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COMPARATIVE STUDY OF THE MECHANICAL PROPERTIES OF SAND-CAST AND DIE-CAST ALUMINIUM FOR ENGINEERING APPLICATIONS

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ABSTRACT

In this study, the mechanical properties of scraped and recycled Aluminium cooking utensils were examined to assess their suitability for engineering applications. The scraps collected from dump sites and other places were melted and cast into sample rods using sand casting and die casting methods. Cast components were then machined into standard dimensions to suit available machines for testing. The tests carried out include composition before and after melting, tensile testing, and hardness testing as well as metallographic test. Universal testing machine was used for tensile test while Rockwell B scale testing machine was used for hardness test. Ultimate tensile test value of 161.34N/mm^2 and 172.25N/mm^2 were obtained for sand-cast and die-cast specimens respectively, Hardness result value of 23.3 HRB was obtained for sand-cast sample while die-cast sample had a result of 26.7HRB. Metallographic investigation reveal that die cast samples have better mechanical properties with closely packed grain size and surface finish compared to sand cast samples. It was then concluded that aluminium cooking utensils can be recycled and reused for other useful engineering applications where less strength and hardness are required.

Keywords: Aluminium, sand-casting, die casting, mechanical properties

1.0 Introduction

The mechanical properties of a material are very paramount in design of machine components as they are among the most important characteristics when subjected to applications. Aluminium being one of the widely used non-ferrous materials is being presently produced by re-melting used Aluminium pots and cans. The resulting molten metal is then cast into new aluminium component using either sand or die casting process. Sometimes, the cast component may need to be machined to obtain the desired component or surface roughness. According to Olaiya, et al [1], the major factors influencing the use of aluminium and its alloys include high strength to weight ratio, resistance to corrosion by many chemicals, high thermal and electrical conductivity, non toxicity, reflectivity, ease of forming and machining, etc.

Aluminium and its alloys find useful applications in building (roofing sheets, partitioning, windows and doors), production of containers and packaging (aluminium cans and foils), transportation (aircraft and aerospace, buses, automobiles, railway cars and marine craft), electrical applications (as a non magnetic and electrical conductor), consumer durables (appliances, cooking utensils and furniture). Consequently, the need for thorough investigation of its properties cannot be over-emphasized as this will be the determining factor in predicting it's behaviours under various service conditions. To a design Engineer, a material must possess suitable mechanical properties, prominent among which are strength and hardness. These properties are reflections of the response of the material under applied load or force. Properties of material may also be significantly affected by it's metallurgical condition. Metallurgically, Aluminium is of face centre cubic (FCC) structure and is usually alloyed with one or more elements to accomplish desired mechanical properties. The knowledge of melting temperature of metals and alloys is necessary in estimating their corresponding pouring temperature [2]. Aluminium has a melting temperature of 660^{o}C with a corresponding pouring temperature range of 700^{o}C to 750^{o}C [3]. The use of sand and die casting processes are very common in casting components made of Aluminium and its alloys. Sand casting process is one of the expendable mould methods and is considered the most widely used casting process due to its economical characteristics. This process is used to produce approximately 70% of all metal cast [4]. Die casting process has been widely used to manufacture large variety of products with high dimensional accuracy and productivities. It has a much faster production rate in comparison to other methods and it is an economic and efficient method for producing components with low surface roughness and high dimensional accuracy. All major Aluminium automotive components can be produced by this technology [5 – 10]. The casting of a very warm alloy into a cold mould cavity causes serious strain on the surface layers of the mould material. The temperature of the alloy for die casting has to be higher by about 10 – 20oC than the initial recrystallization temperature [11].

1.1 Nature of the Problem

Aluminium and its alloys are commonly used in automobile industry, production of cooking utensils, roofing sheets and components of air craft. After some period of use, these components become worn or faulty and then discarded constituting in environmental pollution. This trend, if not controlled might aggravate the problem of environmental pollution. Hence, the need to examine reusability of these scraped aluminium components becomes very paramount. This will involve re-melting the scraped components, alloying, casting into standard components and conducts tests to examine the actual properties. These properties are then compared to standards to determine further useful engineering applications.

2.0 MATERIALS AND METHODS

2.1 Materials

For this study, the material used was scraped Aluminium cooking utensils picked up from dump sites and along the streets. This category of scraps is abundantly available in our environment.

2.2 Methods

2.2.1 Melting and Casting of Specimen

The scraped cooking utensils collected were properly washed and cleaned with water. It was then cut into pieces, charged in crucible pots and melted in fuel-fired crucible furnace. The melting lasted for 1 hour 15 minutes. The material was heated to a temperature of 700^{o}C which is 60^{o}C above the melting temperature of Aluminium (660^{o}C). This is to allow for temperature drops normally encountered during pouring of molten metals. The temperature was monitored by means of a radiation pyrometer. After the charging has been added, the mixture was stirred and the slag removed [12]. By means of a ladle, the molten metal was carried to a pouring area and the pouring was facilitated by a gating system designed to enhance easy flow of molten metal into the cavity of the sand mould. This prevented erosion of mould walls which may bring about formation of slag inclusions in the castings [13]. Die casting was also carried out using the same process.

After solidification, the casting was allowed to cool to room temperature before removal. The cope and drag parts of the moulding box were separated and the cast product removed by knocking it out of the mould. The procedure was replicated three (3) times to produce three sets of test samples.

2.2.2 Determination of Chemical Composition

For the purpose of determining the composition of the cast specimen, an optical emission spectrometer was used.

The procedure involves cutting a small piece of the prepared specimen having a thickness of 10mm from the cast stock by means of a hacksaw. The surface of the material was then prepared by proper filling, smoothening and polishing using file, sand paper and emery clothe respectively. The prepared specimen was then positioned in the machine's burning chamber and the machine switched on. After three buzzer alarms, the specimen was removed and the material chemical composition appears on the computer screen.

Plate I: Optical Emission Spectrometer

2.3 Testing

2.3.1 Tensile Testing

The American society for testing and materials (ASTM) specifies test procedure for determining the various properties of materials [14]. Cast test pieces machined to ASTM specification and to also suit the universal testing machine was used. The samples have a gauge length of 50mm and diameter of 12.5mm. The test pieces were gripped in the jaws of the universal testing machine and then subjected to tensile loading until fracturing occurs. The fracturing force was then noted and recorded. The broken test pieces were then removed from the machine and the neck diameter measured and recorded. The two broken pieces were then placed together and final length was measured.

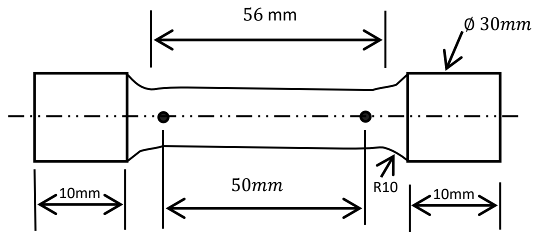

Figure 1: Tensile test specimen before test

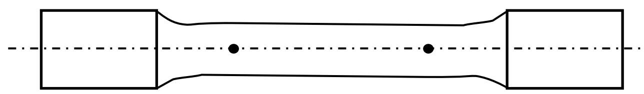

Figure 2: Shape of specimen after elongation

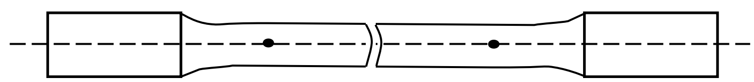

Fig. 3: shape of specimen after fracture

2.3.2 Hardness Testing

According to Davies and Delman [15], the hardness of a metal is it's resistance to surface indentations under standard test conditions. Hardness is also a measure of resistance of metal to wear, scratching, abrasion and cutting. In this study, the Rockwell test method was used. The test piece was positioned on the machine table and the indenter was brought in contact with the prepared surface under a minor load of 10kgf. This takes off the slack in the system and dial indicator was set at zero. The major (additional) load was applied, and the reading of the dial indicator became steady, the major load was taken off. The test piece remained under the minor load while the hardness value was read directly from the dial indicator. About nine (9) scales of hardness are available (A to k inclusive) but the most commonly used are the B and C scales [16]. For this study, 'B' scale was used.

2.3.3 Metallographic Test

Metallographic test include all methods of determining the structure of metals. It includes both macroscopic and microscopic examination [17]. In this study, the term is confined only to microscopic examination. Microscopic examination of a material involves three distinct steps. This includes surface preparation, chemical etching, actual observation and recording of the structure.

Specimen Preparation

By means of hack-saw, specimen of 20mm diameter and thickness of 10mm was cut from the cast stock. The specimens taken are true representatives of the mass of the material as they are out from the transverse section of the material in the as cast condition. A file was then clamped horizontally in a vice and the specimen was rubbed on it. When the hack-saw mark was no longer visible, the specimen was washed in running water to remove loose grits. Grinding was then carried out on abrasive silicon carbide papers of successively finer grades, lubricated by a gentle flow of water.

The specimen was then rubbed back and forth, first on the 220 grade paper in a direction roughly at 90^o to the scratches left by filling. When the filling scratches have been removed, the specimen was washed free of grit. Grinding continued on the 240 grade paper after turning the specimen through 90^o. Grinding was continued until previous scratches were removed. The process was then repeated with 400, 600 and 1000 grade papers. During the grinding operations therefore, each set of parallel scratches have been successively replaced by a finer set. Finer polishing which completely removes the fine scratches and make the surface smooth was then carried out. This is accomplished by slightly pressing the specimen on a rotating cloth pad impregnated with a paste of alumina in a rotary wheel polishing machine which provides circular motion to the wheels. Polishing was then continued until the surface was satisfactorily free of scratches. The specimen was then thoroughly washed in warm water; the surface swabbed with methylated spirit, and dried using warm air.

Chemical Etching

This is accomplished by immersing the specimen in a suitable chemical reagent (for this study, hydrofluoric acid was used) by means of tongues. The etching reagent gradually dissolves the surface layer of the specimen and preferentially attacks the grain boundaries. The progression of the etching was observed and, when the specimen surface appears dull, the specimen was quickly removed to running water. This exercise lasted a period of 30 seconds. The specimen was then dried by spraying the surface with methylated spirit and blowing with warm air.

Microscopic Examination

The prepared specimen was then viewed under metallurgical microscope and its photograph taken by means of a camera. These are shown in plates I to IV.

3.0 RESULTS AND DISCUSSION

3.1 Chemical Composition

The chemical composition that result is presented in tables 1 and 2.

Table 1: Chemical composition before melting.

Element	**Al**	**P**	**K**	**Ca**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Ni**
% Composition	98.3	0.23	0.55	0.21	0.035	0.006	0.094	0.036	0.684	0.017
Element	**Cu**	**Zn**	**Ga**	**Aa**	**Y**	**Ru**	**Pb**	**P**	**-**	**-**
% Composition	0.1743	0.104	0.020	0.002	0.02	0.012	0.27	0.012	-	-

Table 2: Chemical Composition after melting.

Element	**Al**	**P**	**K**	**Ca**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Ni**
% Composition	97.2	0.24	0.22	0.049	0.009	0.015	0.073	0.776	0.016	0.076
element	**Cu**	**Zn**	**Ga**	**Aa**	**Y**	**Ru**	**Pb**	-	-	-
% Composition	0.0140	0.028	0.016	0.279	0.79	0.00	0.073	-	-	-

The chemical composition result revealed that that Aluminium pot scrap before melting is 98.3% pure Aluminium while the sum of other elements is 1.7%. After melting, the material was found to have 97.2% Aluminium while other elements present sum up to 2.8%

3.2 Tensile Test

The result of tensile test is presented in table 3.

Table 3: Tensile test results.

Casting process	Yield Stress (N/mm2)	UTS (N/mm2)	% Elongation	%Reduction in Area
Die - casting	125.15	172	10.4	18.3
Sand - casting	101.6	161	8.0	15.4

As shown on table 3, the investigation carried out gave an ultimate tensile strength (UTS) result of 161.3N/mm2 for sand cast specimen and 172.25 N/mm2 for die cast specimen. UTS values of 75N/mm2; 115.34N/mm2 and 150N/mm2 was given for soft, half hard and hard aluminium sheets of 99.5% purity [15]. Percentage elongation of 8.0 and 10.4 were obtained for sand cast and die cast samples respectively.

Percentage reduction in area values of 15.4 and 18.3 were obtained for sand cast and die cast samples respectively.

3.3 Hardness Test Results

The hardness test result is presented in table 4

Casting process	Rockwell (RB) Hardness			
	Test 1	Test 2	Test 3	Mean
Die casting	27.0	26.5	26.6	26.7
Sand casting	23.5	23.0	23.4	23.3

The differences and deviations in values obtained could be due to variations in pouring speed, which significantly affect solidification of the casting. This invariably determines crystals arrangement and ultimately affects the mechanical properties. According to Ndaliman and Akpan [18], for Aluminium alloys the optimum pouring temperature range is between 700oC and 750oC. This is the region where good quality casts are produced with good mechanical properties. The pouring speed range, which gave the best surface finish, is between 2.0cm/s and 2.8cm/s. Optimum values of hardness, tensile strength and deformations were obtained at this temperature range.

It was discovered that the ultimate tensile strength and the hardness values increased in the order of sand casting and die casting. This may be attributed to the solidification rate of the molten metal in different moulding materials. In sand casting, the cooling and solidification rate is retarded by the insulating properties of the sand mould resulting in coarse structure which reduce both tensile strength and hardness values. Similarly, in permanent mould and die casting methods, rapid cooling and solidification rate can be attributed to the conducting properties of the metallic mould which results in the formation of fine crystals which ultimately enhance higher tensile strength and hardness values.

Values obtained for percentage elongation and percentage reduction in area revealed the non ductility property of the die cast specimen with little plastic deformation. The sand cast Aluminium sample is a little more brittle in comparison with die cast specimen.

3.4 Microstructure

The microstructure of the specimens are shown in plates I to IV

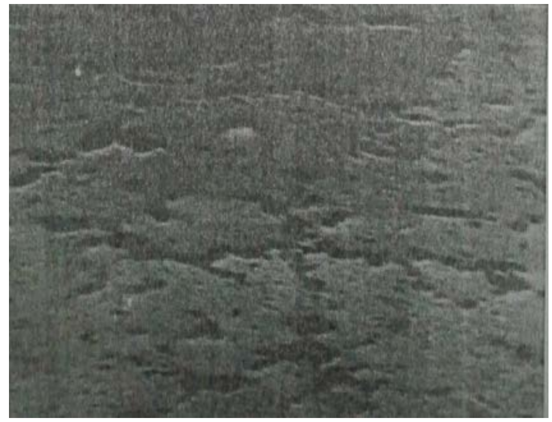

Plate I: Micrograph of unetched sandcast Aluminium scrap x 400

Plate II: Micrograph of unetched die cast Aluminium scrap x 400

Plate III: Micrograph of etched sandcast Aluminium scrap x 400

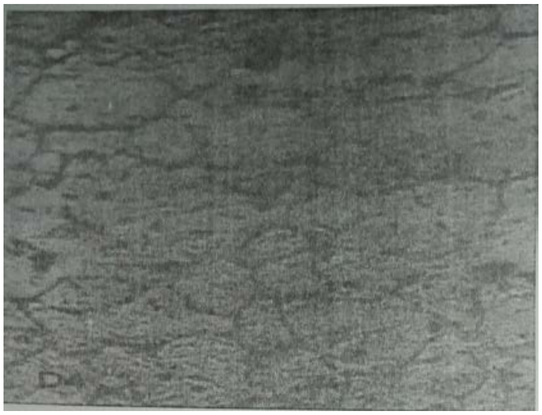

Plate IV: Micrograph of etched die cast Aluminium scrap x 400

Plate I: Unetched sand cast Aluminium scraps. The micrograph clearly shows deformation that has produced coarse elongated grains which clearly show a fatigue failure believed to have been caused by the way and manner the scraped cooking utensil was bent or stretched during casting. The micrograph shows that the region at which failure occurs on the grains are more compared to the region where failure did not occur.

Plate II: Unetched die cast aluminium scraps. The micrograph shows deformation which produced tiny elongated grains. The extent of deformation could not be clearly seen.

Plate III: Etched sand cast aluminium scraps. The micrograph shows deformation that is worse. The grains clearly show fatigue failure that is very obvious.

Plate IV: Etched die cast aluminium scraps. The micrograph clearly shows deformation which produce elongated grains. It is clearly seen that fatigue stirations has occurred on the grains which are yet to reach the stage of fatigue failure.

4.0 CONCLUSION

Mechanical properties of sand cast and die cast aluminium pot scraps have been investigated. The result have shown that die cast aluminium pot scraps have better mechanical properties than sand cast ones. This could be attributed to factors which include pouring speed, cooling and solidification rate, crystal arrangement and gating and risering design. It is also discovered that scraped aluminium pots can be re-used after recycling for other useful engineering applications especially for household utensils and other purposes where less strength and hardness are required.

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