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Effect of Sand and Permanent Casting Methods on Impact and Fatigue Properties of Cast 6063 Aluminium Rods

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ABSTRACT: This experimental investigation were carried out to determine the effect of sand and permanent methods on the impact and fatigue properties of AA6063 Aluminum. Sand and permanent moulds were fabricated and used to pr5oduce Aluminum rods. The test samples from cast rods were subjected to mechanical tests. The results obtained showed better impact and fatigue properties in the sand cast samples than the permanent samples. In impact strength analysis, the toughness increased in sand casting, with 6.1J against that of permanent casting of 5.2J. The fatigue life also increased from 1532.8MPa to 1680MPa on permanent and sand casting respectively. Conversely, the impact and fatigue properties of the cast products improved from permanent casting to sand casting. Therefore, sand cast products could be used in as-cast condition in engineering applications requiring better quality parts while permanent casting may be used in as-cast condition for non-engineering applications or engineering applications requiring less quality parts.

KEYWORDS: Sand Mould, Permanent Mould, Impact Properties, Fatigue Properties, Cast Aluminium Rods.

I. INTRODUCTION

Aluminium is the most abundant metal in nature. Some 8% of the weight of the earth crust is aluminium[1]. Aluminium is the most widely used non-ferrous metal, being second only to steel in world consumption[2]. The unique combination of properties exhibited by aluminium and its alloy make aluminium one of the most versatile, commercial and attractive metallic materials for a broad range of users, from soft, highly ductile wrapping foil to the most demanding engineering applications. Aluminium and many of its alloys can be worked readily into any form indeed and can be cast by all foundry processes. It accepts a variety of attractive, durable functional surface finishes. [3]

Aluminum alloys find extensive usage in engineering applications due to its high specific strength (strength/density). These alloys are basically used in applications requiring lightweight materials, such as aerospace and automobiles. The 6xxx-group alloys have a widespread application, especially in the building, aircraft, and automotive industry due to their excellent properties. The 6xxx series contain Si and Mg as main alloying elements. These alloying elements are partly dissolved in the primary α-Al matrix, and partly present in the form of intermetallic phases. A range of different intermetallic phases may form during solidification, depending on alloy composition and solidification condition[4]

Casting can be defined as a process whereby molten metal is poured inside a mould cavity and allowed to solidify to obtain required size and shape.Casting is one of the oldest manufacturing processes which dates back to approximately 4999BC. The manufacture and use of casting can be traced to both ancient and medieval history[5]

The basic simplicity of the casting process proves to be a boom for the growth of foundry industry and today a wide variety of products (or components) ranging from domestic to space vehicles are produced through foundry technique. The historical perspective of foundry in Nigeria shows that foundry is the oldest engineering industry, starting over twenty centuries ago.[6]

Casting has remarkable advantages in the production of parts with complex and irregular shapes, parts having internal cavities and parts made from metals that are difficult to machine. Because of these obvious advantages, casting is one of the most important manufacturing processes, the various processes differ primarily in the mouldmaterial and the pouring method [5].

Sand casting utilizes sand as the mould material. The small sand particles will pack into thin sections, and sand also may be used in large quantities so that products covering a wide range of sizes and detail can be made by this method. In this process a new mould must be prepared for each casting desired, and gravity usually is employed to cause the metal to flow into the mould.

In sand casting, re-usable permanent patterns are used to make the sand moulds. The preparation and bonding of this sand casting involves the use of cope and drag and wooden patterns. The molten metal is poured into the mould cavity through an incorporated gating system. After the solidification of the molten metal in the cavity, the cope and drag housing the cavity is then dismantled or shaken out. [6]

Permanent-mould casting also utilizes a mould made of metal or graphite into which the molten metal is poured, usually under gravity. The same mould can be used repeatedly to produce a large number of duplicate castings.

Permanent moulds are made of dense, fine-grained, heat resistant cast iron, steel, anodized aluminium, graphite or other suitable refractories. A permanent mould is made in two halves in order to facilitate the removal of casting from the mould. The design may be with a vertical parting line or with a horizontal parting line as in conventional sand moulds. [1]

In a study by Oyetunji [7], the effect of foundry sand size distribution on the mechanical and structural properties of grey cast iron was examined. The results showed that cast sample from fine sand size-grade have highest impact energy value, best tensile strength value, better hardness value and fine surface finish.

Also, Akpan etal.[8] Investigated the degrading of the fatigue life of 6061 aluminum reinforced with boron fires oriented in the 0, 90 and + 45degree directions. The Boron – aluminum composite panels were cut into 6 inch by 0.5 inch specimen and subjected to constant temperature of 148, 260 and 427^{0}C for 10, 100 and 1000 hours and cooled. The fatigue life was measuredfor the various conditions and compared to the – as received condition. Also metallographic studies were conducted on each of the fractured specimens. The fatigue life of boron-aluminium laminate appeared to be unaffected by exposure times at 148^0 and 260^{0}C. Severe reduction (about 50%) in fatigue life occurred only at the 427^{0}C – 1000 hours specimen. Increase in the accumulation of which at the interface did not follow the reduction in fatigue life, showing that the susceptibility of specimen to failure is dependent upon the extent of reaction.

Adeyemi [6] investigated the mechanical properties of Aluminium produced from sand casting under different pre-heat temperatures and shake-out times. Also Sowole and Aderibigbe [9] found that a range of mechanical properties can be obtained in commercially pure Aluminium 1200 by temper-annealing process and that it is possible to select an appropriate temper-annealing schedule that would impart improved strength and provide acceptable ductility of AI-1200 sheets at different levels of cold work.

Oke [4] investigated the influence of rolling operations on the mechanical properties of Aluminium alloy 1200. As-received Aluminium ingots were subjected to rolling, a form of cold working, and thereafter annealed within a temperature range of 300-415^{0}C while others were annealed at temperature of 500°C. Rolling was found to have increasing effects on the strength and hardness but decreasing effects on percentage elongation, percentage reduction in area and impact energy. The tensile strength and hardness of as-received Aluminium ingot increased from 49.06MPa and 15.9BHN to 69.03MPa and 24.6BHN respectively, while the impact energy, percentage elongation and percentage reduction in area respectively decreased from 4.73J, 13.6 and 28.9 to 4.06J, 4.0 and 7.7 respectively due to the rolling operation. However, increase in annealing temperature was observed to decrease the strength and hardness of the as-rolled specimens, while increasing the ductility and impact energy. The tensile strength and hardness of the as-rolled specimen respectively decreased from 69.03MPa and 20.4BHN to 61.37MPa and 19.5BHN when annealed at 500°C, while the impact energy, percentage elongation and percentage reduction correspondingly increased from 4.06J, 4.0 and 7.7 to 4.60J, 25 and 52.9 respectively.

Avalle, et al. [10] worked on static and fatigue strength of a die cast Aluminium alloy under different feeding conditions. They investigated the influence of porosity and casting defects on the static and constant-amplitude fatigue strength of a die cast Aluminium alloy. Three batches of specimens, differing for the sprue-runner design and consequently for content and type of defects, are tested in as-cast conditions. Defects consist in gas and shrinkage pores as well as cold fills, dross and alumina skins. Casting defects are observed to significantly lower the static and fatigue properties of the material. While for the static characteristics the decrease is progressive with the porosity range, for the fatigue strength the decrease is most significant from the lowest to the middle porosity range. The batches are classified with regards to the porosity level, as the metallurgical defects are not detectable a priori through X-ray examination. However, content and size of metallurgical defects are observed to increase with the porosity level. SEM observation of the fracture surfaces proved the important role played by dross, alumina skins and, above all, cold fills on the fatigue fracture.

Agbanigo and Alawode [11] evaluated the mechanical properties of Aluminium-based composites reinforced with steel fibres of different orientations. This work was experimentally investigated, presented and compared with those of unreinforced Aluminium alloy. Unreinforced specimens and composites reinforced with longitudinal and transverse fibres were characterized by percentage elongation at fracture of 12.75, 27.50 and 11.00% respectively; ultimate tensile strength of 83.51, 96.75 and 66.71MN-^{2}, respectively; fatigue life of 209, 458 and16 cycles-to-failure, respectively at 550MNm-^{2} and impact energy of 47.80,51.20 and 45.00Nm, respectively. The least values of mechanical properties exhibited by composite specimens with transverse fibres is attributed to the fact that transverse fibres create areas of stress concentration, which aids initiation and propagation of cracks resulting in early commencement of deformation during testing and fibre matrix rebounding. However, the resistance to deformation offered by longitudinal fibres during testing is responsible for the highest values of mechanical properties displayed by composite specimen with longitudinal fibres.

Gaurav [12] in his work, comparison of sand casting and gravity die casting of A356 AL-Alloy, investigated the possibility of improvement in the mechanical properties of hypo- eutectic Al-Si alloy. Grain refinement and modification of hypo-eutectic Al – Si alloy was achieved by the addition of Al–3%Ti–1%B grain refiner and Al–10%Sr modifier. For achievement of better grain refinement and modification with melt treatment mechanical Vibration set of mould was used. Vibration with different frequency and amplitude has given to the mold at the time of pouring and solidification of the hypo-eutectic Al-Si alloy. In this dissertation work, it is concluded compared to sand casting, permanent mold gravity die castings have high mechanical properties. Compared to only grain refined die casting, grainrefined and grain modified castings have high mechanical properties. Finally it is concluded that increasing vibration frequency to 25Hz results into maximum. Grain refiner and modifier reflect with higher mechanical property.

Raji [13] in his study compared cast microstructures and mechanical properties of aluminium silicon alloy components cast by sand casting, chill casting and squeeze casting methods to produce similar articles of the same shape and size from an Al-8%Si alloy. It was observed that the grain size of the microstructures of the cast products increased from those of squeeze casting through chill casting to sand casting. Conversely, the mechanical properties of the cast products improved from those of sand casting through chill casting to squeeze casting. Therefore, squeeze cast products could be used in as cast condition in engineering applications requiring high quality parts while chill castings and sand castings may be used in as cast condition for non-engineering applications or engineering applications requiring less quality parts.

Awedaetal.[14] Investigated the performance evaluation of permanent steel mould for temperature monitoring during squeeze casting of non-ferrous metals.

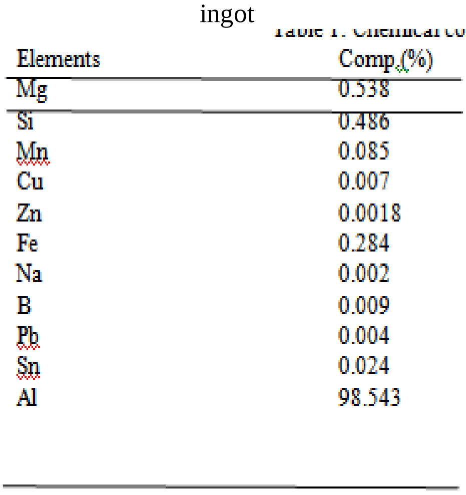
Permanent steel mold was designed, machined and evaluated by monitoring the temperature of squeeze cast aluminium and brass rods on a Vega hydraulic press. The operation was performed with and without pressure on the cast specimen at pouring temperature of 700^{0}C and 980^{0}C for aluminium and brass metals, respectively. The solidification rate (temperature with time) was monitored with a three-channel digital temperature monitor data logger while the tensile strengths of both samples were also determined.

The results showed an increase in the solidification rate for both samples with increase in the applied pressure. The maximum solidification rate for aluminium was obtained at an applied pressure of 127 MPa and 95 MPa for brass. The tensile strength of both samples increased with increase in applied pressure. The maximum tensile strength of 34.38 MPa was obtained for aluminium at applied pressure of 127 MPa and 80.21 MPa for brass at an applied pressure of 95 MPa. Above these values there was no significant increase in the tensile strength with increase in applied pressure. The results obtained were similar to that already established in the literature which make the machined permanent steel mold suitable for squeeze casting of non-ferrous metals.

II. MATERIALS AND METHODS

The material used for the study was AA6063 Aluminium ingot obtained from Aluminium Tower Company, Ota, Ogun State. The chemical compositions of the Al ingot was determined by using plasma spectroscopy metal Analyzer. The results obtained are presented in Table 1.

Table 1: Chemical composition of the aluminium ingot



Elements	Comp.(%)
Mg	0.538
Si	0.486
Mn	0.085
Cu	0.007
Zn	0.0018
Fe	0.284
Na	0.002
B	0.009
Pb	0.004
Sn	0.024
Al	98.543

Design and Fabrication of Experimental Rigs

The experimental rigs used in this research work were designed and fabricated. The rigs comprise of permanent mould and sand mould.

In the design and fabrication some basic of the rigs, factors were considered ranging from cost availability, machinability, melting temperature, durability to maintainability of the materials used in the fabrication.

The mould of the permanent is made up of a steel material of 150mm x 250mm x 50mm sliced into two making it a male and female mould as shown in Fig.1

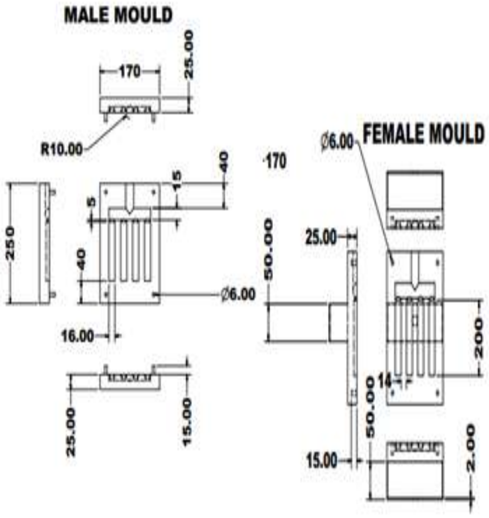


Fig. 1: Male and Female Moulds for Permanent Cast Moulds

The Mould was made of steel plate 50mm thick sliced into two by milling operation. The steel plate block was drilled with the aid of 16mm drill bit in four different places equidistantly to leave a cavity for casting. (See Fig. 2).

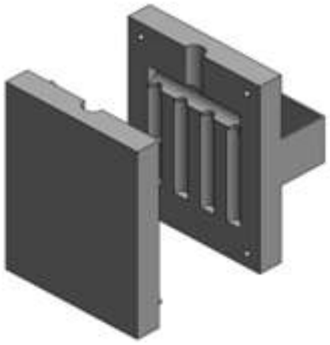


Fig. 2 Permanent Cast Mould

After slicing the steel block, gate and pouring hole were made.A system to hang and house the mould for easy pouring of molten metal and ejection of the solid cast material was constructed. The product of this rig was a permanent cast. (See Fig. 3).

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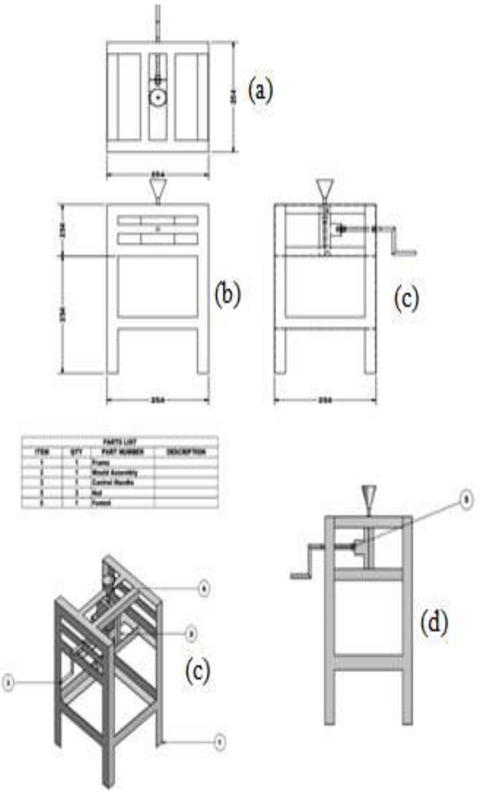

Fig. 3Permanent Mould

Design of Sand Cast Mould

The sand cast mould rig was produced from a mild steel sheet plate 3mm thick having dimensions of 300mm x 150mm x 75mm. This was made of two numbers to form cope and drag for the sand casting . (See Fig. 4).

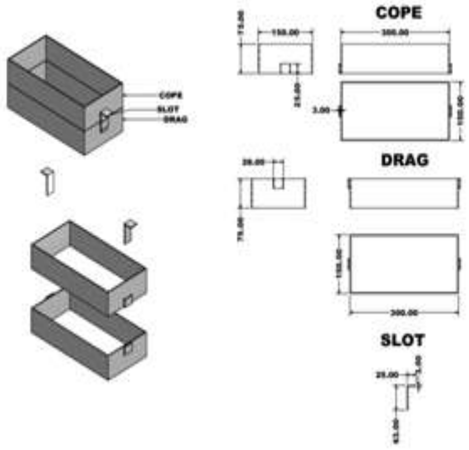

Fig. 4: Sand Cast Flask

Experimental Procedures

The Aluminium ingot was melted using blacksmith open furnace. The hot liquid Al metal was cast into solid rods by sand casting and permanent casting and squeeze casting processes using the fabricated rigs.
The cast rods were rid of excesses from gating, runners, risen, sprue and parting line to give the cast specimen a good shape.

Sample Designation

Aluminum rods were successfully produced from sand and permanent moulds for simplicity and analysis sake, the samples were designated as shown in Table 2

Table 2: Sample designation

S/N	Symbols	Interpretation
1	M_p	Permanent mould
2	M_s	Sand mould

Fatigue Test

Fatigue test specimen were machined from the bulk specimen in accordance with American Society for Testing and Materials E1942 - 98 (ASTM) as shown in Figure 5

The machined specimens were loaded into the Avery Denison Fatigue Machine and subjected to fatigue test in accordance to ASTM test method. The fatigue properties obtained are shown in Fig. 8

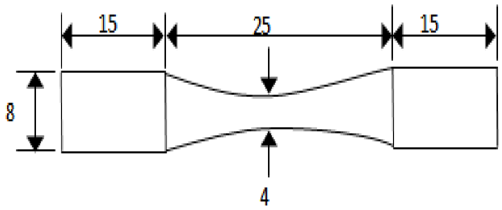

Fig. 5: Fatigue Test Specimen (All dimensions in mm)

Impact Test

Impact test specimen were machined from the bulk specimen in accordance with American Society for Testing and Materials D256 (ASTM D256) as shown in Figure 6
The machined specimens were loaded into the Izod Impact Machine (see Plate 3.3) and subjected to Impact test in accordance to ASTM test method. TheImpact properties obtained is shown in figure 7

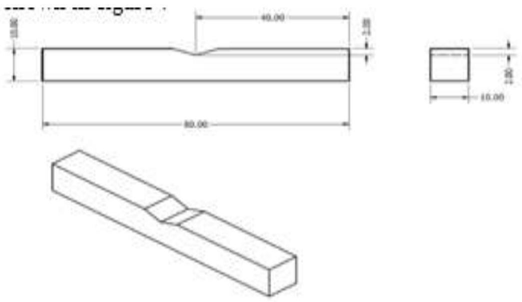

Fig. 6: Impact Test Specimen (All dimensions in mm).

III. RESULTS AND DISCUSSIONS

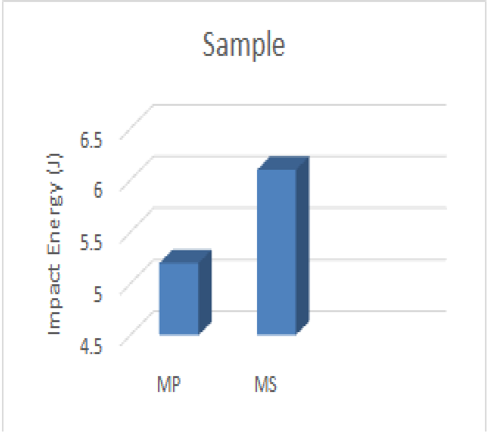

Fig. 7: Effect of Various Casting moulds on Impact Energy

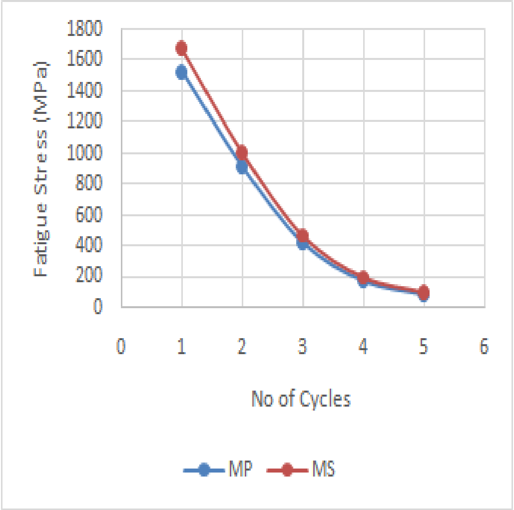

Fig 8: Fatigue Stress against Number of Cycle for M_p &M_s

Impact Properties:

Fig. 7 shows variation of impact energy for sand and permanent moulds. It is revealed that Sand Castings have highest impact values of 6.1J and 5.2J in permanent mould. This indicated that there is increase in the toughness of the Cast Aluminium in sand casting than permanent casting.

Fatigue properties

Variation of fatigue properties of the castings from sand and permanent moulds are shown in figures 8. Increase in fatigue stress was found to shorten the fatigue life of the respective castings. The number of cycle-to-failureis a measure of the fatigue life of the test materials. Castings from sand casting exhibited longest fatigue life with fatigue stress of 1680MPa, N_f of 5 and permanent casting has fatigue stress of 1532.8MPa, N_f of 5. The trend of variation shows that fatigue strength increases in sand casting than permanent casting.

IV. CONCLUSION

This experimental investigation of AA6063 cast Aluminium from fabricated rigs of sand and permanent and squeeze cast moulds, show that fatigue and impact properties of AA6063 are significantly improve in sand castings than that of permanent castings. Sand casting can be employed in as-cast condition where better fatigue and impact properties are required in engineering applications.

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