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EFFECT OF CASTING MOULD ON MECHANICAL PROPERTIES OF 6063 ALUMINUM ALLOY

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Abstract

Modern production methods for casting articles include the use of sand- mould, metal-mould, die, and centrifugal castings. Castings produced using sand mould is known to have peculiar microstructures depending on average size, distribution and shape of the moulding sand grains and the chemical composition of the alloy. These affect the surface finish, permeability and refractoriness of all the castings. In this paper, the effect of using CO_2 process, metal mould, cement-bonded sand mould and naturally-bonded sand mould on the hardness, tensile and impact strengths of as-cast 6063 Aluminum alloy is presented. The results show that there is significant increase in hardness (33.7 HB) of the alloy when naturally-bonded sand mould is used for its production over that of metal, CO_2 and cement moulds. The stress-strain curves behaviour of the samples also indicated that sample from naturally bonded sand has highest tensile strength with superior ductility. The alloy shows highest impact strength when metal mould is used for sample preparation in comparison with other moulds.

Keywords: Aluminum, Mould, Tensile strength hardness, Casting.

1. Introduction

The properties of commercial aluminum alloys depend on the amount of magnesium, copper, silicon, chromium and other alloying elements present in them. The properties are also influenced by the manufacturing techniques and heat treatment procedures employed [1-2]. Aluminum alloy 6063 which has silicon and magnesium as the major alloying elements possess properties such as high strength, excellent corrosion resistance, heat treatability and weldability [1-3].

These two elements (magnesium and silicon) form the primary hardening phase (magnesium silicide, Mg_2Si) in aluminum alloy 6063 [4-5].

Aluminum alloy 6063 is formed into semi-finished or finished products, using various available fabrication techniques with casting accounting for the greatest percentage of such products. The properties of casting are influenced by moulding process employed and the properties of moulding materials used [1, 6]. The type of mould used in metal casting depends heavily on the type of casting to be produced, the alloy involved and the complexity of the shape to be cast. Heat transfer between the solidifying casting and mould is critical for high quality casting. In addition, heat transfer between the casting and the mould is primarily controlled by conditions at the mould-metal interface. The quality of castings in a green sand mould are influenced significantly by its properties, such as green compression strength, permeability, mould hardness and others which depend on input parameters like sand grain size and shape, binder, water, etc. [7].

The effect of clay content, amount of tempering water and sand texture on moulding properties such as dry and green strengths and shatter index of Igbokoda clay in Nigeria have been studied [8]. Both green and dry strengths of the Igbokoda clay test (mixed with the silica sand and at optimum water content) gave good values for synthetic moulding sand. The shatter index test shows a decrease in collapsibility as the water content decreases at fixed clay content and this resulted in improvement in the quality of the moulding sand.

During casting, chilling of the molten metal occurred at the mould wall and this result in the formation of a thin skin at mould/metal (alloy) interface which increases around the mould/metal interface as solidification progresses. Mould surface roughness will cause decrease in the heat-transfer coefficient at the metal/mould interface. In general, the rate of freezing depend on rate of heat transfer from melt into mould, the thermal properties of the metal, solidification rate (controlled by geometry of the mould) and physical properties of the mould.

Improper casting procedures may give rise to defects such as pin hole, porosity, shrinkage cavity and which are largely responsible for poor mechanical properties of aluminum alloys produced [9]. In this study however, the effect of mould-type on hardness, tensile strength, impact energy absorption capacity of 6063 Aluminum alloy is presented.

2. Experimental Procedure

2.1. Materials

Aluminum alloy 6063 ingot used for this study was obtained from Nigeria Aluminum Extrusion Company, Lagos, Nigeria and its chemical composition is given Table 1.

Table 1. Chemical Composition of AA6063 Aluminum Alloy.

Element	**Al**	**Mg**	**Si**	**Cu**	**Mn**
(%) comp.	98.64	0.5141	0.5351	0.0013	0.0283
Element	**Fe**	**Zn**	**Cr**	**Ti**	**Ca**
(%) comp.	0.2108	0.0035	0.0007	0.0114	0.051

The moulds for casting test samples were made from CO_2, cement, naturally-bonded sand and metal (hardened steel) moulds. Listed in Table 2 are the mould constituents used for this study. Wooden pattern of cross sectional area 10 mm x 150 mm were used for the moulding process (Fig. 1).

Table 2. Mould Make-Up.

Mould Type	Mould Make-up	Proportion (%)
CO_2	Silicon Sand Sodium Silicate (Na_2 SiO_3) CO_2 Gas	95.20 4.76 Open Air (Negligible)
Cement	Silica Sand Portland Cement Tempering Water	86.95 8.70 4.35
Naturally bonded sand	Natural Bonded Sand Tempering Water	92.59 7.41

The silica sand used is a mixture of angular and sub-angular sand grains and its constituents is shown in Table 3.

Table 3. Constituent of Silica Sand.

Constituent	Total Iron	Al_2O_3	SiO_2	TiO_2
Composition (%)	0.10	0.39	99.08	0.43

Constituents of the naturally bonded sand were determined using x-ray analysis and the result is presented as follows; silica (SiO_2), Illite $[(OH)_4\ k\mu$ $(Al_4Fe_4\ Mg_4\ Mg_6)(Si_{8-y}.Ay)O_{20}]$, kaolin $[(OH)_4Al_4\ Si_4O_{10}]$ and monotmorillonite $[(OH)_4Al_4Si_8O_{20}.n\ H_{20}]$.

2.2. Materials processing

CO_2 mould was prepared by mixing silica sand with sodium silicate (Na_2SiO_3) solution to effectively coat individual sand grains. The mixed sand was rammed and kept in open air for fifteen days for proper hardening.

In preparing cement mould, the constituents were mixed together and the damp mixture was allowed to cure for 3 hours. Prior to casting, setting of the half moulds were achieved by stripping off the loose sand and stored in a damp atmosphere for about 24 hours. Naturally-bonded sand was mixed with tempering water to prepare the mould. The degrees of surface finish of the moulds were macroscopically examined and the result presented in Table 4. Surface finish characteristic of the moulds were based on physical appearance and sand distribution within the moulds.

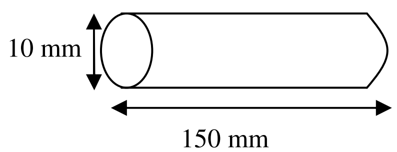

Fig. 1. Cylindrical Wooden Pattern.

2.3. Production of the AA6063 aluminum alloy test samples

AA6063 aluminum alloy ingot was charged into a 5 kg standard crucible and placed in a lift-out crucible furnace. The molten alloy was poured into the cavities of the various prepared moulds at 780°C and the cast samples were allowed to cool for 8 hours before stripping. In all, twelve (12) as-cast samples were made with three per mould-type. Fettling and cleaning of the cast samples were carried out to remove protrusions and to obtain clean surface.

Table 4. Degree of Surface Finish.

Mould-type	CO_2	Metal	Naturally Bonded Sand	Cement
Surface Smoothness Degree	Smooth	Very smooth	Averagely smooth	Averagely smooth

2.4. Hardness tests

The Brinell hardness test for the cast samples was conducted on a 15 mm x 10 mm test pieces. Both grinding and polishing were carried out starting with coarse filing and finishing using a motor-driven emery belt. A load of 125 kg was applied on the test piece for 15 seconds and the diameter of the impression measured. The average hardness values of the test pieces are displayed in Table 5.

2.5. Tensile tests

Tensile test pieces were prepared from the as-cast samples to ASTM E-8 standard [10] (Fig. 2) and these were subjected to a 10 kN load from an Instron Universal tensile test machine model. The load-extension results obtained from the cast were used to generate the true stress and true strain relationship shown in Fig. 3.

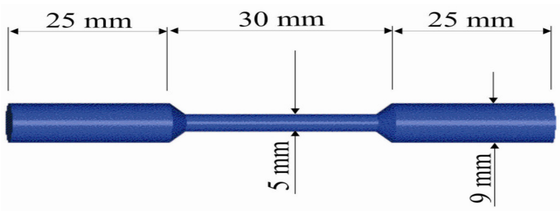

Fig. 2. Cylindrical Tensile Test Piece.

2.6. Impact test

Impact test was carried out on 10 mm x 60 mm test pieces with a V notched angle of 45° using a fully instrumented Avery Impact Testing Machine at 27° C while maintaining a uniform striking velocity.

2.7. Microstructural examination

A microstructural test piece of 30 mm x 30 mm x 30 mm was cut from each of the as-cast samples. These pieces were successively ground using 80, 200 and 600 microns grades of emery papers. The ground surfaces were washed with water, polished on a rotating cloth pad with diamond paste and etched for 2 minutes in a solution containing mixture of 10 g ferric chloride, 30 cm^3 HCl and 120 cm^3 distilled water. Photomicrographs of etched test pieces were taken using a Digital Metallurgical Microscope at x 100 magnification.

3. Results and Discussion

In Fig. 3, the strengths of the cast samples are similar at small strain (≤ 0.02) and independent of mould material used. However, significant differences occurred beyond the 0.02 strain. The peak tensile strengths and its corresponding strains for cement, CO_2, metal and sand moulds are 118 MPa (0.066), 125 MPa (0.070), 90 MPa (0.034) and 130 MPa (0.01) while the peak elongations are 0.104, 0.082, 0.058 and 0.106 respectively.

The hardness of the cast samples obtained from cement, CO_2, metal and sand moulds are 21.80 HB, 33.70 HB, 26.40 HB and 23.80 HB respectively (Table 5). The impact resistance of cast sample from metal mould is superior (0.421 J) to that obtained in CO_2 mould (0.2536 J). Cast sample made in naturally bonded mould (0.3368 J) is superior to that from cement mould (0.1684 J). Thus, cast done in metal mould possesses superior toughness. In casting, the time it takes to cool a profile depends on the chemistry of the alloy and mould-type [11]. In naturally-bonded sand and cement moulds, the rate of heat extraction was considerably less than in CO_2 and metal moulds. This phenomenon enhanced the hardness of castings made in CO_2 and metal moulds significantly over castings from cement and naturally bonded sand moulds. This is linked to the high rate of chilling and the precipitation hardening effects of the CO_2 and metal moulds. The crystal lattices of Mg_2Si precipitates show coherence with that of the α-aluminum matrix. Consequently, severe strain fields are created around these crystals which impede the motion of dislocations and thereby causing increased hardness of castings obtained from CO_2 and metal moulds [12-14]. The equi-axed grain structures of such precipitates produced in castings from metal and CO_2 moulds are fine compared to castings from cement and natural sand moulds. However, casting produced using CO_2 mould (which is a mixture of rounded sand grains and sodium silicate) has the highest hardness (33.70 HB) which is made possible by the formation of hardened silica gel by the mould which aids its chilling effect [15].

Table 5. Hardness Value for Different Mould-Types.

Mould-Type	CO_2	Metal	Naturally bonded sand	Cement
Hardness Value (HBN)	33.70	26.40	23.80	21.80

Solidification of the aluminum alloy in CO_2 mould-type occurs by nucleation of minute equi-axed grains and developed under the influence of crystallographic and thermal conditions that prevailed due to the presence of silica gel formed by the mould. The rate at which heat is being extracted from the alloy as it enters the CO_2 mould is faster than other mould-types. These characteristics resulted in improved hardness and reduction in impact resistance of the aluminum alloy (Table 6).

Table 6. Impact Test Results for Different Mould-Types.

Mould-type	CO_2	Metal	Naturally Bonded Sand	Cement
Impact Resistance (Nm)	0.2526	0.421	0.3368	0.1684

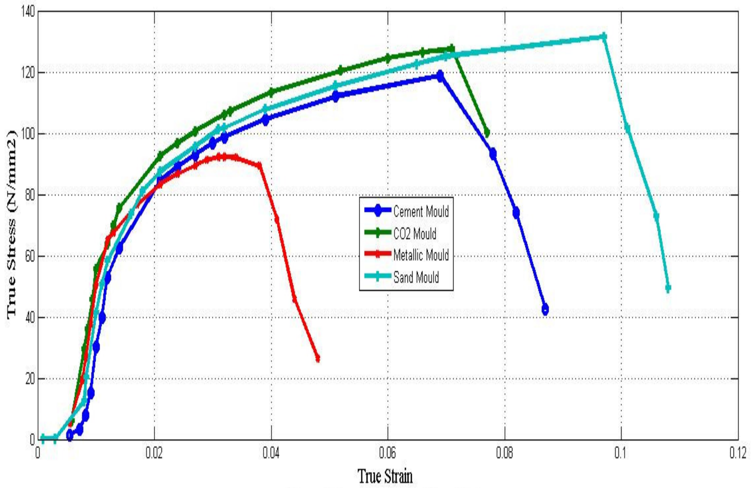

Fig. 3. True Stress against True Strain.

Other critical factors which influenced the hardness and impact resistance results of cast samples made in these moulds are the degree of surface smoothness and permeability of the moulds. Surface finish of metal and CO_2 moulds are better than that of natural-sand and cement moulds. The natural-sand mould consists of sand grains of different sizes which exhibited low level of permeability due to interlocking nature of the sand. In such mould, heat transfer is slow and rate of solidification will be high. Cement and natural-sand moulds show similar heat transfer characteristics. Cement mould is characterized with poor permeability due to the formation of Portland cement silica gel.

Figures 4(a-d) show the microstructures of the samples cast from CO_2 process, naturally-bonded sand, cement-bonded sand and metal moulds. The microstructures generally consist of fine crystals of α-aluminum, Mg_2Si, and AlMgSi phases. The volume fractions of these phases are present in an approximately the same proportion in the matrix. However the average crystal size and shape differ within each of the matrices. In samples cast with CO_2 and naturally-bonded sand moulds the crystal of α-aluminum Mg_2Si and AlMgSi phases, Figs. 4(a) and (d), are averagely fine and well dispersed in the matrix. Small crystals of Mg_2Si are also found in clustered form and this occurrence will hinder the motion of dislocations with tendencies for the formation of dislocation pile up. This phenomenon has a contributory effect for the appreciable increase in hardness and strength recorded in cast samples obtained in CO_2 and naturally-bonded sand moulds as shown in Table 1 and Fig. 3 respectively (Adeosun, 2006). In Fig. 4(c), clustering of Mg_2Si crystals in α-aluminum are observed in cast sample produced in metal mould, due to mould's high thermal conductivity property. It is also observed that there is significant reduction in volume fraction of AlMgSi in the matrix. This adversely affects the hardness value obtained in Table 5. In Fig. 4(d) cast sample matrix, there is increase in volume fraction of AlMgSi with clustering of its crystals. Crystals of AlMgSi are evenly dispersed in the α-aluminum matrix and this enable easy flow of dislocations.

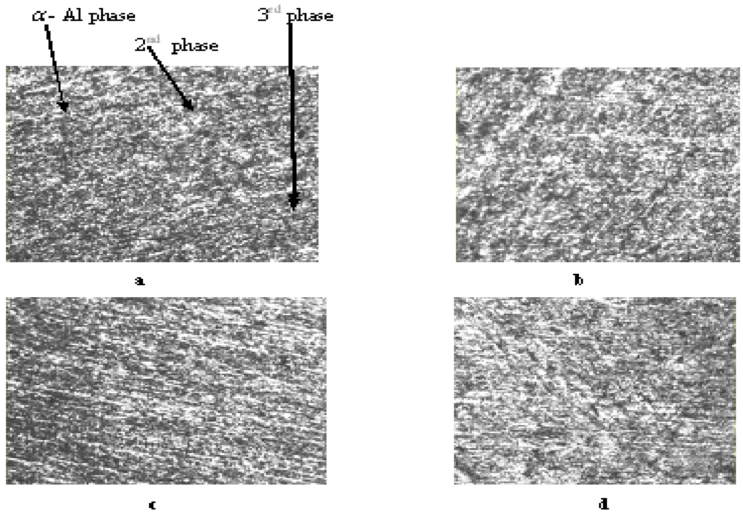

Fig. 4. Microstructures of Cast Samples (a) CO_2, (b) Cement, (c) Metal and (d) Sand Moulds.

4. Conclusions

In this study, it was discovered that strength of cast 6063 aluminum alloy does not depend on mould materials at a small strains (≤ 0.02). The slow rate of heat lost in naturally bonded sand mould can be utilized to obtain improve strength in this aluminum alloy. The high hardness values observed in samples made in metal and CO_2 moulds are due to the chilling effects of the moulds on the solidifying 6063 aluminum alloy. Surface finish of cast samples depends on the mould materials, physical, thermal and chemical properties.

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