Effect of different melting practices on mechanical properties of sand cast Al-Si alloy scraps

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Abstract

The effect of different melting practices on the mechanical properties of sand cast aluminum-silicon alloy scraps have been investigated in this study. Samples of aluminum alloy products were cast using automobile pistons scraps as charge materials. The castings were carried out at four different locations in Nigeria of Oyo, Ondo, Kaduna States and Abuja. At Oyo and Abuja, the samples were cast in the local aluminum pots casting shops at Saki and Tungamaje respectively. At Kaduna, the samples were cast in Clement Yaro foundry in Kaduna a private foundry, while the samples from Ondo were cast at the foundry of Federal University of Technology, Akure (FUTA). Green sand casting was used to cast all the samples. Chemical and microstructure analysis carried out shows near uniform distribution of Silicon (Si). The results showed that the cast aluminum alloy is hyper eutectics Al-Si (over 16% Si) alloy. Tensile, hardness and impact tests were carried out to determine the mechanical properties. This produced an average percentage accuracy of the ultimate tensile stress and Brinell hardness number for Saki sample, 80.84%; FUTA sample, 82.5%; Kaduna sample, 93.48% and Tungamaje sample, 75.23%. The study has established that with adequate melting practice indigenous casting shops in Nigeria can produce cast products with 90% quality.

Keywords

Melting practice; Casting; Aluminium; Silicon; Alloy; Mechanical properties; Foundry; Microstructure

Introduction

Metal casting is a process of pouring molten metal into the cavity of a mould and allowed to solidify into a required shape. Casting is an ancient method used to manufacture complex parts of components and equipment by imparting desirable characteristics of the casting for specific area of application as in transportation, communication, power, agriculture, construction, Airspace, chemical, petrochemical and other industries [1, 2]. Aluminium casting is a well-established practice in some parts of Nigeria but predominantly in Oyo and Osun State [3]. The major raw material for indigenous aluminium casting is processed aluminium metal obtained in form of scraps from household utensils and other disused aluminium products. Aluminum is a very important and common metal on earth because of its low density and excellent mechanical properties. It is alloyed with elements like magnesium, silicon, copper, manganese, and zinc to produce variety of wrought products from beverage cans to aircraft structural parts, to cast products like engine blocks and steering knuckles for automobile [4]. The addition of alloying elements is made principally to improve mechanical properties, such as tensile strength, hardness, rigidity and machinability, and other casting properties. Aluminium-Silicon alloys are of greater importance to engineering industries as they exhibit high strength to weight ratio, high wear resistance, low density and low coefficient of thermal expansion. Silicon imparts high fluidity and low shrinkage, which result in good castability and weldability [5].

The mechanical properties of any material describe the response of the material under applied load/ force. Although different manufacturing methods of engineering components have been developed, the primary aim of each method is to produce components with good mechanical properties. Some of these methods include forging, drawing, rolling, and extrusion. The raw materials for most of these processes are ingots which are usually produced through casting [6].

It has been stressed that development of indigenous technology for developing small-scale industry in which local aluminium casting shop is one, is important for fast development of complex technology industries in Nigeria [7]. Ozi and Lawal [8] stated that development of small-scale manufacturing industries is the corner stone of sustainable economic self-reliance. However, production of aluminium castings in Nigeria does not have a long history of existence. This is due partly to the non-existence of the ancient technology of extraction and purification of aluminium, and unlike Copper, the naturally occurring pure aluminium is very rare. The local technique of aluminium pot production could only be traced as far back as two centuries ago when the incursion of industrial products from Europe and America into Africa commenced. Thus, the impetus to the art of aluminium pot production was given by the availability of aluminium scraps from the imported aluminium industrial products. This art has undergone gradual development passing from generation to generation through family lineage [9].

The re-melting of aluminium scraps is important to enhance the availability of the product without over reliance on the foreign market and thereby improving the foreign reserve. Different melting techniques are in practice in the melting of aluminium alloy with different energy sources [10]. In the indigenous technique, aluminium scraps is melted in a steel container placed on the hearth and fired continuously using charcoal [9].The local methods of melting has disadvantage of producing low quality products as a result of impurities present in the charcoal fuel [10]. The local aluminium casting industry in Nigeria adopts various methods of melting practices in the recycling of scraps to cast products for various uses most especially pots of various sizes. For reasonable improvements in this industry in Nigeria, there is a need to know the quality level of their production process as related to the standard practices. This is in order to know how to improve the production processes so as to enhance the quality of the products.

The present study focused on the effect of different melting practices on the mechanical properties of the sand cast aluminium-silicon alloy in order to determine the suitability of the melting processes as practiced in Nigeria.

Material and method

The materials used for this research include aluminium scraps (automobile engine pistons scraps), chlorine tablets, powdery part of dry-cell battery and foundry sand. The tools used includes wooden patterns, mould, metal crucible, hearth furnace, gas fired lift-out crucible furnace, shovel, rammer, tensile and hardness testing machine, metallography testing machine, lathe machine, grinding machine, hack saw, emery paper and Energy Dispersive x-ray fluorescence (EDXRF) spectrometer of model Minipal 4 (DY1055).

The casting of samples was carried out at four different locations in Nigeria at Oyo state, Ondo state, Kaduna state and Federal Capital Territory (F.C.T.), Abuja. Three samples consisting of two cylindrical rods and one rectangular rod were cast from each location. In Oyo state, the samples were cast at a local aluminium pots casting shop in Saki, Saki local Government area. In Ondo state, the casting of the sample was carried out at the university foundry of Federal University of Technology, Akure (FUTA), at Kaduna, the casting was carried out at Clement Yaro foundry (a private foundry) old Panteka market Kaduna. While in F.C.T the casting was carried out at a local aluminium casting shop in Tungamaje, Gwagwalada Area Council Abuja. In all the places, the samples were cast using sand casting method. Sand moulds were prepared silica sand and mixed with clay (bentonite), and required quantity of water. Wooden patterns of cylindrically shaped with diameter 25mm and 100mm long a rectangular shaped of dimensions 15mm×30mm×70mm were used to produce the moulds.

Saki and Tunganmaje melting practices

The melting process adopted at Saki and Tunganmaje local aluminum casting shops involves the charging of aluminium scrap into a steel crucible kept on a hearth made of caked mud filled with charcoal. The hearth has an opening through which air was supplied to it with a blower. The aluminum scraps were melted in the steel crucible at a temperature of about 600°C but superheated to a temperature of 680°C to allow for homogenous composition of the alloy. The charge was stirred continuously during melting with addition of carbon powder of the dry-cell battery which served as fluxing material. The flued impurities were scooped out with the use of foundry spoon thereafter the melt was ready for pouring into the mould cavity.

Kaduna melting practice

At Clement Yaro foundry, Kaduna, the melting process of the aluminium scraps and the melting furnace were almost the same with the saki and Tunganmaje melting practices except that manganese (IV) oxide from powdery part of dry-cell battery was added during melting to serve as dross flux to the molten alloy and then degassed with about 1% chlorine tablets at a temperature of about 700ºC to prevent gas porosity in the casting.

FUTA melting practice

At the university foundry of FUTA melting was carried out in a gas-fired lift-out crucible furnace. The melt was held at a temperature of 700ºC in order to attain homogeneous composition. The melt was stirred for one minute and then poured into the mould cavity. No fluxing and degassing agent was added to the molten alloy during the melting process.

Pouring, solidification and fettling of castings

After the melting of the charged materials, the molten alloy was poured into the mould cavity to solidify. Then, the mould was broken to remove the castings. The gates were cut off by the use of hacksaw. The rough parts of the specimens were grinded by the use of grinding machine to smoothen the outer parts of the sample.

Mechanical properties

Tensile test

Tensile test specimens were machined from the cast samples of cylindrical rods to required specifications. The test was conducted at the mechanical laboratory of Kaduna Polytechnic using Mosanto Tensometer Type 'W' Serial Number 10975, U.K. The test specimen was fed into a locking socket which provided the grip of specimen at the base and at the top. The specimen was held at both ends with force in tension applied slightly and the meter was set to zero. The handle was raised and pressed down so as to apply the load. The load was increased uniformly at interval of 2kN until the specimen rupture. The corresponding extension was noted on the graph sheet attached to upper part of the tensile test machine. This process was repeated for other samples.

Hardness test

The hardness tests of all the samples were done at Mechanical Engineering laboratory Kaduna Polytechnic using universal hardness testing machine. The applied load during the testing was 40 kgf with a dwell time of 15 seconds. The test was carried out to obtain Brinell hardness number (BHN) and Vickers hardness number (VHN). For Brinell test, a steel ball of diameter 2mm was used as an indenter while for Vickers test, a square-base diamond pyramid indenter was used.

The Brinell hardness number (BHN) was obtained by using the equation (1).

$$BHN = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]} \tag{1}$$

where, P = applied force (kgf), D = diameter of the ball (mm), d = diameter of indentation, mm.

The Vickers hardness number was obtained from the equation (2).

$$VHN = \frac{1.85P}{d^2} \tag{2}$$

where P = applied force (kgf), d = average length of diagonals, mm.

Impact test

The charpy impact test was carried out on the samples at the mechanical engineering laboratory Kaduna polytechnic. The rectangular shaped samples were prepared into small notched specimens to be used on the universal impact testing machine. This machine consists essentially of a rigid specimen holder and a swinging pendulum hammer for striking the impact blow. Before striking, the potential energy of the pendulum was noted. Then the swinging pendulum hammer was raised to the higher level and released to allow the pendulum hammer to strike the specimen. After striking the potential energy of the pendulum was read from the gauge. Finally, impact energy which is difference in potential energies of the pendulum before and after striking the specimen was calculated. The machine was calibrated to read the fracture energy in foot pound (ft-lb) which was converted to joule (J) by multiplying each of the values obtained by 1.356.

Microstructures test

Microstructural characterization of the specimens was done to observe the microstructure of samples surface. This was done at metallurgy laboratory of Federal University of Technology, Minna by using Metallurgical Trinocular Microscope MM039BOOM. The samples were mechanically grinded using waterproof silicon carbide emery paper, polished using Metron polishing cloth and Dialap fluid. Etching of the samples was then carried out using dilute hydrogen chloride (HCL) acid, nitric acid (HNO_3) and water

(H_2O) before the examination. The micrographs of the samples were obtained from the microscope.

Chemical composition analysis

The chemical composition of the samples was carried out at National Geosciences Research Laboratory, Kaduna. The samples were carefully cut using cutting blade. The measuring surfaces were polished using emery paper. This was done to remove surface contaminants as well as exposing fresher portions of the sample. Energy Dispersive x-ray fluorescence (EDXRF) spectrometer of model “Minipal 4” (DY1055) was used for the analysis. The prepared samples were carefully placed in the respective measuring positions on a sample changer of the machine. When the machine was switched on, the condition sets were chemical composition determination, nature of the samples to analyze as metal/alloy, the voltage used as 14kV for major oxides, 20kV for the trace elements/rare earth metals (all in oxides), selected filters were “kapton” for major oxides, Ag/Al-thin for the trace elements/rare earth metals. The selection of filters was guided by a given periodic table used for elemental analysis. Time of measurement for each sample was 100 seconds and the medium used was air throughout. The machine was then calibrated by the machines “gain control”, after which the respective samples were measured by clicking the respective positions of the sample changer.

Results

The result of chemical composition of the samples in their oxide forms is presented in Table 1. The engineering stress versus strain curve obtained from the result of the tensile tests for the samples of Saki, FUTA, Kaduna and Tungamaje are as shown in Figures 1, 2, 3, and 4. The relationship between the engineering stress and strain is unique for each material and it is significant in determining the mechanical properties of a material such as loading bearing capability (loadability), elastic deformation limit (yield point), the plastic deformation limit, the ultimate tensile strength and the fracture or rupture point, including data to establish the Modulus of Elasticity. These values are very important, especially for design engineers, as it enables them to determine how much force a material can withstand with regard to the crosssection used without deforming permanently. The values of the mechanical properties obtained are presented in Table 2.

Table 1. Weight percentage of different oxides present in the cast aluminium samples

Oxides	Saki (Wt %)	FUTA (Wt %)	Kaduna (Wt %)	Tunganmaje (Wt %)
SiO_2	16.60	17.30	16.95	16.01
TiO_2	0.056	0.029	0.031	0.061
Al_2O_3	79.10	79.30	79.34	79.08
P_2O5	0.310	0.310	0.320	0.255
Fe_2O_3	0.753	0.559	0.612	0.712
CaO	0.195	0.188	0.175	0.189
MgO	0.110	0.100	0.091	0.210
Na_2O	0.020	0.050	0.045	0.030
K_2O	0.018	0.017	0.017	0.019
MnO	0.082	0.075	0.100	0.063
V_2O_5	0.015	0.016	0.014	0.044
Cr_2O_3	0.0095	0.014	0.0085	0.010
NiO	1.080	0.727	0.956	0.952
CuO	1.420	1.050	1.132	1.340
ZnO	0.184	0.156	0.178	0.175
BaO	0.010	0.026	0.032	0.009

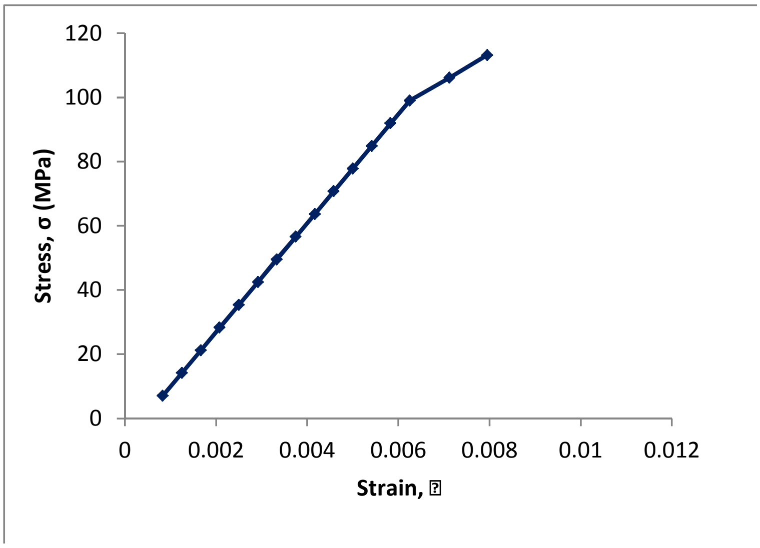

Figure 1. *Engineering stress-strain curve for Saki sample*

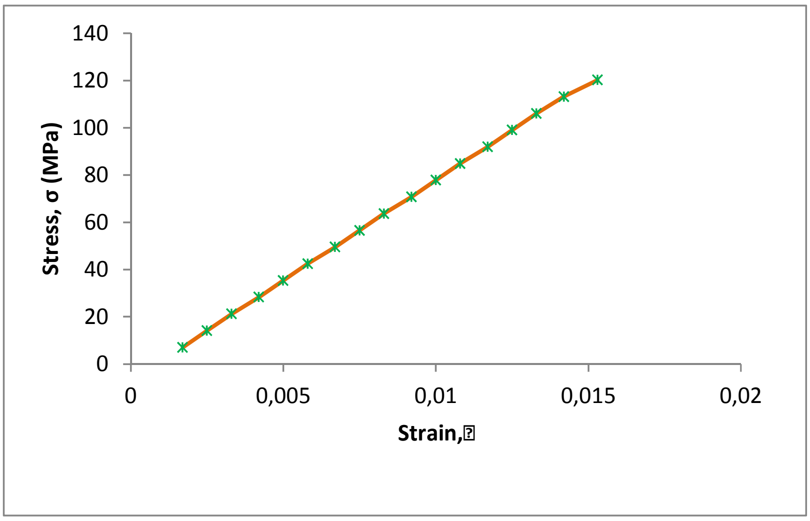

Figure 2. *Engineering stress-strain curve for FUTA sample*

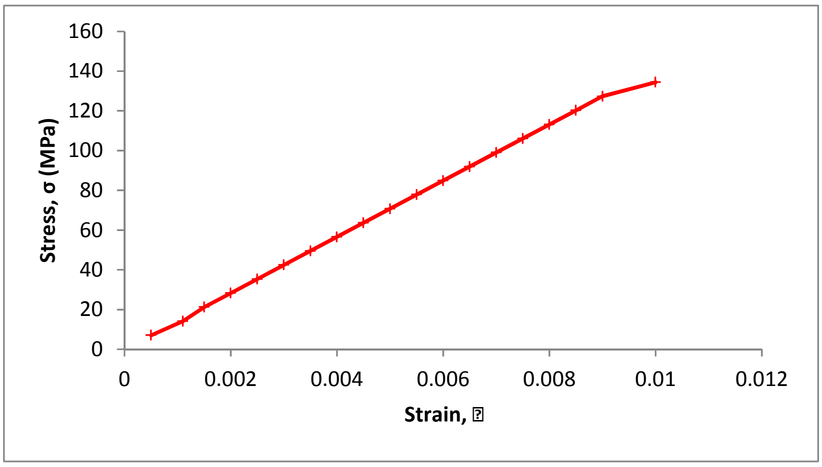

Figure 3. *Engineering stress-strain curve for Kaduna sample*

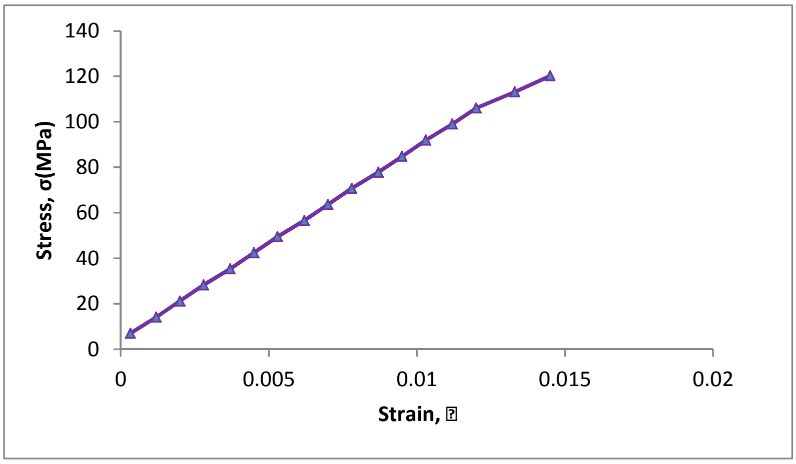

Figure 4. *Engineering stress-strain curve for Tunganmaje sample*

Table 2. Mechanical properties for various aluminium samples

Location	Ultimate tensile Stress, σ_{UTS} (N/mm^2)	Elongation (%)	Modulus of Elasticity, E (N/mm^2)	Hardness		Impact fracture energy (J)
				BHN	VHN	
Saki	120.23	1.10	12,061.00	83.23	91.36	1.627
FUTA	120.23	1.30	8,520.48	87.23	91.36	2.712
Kaduna	134.38	1.20	14,144.62	100.64	91.36	2.712
Tunganmaje	113.38	1.50	8,456.52	76.25	70.43	1.356
FOSECO [11]	130.00	0.5	-	120	-	-

The results compared to the FOSECO values gives the average percentage of accuracy of the mechanical properties in terms of ultimate tensile stress and Brinell hardness number of the cast samples as Kaduna sample: 93.48%; FUTA sample: 82.5%; Saki sample: 80.84% and Tungamaje sample: 75.23%.

Discussion

The percentage weight of silicon (IV) oxides (SiO_2) in the Saki, FUTA, Kaduna, and Tungamaje samples shown in Table 1 suggests that the cast samples are aluminium-silicon of over 16%Si regarded as the hypereutectic Al-Si alloys. The standard casting temperature for this group of aluminium alloy is 750ºC - 760ºC [11]. Figures 1, 2, 3 and 4 show the tensile properties of each sample. The linear elastic region shows the linear relationship between stress as a result of the tensile load on the specimen and strain due to the extension of the specimen. The final stages of the curves correspond to the stage where brittle fracture occurred. The fracture strength in tension was taken as the maximum stress attained by the sample (ultimate tensile strength). The total elongation was obtained by taking the ratio of the maximum displacement in the samples (change in length) to the original length. The modulus of elasticity was obtained from the slope of the elastic region of the curve. The results indicates that the ultimate tensile stress of the Saki and FUTA samples are the same while the ultimate tensile stress of Kaduna sample has the highest and Tungamaje sample has the lowest value. This suggests that the quality of the cast products from Saki and FUTA are closely related due to good melting practices in the Saki and university foundry at FUTA casting shops as compared to Tungamaje casting shop. The quality of the Kaduna sample is attributed to the melt treatment with degassing agent of chlorine tablets and manganese (IV) oxide. The percentage elongation of the samples as presented in Table 2 shows that the aluminium casting with higher silicon composition has lower elongation, i.e. the ductility of the aluminium alloy decreases with increase in the amount of silicon present in the alloy. Modulus of elasticity, also known as Young's modulus (E) of the material is the stiffness of the material. Table 2 indicates that Saki and Kaduna has higher stiffness value [12].

Conclusion

The investigation has shown that the cast aluminium alloy is hypereutectic Al-Si alloy with the mechanical properties of the cast samples in the foundry better than those casts in the local aluminium casting shop. The variation in the mechanical properties and the quality of the cast aluminium product is mainly attributable to melt treatment and the furnace used. Our investigation has established that with adequate melting practice in the indigenous casting shops in Nigeria aluminum alloy casting can be produced to about 90% quality.

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