	5.27	6.00	5.85	4.94	136.76	4.90	4.94	129.26	42.26
2	30	31.25	4.17	6.00	5.85	4.94	121.95				
3	30	31.58	5.27	6.00	5.85	4.94	131.07				

Table 5: Mechanical Tests Results of Aluminium Cast Sample Using Wuya Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reducti on Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.58	5.27	6.00	5.85	4.94	123.17	4.90	5.26	114.17	39.25
2	30	31.25	4.17	6.00	5.82	5.91	102.64				
3	30	31.58	5.27	6.00	5.85	4.94	116.70				

Table 5 presents the mechanical test results of Wuya aluminium cast sample. The average tensile stress of 114.17 N/mm^2, average percentage elongation of 4.90 %, also an average reduction area of 5.26 % and Brinell hardness number of 39.25.

Table 6 presents the mechanical test results of Zungeru aluminium cast sample. The average tensile stress of 114.99 N/mm^2, average percentage elongation of 4.71 %, also an average reduction area of 5.59 % and Brinell hardness number of 39.66.

Table 6: Mechanical Tests Results of Aluminium Cast Sample Using Zungeru Sand

S/No	Original Length (mm)	Final Length (mm)	Elongation (%)	Original Diameter (mm)	Final Diameter (mm)	Reduction Area (%)	Ultimate Tensile Stress (N/mm^2)	Average Elongation (%)	Average Reduction Area (%)	Average Ultimate Tensile Stress (N/mm^2)	Hardness (HB)
1	30	31.58	5.27	6.00	5.82	5.91	102.57	4.71	5.59	114.99	39.66
2	30	31.25	4.17	6.00	5.85	4.94	127.43				
3	30	31.41	4.70	6.00	5.82	5.91	114.99				

3.2. Metallographic Test Result and Analysis

The metallographic results show the microstructures of the casts from the five different sand samples as shown in plates 1 to 5. The microstructures generally consists of fine crystals of aluminium (Al), magnesium silicide (Mg_2Si), and Al-Mg_2Si phases. These structures basically consists of primary alpha solid solution of magnesium silicate in rich solid aluminium (α)) in a matrix of eutectic magnesium silicate (Mg_2Si). The aluminium rich portion of the Al-Mg_2Si is a precipitation of the magnesium silicide (Mg_2Si). The primary solid solution of silicon in aluminium is revealed in white patches while the eutectic magnesium silicide (Mg_2Si) is seen as dark patches in the micrographs in Plates 1- 5. There is also a very thin gray structure indicating the presence of Fe_3SiAl_2. Tungan Mallam sand shows white patches of primary alpha solid solution of silicon in aluminium in matrix form (α) is visible but it is not as pronounced as that of Gidan Mangoro in Plate1. Similar observation shows that Tagwai dam area (Plate 3) sand has more white patches in Plate 3 than in Plate1. Plate 4 and 5 shows the microstructure of aluminium cast produced from Wuya sand. It shows similar characteristics in terms of primary alpha solid solution of silicon in aluminium (α) matrix form and magnesium silicide (Mg_2Si) in the eutectic state with the microstructure of Plate 3.

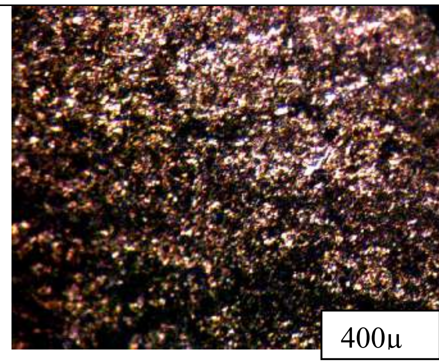

Plate 1. Micrograph of etched Aluminium test sample using Gidan Mangoro sand

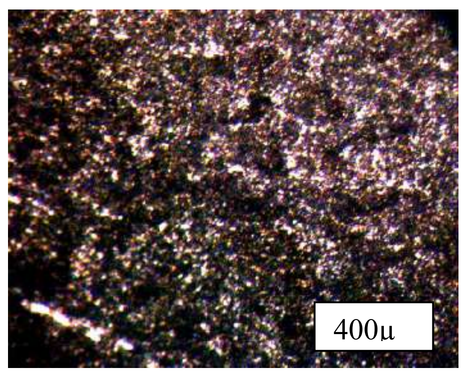

Plate 2. Micrograph of etched Aluminium test sample using Tungan Mallam sand

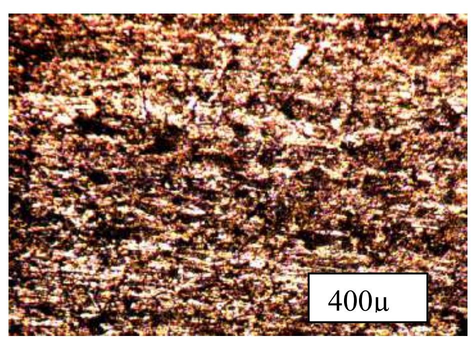

Plate 3. Micrograph of etched Aluminum test sample using Tagwai Dam sand

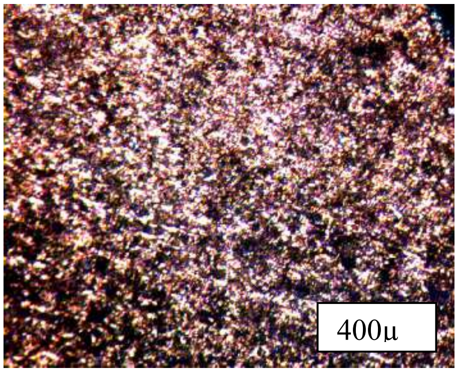

Plate 4. Micrograph of etched Aluminium test sample using Wuya sand

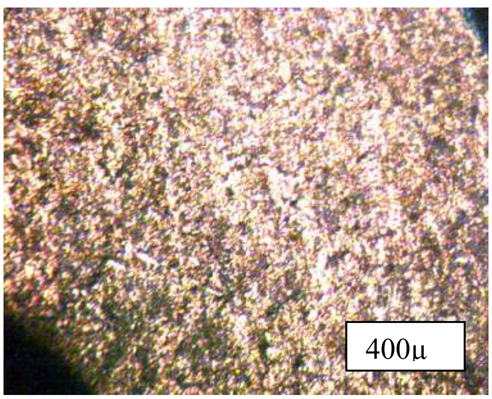

Plate 5. Micrograph of etched Aluminium test sample using Zungeru sand

The aluminium alloy casts produced from all the five sand samples indicates that the sand with low permeability (Shuaibu, 2014) had microstructures in which the white patches of primary alpha solid solution of silicon in aluminium (α) to be more pronounced i.e Zungeru, Tagwai and Wuya sands, these sands exhibited very similar permeability number while the sands with higher permeability showed less white patches of primary alpha solid solution of silicon in aluminium (α) with Tungan Mallam sand microstructure showing the least primary alpha solid solution of silicon in aluminium (α). The relationship between the microstructure and permeability can be explained by the fact that permeability is a measure of gas passage through the sand. The ability of air to pass through sand affects the temperature of casting and the rate of cooling which consequently affects the solidification process and time also affects the types of phase and grains formed. Similarly, the average tensile strength and the hardness values of the three sands from Zungeru, Tagwai and Wuya were very close as compared to the other values which implies that the microstructure of the sand produced are in agreement with the mechanical tests carried out.

4.0 CONCLUSION

The investigation has shown that all the sand collected from the five locations were suitable for casting aluminium alloy. The Mechanical tests carried out included tensile strength, hardness, elongation and reduction in cross sectional area. Results from the mechanical tests of the aluminium casts from all the five different sand were also compared with standard ranges of mechanical tests for aluminium alloy cast using sand moulds.

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