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EVALUATION OF THE PERFORMANCE OF VARIOUS MATERIALS AS CHILLS IN SAND CASTING OF AN ALUMINUM ALLOY

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Abstract:

This study has evaluated the effectiveness of metallic materials as chill in sand casting of aluminium alloy. Four plates of dimension 165mm x 80mm x10mm were cast using sand mould. Steel, copper and brass chills in form of cylindrical bar of geometry 7mm in diameter and 50mm long were inserted, side by side at regular intervals of 30mm in each sand mould and the last sample was left unshelled. Experimentation involved testing of mechanical properties and metallographic analysis of cast samples. The results obtained revealed that the sample chilled with copper has the highest mechanical properties.

Keywords:

casting; chills, aluminium alloy, impact strength test, mould

INTRODUCTION

Metal casting is a shape forming process whereby molten metal is poured into a prepared mould and allowed to solidify such that the shape of the solidified object is determined by the shape of the mould cavity. Sand casting is a metal casting process characterized by using sand as the mould material (Ibadite, 2001). Casting can be broadly divided into two main categories as expendable and nonexpendable mould casting. It can also be classified according to the mould material used to cast the metal such as sand casting, ceramic casting or metal mould casting and depending on the pouring methods as gravity casting, low pressure die casting and high pressure die casting (Navaneeth, 2009). Good mechanical properties are achieved in sand casting with the help of metallic insert in the mould known as chill (Mehr, 2012). Strong directional solidification is difficult to obtain in casting of intricate part made of aluminium alloys without the use of chills. The tendency for solidification to start throughout the metal makes proper feeding difficult. Chills must often be used to obtain satisfactory directional solidification (Chi-Yuan et al., 2006). Chills are metallic inserts moulded into the sand surface to promote high solidification rate in metal casting. Normally the metal in the mould cools at a certain rate relative to thickness of the casting. When the geometry of the moulding cavity prevents directional solidification from occurring naturally, a chill can be strategically placed to help promote it to obtain good mechanical properties. Chills are of two types, internal and external chills. Chills are usually made from iron, aluminium or copper and can be machined or cast. The type of chill used depends on ease of manufacture and the desired thermal effects of the chill. Its effectiveness depends on size, conductivity, thermal capacity and the thermal transfer across the molten metal alloy/chill interface. Chilling has been found to improve the soundness of a casting when measured by standard non-destructive testing techniques like radiography or dye penetration inspection, but the influence of microstructure and mechanical properties can be significant (David, 2011). This research purely emphasized on evaluation performance of different material as chill in sand casting to increase solidification rate and to improve the mechanical and microstructural properties.

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MATERIALS AND METHODS

The materials used in this research work include; # Aluminium alloy scrap: Aluminium alloy scrap was obtained from pantmaker (a spare part market) in Kaduna metropolis, Nigeria. # Chills: Mild steel, brass and copper chills were used in this research work. # Foundry sand: Foundry sand and other additives used in the present investigation were made available in metallurgical and Materials engineering foundry workshop of Ahmadu Bello University, Zaria.

Equipment

Furnace: The melting of the alloy was carried out on charcoal fired furnace available in metallurgical and Materials engineering workshop. # Vicker Hardness Tester: Vicker Hardness machine of capacity 10 kg was used to carried out the hardness test of the samples. # Charpy Impact Tester: Impact test was carried out on a Charpy Impact Testing Machine of capacity 25J. # Optical Metallurgical Microscope: Microstructural examination was conducted on optical metallurgical microscope available at Metallurgical and Materials Engineering workshop. # Hounsfield Tensimeter: Tensimeter machine in Mechanical Engineering workshop was used to carry out tensile test for the samples. # Thermocouples: Thermocouples were employed in the measurement of temperature gradient of the solidifying metal during casting operation.

Experimental Procedures

The experimental procedures of this study consist:

Casting of Alloys

Four samples of the aluminium silicon alloy were cast by melting the spare part scrap on charcoal fired furnace using four different sand moulds where three of the moulds were inserted with steel, brass and copper chills respectively and the fourth one without chill which serve as control. The castings were labelled as samples A, B, C and D accordingly. The sample geometry is 165mm x 80mm x

10mm and the chill is of cylindrical shape of diameter 7mm with length 50mm. There are 10 pieces of chills in each mould and the chills were arranged side by side at regular intervals of 30mm. The fluxing and degassing were done before the molten metal was poured into the mould's cavity. The rates of cooling (temperature gradient) were studied with the aid of thermocouples attached to the sand mould immediately before the pouring of the molten metal. The arrangement of the chills within the sand mould is shown in Figure 1 whereas sand mould without chill is shown in Figure 2. The chemical composition of the sample is presented in Table 1

Figure 1: Sand mould with chills

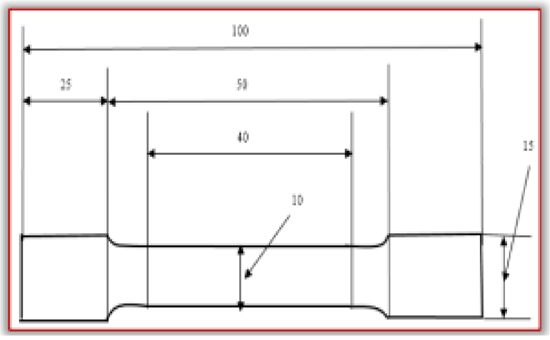
Figure 2: Sand mould without chill Table 1: chemical composition of the cast aluminium alloy

Al	Si	Mg	Fe
90.742	7.155	0.388	0.359
Cu	Mn	Zn	Ti
1.228	0.054	0.008	0.066

The chemical analysis of the cast samples was conducted in the Tower Aluminium Rolling Mills Industry, Ogun State using Optical Emission Spectrometer

Tensile Strength Test:

The tensile test specimens were machined from the cast samples. The test piece was locked securely within the grips of the Tensimeter machine. The test piece was stretch with force generated from manually operating the screw attached to the Tensimeter until the test piece broke apart. The load and extension data available from the graph sheet attached to the machine were converted to specific values of stress and strain. The geometry of the tensile test sample is shown in Figure 3.



Hardness Test

Hardness test was carried out on Vicker Hardness testing machine. An inventor was placed above the sample flat surface. A load of 50gm was applied on the inventor for about 10-seconds which then penetrates the surface of the sample and the hardness value is displayed on the machine. Three different indentations were made on a sample and the average is taken as the hardness value of the samples. This procedure was repeated for the remaining samples.

Impact Strength

Test Charpy Impact Testing machine was employed in conducting the impact test of the samples. A V-notch was machined into a 10mm wide and 100mm long test pieces with the notch depth of 4mm. The specimen was placed across parallel jaw of the testing machine and a heavy pendulum, released from a known height, struck and broke the test piece. This measured the energy necessary to fracture the standard notch test piece by an impact load and the dial pointer of the scale on the machine indicates the energy absorbed, in Joules, by the test piece from the impact. The value of the energy absorbed in breaking the test piece was recorded for the whole samples.

Metallographic Examination

Four specimens were prepared from the four aluminium alloy samples for metallographic examination. The procedure consists of cutting, successive grinding using silicon carbide grit paper of 240, 320, 400 and 600 microns. Polishing was carried out on a rotating cloth to ensure mirror-like surface. A solution containing 5ml nitric acid, 2ml hydrofluoric acid and 100ml of distilled water was used to etch the specimens for about 10 seconds. The specimens were observed under Digital Metallurgical Microscope where the micrographs of the specimens were recorded at a magnification of 100X. The results of the tests carried out are shown in Table [2-3] below.

Time (min)	Sample A (J/min)	Sample B (J/min)	Sample C (J/min)	Sample D (J/min)
0	503.0	479.0	472.5	490.5
4	495.0	452.7	419.2	473.2
8	461.3	429.2	383.1	438.9
12	423.2	398.4	351.3	404.8
16	387.0	366.9	324.0	382.7
20	358.4	339.6	303.0	358.8
24	334.3	317.2	285.0	337.1
28	315.2	299.1	270.0	318.9
32	299.6	284.0	258.0	302.4
36	286.5	272.0	247.7	287.0
40	276.0	262.3	240.0	277.1
44	265.5	252.7	232.3	266.3
48	258.4	246.4	226.7	258.3
52	251.1	239.5	221.6	251.5
56	245.2	233.7	216.9	244.3
60	239.2	228.8	212.5	238.4

Samples: A- steel chill, B- brass chill, C- copper chill and D- no chill. Table 3: Mechanical properties of aluminium alloy

Samples	Ultimate tensile strength (MPa)	Hardness (Hv)	Impact Strength (J)
A	101.33	5.40	22.7
B	115.83	5.73	22.4
C	126.13	6.87	23.5
D	70.67	4.2	22.5

Influence of chill materials on solidification of aluminium alloy

Cooling rate plays an important role in determining the microstructure of the casting. Higher cooling rate reduces solidification time and grain size of the casting. This may be attributed to the solidification process of aluminium alloy where a high percentage of solids are formed during the earlier stages of freezing and is followed by a pasty mode of solidification with non-equilibrium eutectic solidifying at the end. Nucleation initiated at the mould wall, chill surface or at dispersoids and then spreads quickly into the interior of the liquid metal in the mould cavity and crystallization occurs at numerous centres in the liquid as presented by Joel, (2001). Hence, at this stage, a pasty mass of liquid and solid exists along with the fully solid and fully liquid zones containing intermetallic particles. It is evident from Figure 4 that casting with copper chill solidified faster than any other one with other chills. This is followed by brass chill and casting with steel chill almost has the same solidification rate with that of no chill at the beginning but slightly higher than no chill casting towards the end of the solidification. The volumetric heat capacity and thermal conductivity of copper is higher than that of brass and steel which enable the copper chill to extract heat faster than any other chill materials from the melt. The brass is

higher than steel in terms of thermal conductivity and this also enhance its heat extraction rate from the melt faster than steel as a chill material. The steel chill shows little heat extraction rate when compared to the casting where chill material is not inserted in the mould. These observations of solidification gradient influence strongly the types of structure and the mechanical properties of the aluminium alloy formed

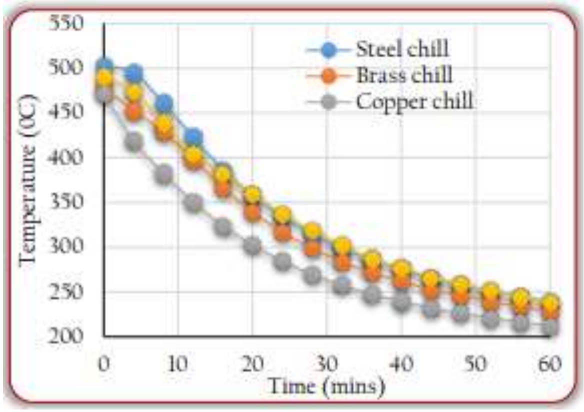


Figure 4: Cooling curves of aluminium alloy during solidification

Influence of chill materials on ultimate tensile strength of aluminium alloy

It is well known (Joel, 2001) that aluminium alloys that freeze over a wide range of temperature are difficult to feed during solidification. The dispersed porosity caused by the pasty mode of solidification can be effectively reduced by the use of chills as presented by Joel (2001). Chills extract heat at a faster rate and promote directional solidification. The casting with copper chill shows the highest ultimate tensile strength followed by the casting chilled with brass. This is as a result of high values of thermal conductivity displayed by the copper and brass materials. The casting with no chill material shows the least ultimate tensile strength when compared to the steel chilled casting indicating the essence of presence of chill materials in improving the soundness of the casting.

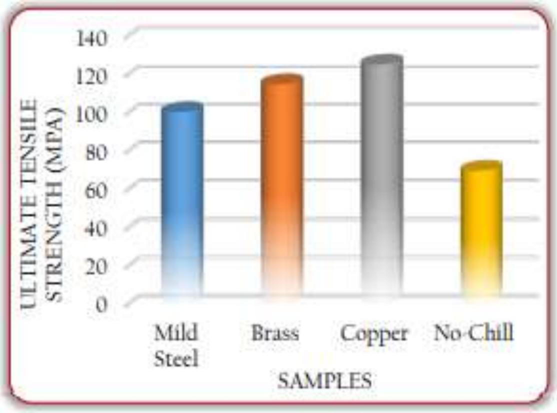


Figure 5: Chart of ultimate tensile strength of samples with different chill materials

The reason for these observations is attributed to the types of microstructures formed during solidification. A fine-grained material is harder and stronger than one that is of coarse grain

structure, since the former has a greater total boundary area to impede dislocation motion as observed by William (2009). The copper chilled sample are characterized with finer grains structure with uniformly distribution of intermetallic particles due to high heat extraction rate and when this sample was subjected to tensile experiment, the material shows a high ultimate tensile strength before fracture occurred. This trend was also observed in other samples chilled with brass and steel. The ultimate tensile strength of sample with no chill which are predominately characterized with coarse grains structure is very low due to slow cooling rate.

CONCLUSIONS

From the results and discussion of the study, the following conclusions can be drawn; # The cast aluminium alloy sample with copper chill displayed the highest mechanical properties (ultimate tensile strength of 126.13mPa, hardness value of 6.87Hv0.05 and impact strength of 23.5j respectively) and finer grains structure than any other samples under investigation. The cast sample inserted with brass chill also shows higher values in mechanical properties than sample with steel chill and unshelled sample. The cast sample inserted with copper chill solidified faster than any other cast sample with chill. The cast sample inserted with brass chill solidified faster than the cast sample with steel chill. # The coarseness of the grains in the microstructure of these samples also increased from samples chilled with brass, steel and no chill.

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