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RESEARCH ARTICLE OPEN ACCESS

EFFECTS OF SQUEEZE PRESSURE ON CAST 6063 ALUMINIUM RODS

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Abstract:

Experimental investigations were carried out to determine the effect of squeeze cast pressure on the mechanical properties of AA6063 Aluminium. Squeeze cast mould was fabricated and used to produce Aluminium rods. The test samples from cast rods were subjected to mechanical tests. The results obtained showed better mechanical properties,as the pressure increases. The hardness of squeeze casting varied from 72.9 to 82.3Hv, as pressure increases from 35N/m^2 to 110N/m^2. Also, Ultimate Tensile Strength increases with increase pressure in from 178.01 to 194.04Mpa. In impact strength analysis, the toughness increases with increase in pressure. The fatigue life as well increased with increase in pressure. The result of metallography showed that as pressure increases, structural changes occurred as a fine microstructure was obtained with increase of pressure in the squeeze castings. It was observed that the grain size of the microstructure of the cast products increased from those of lowest pressure in the squeeze casting, to the highest pressure in the squeeze casting. Conversely, the mechanical properties of the cast products improved from those of lowest pressure to highest pressure in squeeze casting. Therefore, squeeze cast products could be used in as-cast condition in engineering applications requiring high quality parts.

Keywords:Aluminium cast rods, Mechanical Properties, Microstructure, Squeeze cast mould, Squeeze Pressure**.**

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].

Raji and Khan [7] investigated the effects of squeeze parameters on the properties of squeeze castings and the optimum parameters for producing squeeze castings from Al-Si alloy. It also compared the properties of the squeeze castings with those of chill castings. Squeeze castings were made from Al-8%Si alloy using pressures of 25-150MPa with the alloy poured at 650o, 700o and 750oC into a die preheated to 250oC. Squeeze time was 30s. It was found that for a specific pouring temperature, the microstructure of squeeze castings became finer; density and the mechanical properties were increased with increase in pressure to their maximum values while further increase in pressure did not yield any meaningful change in the properties. Compared with chill casting process, squeeze casting enhanced the mechanical properties; it increased the hardness, UTS, 0.2% proof stress and elongation of the alloy to optimum values of HRF58.0, 232MPa, 156MPa and 3.8% respectively at squeeze pressure of 125MPa and pouring temperature of 700oC. The study concluded, among other things, that optimum pouring temperature of 700oC and squeeze pressure of 125MPa are suitable for obtaining sound Al-8%Si alloy squeeze castings with aspect ratio not greater than 2.5:1.

Other research works are the experimental investigation on squeeze cast product by Chatterjee and Das [8, 9] and Frankl and Das [10] worked on the variation of mechanical properties as a result of varying production parameters such as pressure, pouring temperatures, die temperature and lapse times between pouring and pressure application etc. The improved mechanical properties were due to modification of microstructure of the squeeze cast product by pressure application.

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.

Abifarin and Adeyemi [11] used the longitudinal slitting technique to determine and compare the residual stresses in as-cast and squeeze-cast Aluminium rods. Residual stresses in the squeeze-cast Aluminium alloy rods are found to increase with applied punch pressures under a constant die-base thermocouple reference temperature. For the variations of residual stresses with varying die-base thermocouple reference temperature, a peak residual stress is found to occur at a die-base thermocouple reference temperature of 100°C. A semi-empirical formula was derived for the determination of the maximum longitudinal residual stress in the tapered cylindrical as-cast Aluminium alloy from which the maximum longitudinal residual stresses for squeeze cast can be determined, using the residual-stress ratios obtained experimentally.

Aniyi et al. [12] investigated effects of pressure, die, and stress-relief temperatures on the residual stresses and mechanical properties of squeeze-cast Aluminium rods. The effects of die heating and stress-relief temperatures in reducing residual stresses of squeeze-cast Aluminium alloy rods are experimentally determined by the longitudinal slitting method, and their reduction effects on the mechanical properties of the squeeze-cast alloy rods are investigated. Stress relief is much more effective than die heating in reducing residual stresses of the squeeze-cast alloy. Stress relief is substantially completed at 350°C in lh, but at the expense of reduction in strength and hardness. Appreciable reduction in strength and hardness is avoided by using a stress-relief temperature of 250°C for residual stress reduction of squeeze-cast Aluminium alloy. Die heating to a maximum of 200°C is considered adequate to substantially reduce the chilling effect of the metal mould on the solidifying molten metal and to avoid appreciable reduction of strength and hardness resulting from die heating effects.

Avalle, et al. [13] 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.

Abubakre and Khan [14] developed Aluminium based metal matrix particulate composites (MMPC) reinforced with alumina using stir-casting technique in an attempt to develop Aluminium-alumina metal matrix composite of particulate brand for the Nigerian economy. Various equipment and tools were designed and fabricated for the purpose of synthesizing Al-Si/Al_20_3 composite by stir casting technique. Series of trial experiments were carried out to establish the optimum processing parameters. The strongest among the successfully developed Al-SiAl_20_3 composite was the one reinforced with 5wt.% particles having the ultimate tensile strength (UTS) and yield strength values being 180.85MPa respectively. The produced composites were very brittle with percentage elongation close to zero.

Raji and Khan [15] designed and developed a squeeze casting rig. The study was carried out to modify workshop bending press into laboratory squeeze casting rigs for the purpose of producing high quality squeeze cast component with aspect ratio not more than 2.5: 1. Dies used in conjunction with an electrically operated hydraulic press were designed and constructed. The constructed dies were tested and used to produce squeeze castings from molten AL-8%Si alloy. The squeeze cast products were found to be satisfactory in physical and mechanical properties with average density of 2.86g/cm^3, hardness of HRF 58.0, ultimate tensile strength of 232MPa, 0.2% proof stress of 156Pa and elongation of 3.8%.

Gaurav [16] 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 mechanicalVibration 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 thisdissertation 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 concludedthat increasing vibration frequency to 25Hz results into maximum. Grain refiner and modifierreflect with higher mechanical property.

Obiekea etal. [17] work on the mechanical properties and microstructure of die cast aluminium A380 alloy casts produced under varying pressure was investigated experimentally and compared. The resultsobtained show better mechanical properties i.e. hardness, tensile strengths and impactstrengths in the die cast A380 alloy sample that solidified at high pressure when pressure was regulated

Across five samples of the castings. The hardness of the die cast A380 samples that solidifiedunder different applied pressures varied from 76 to 85 HRN. Also tensile strength, yieldstrength and elongation of the samples showed an increase with increased pressure. Also the resultsof SEM and metallography show that at high pressure, structural changes occurred as a finemicrostructure was obtained with increase of pressure.

Obiekea etal. [18] also investigated the influence of pressure on the mechanical properties and grain refinement of diecast aluminium Al350 alloy was carried out and subsequent analysis made. The results obtained from the microstructural analyses carried out on the A1350 alloy cast samples show that structural changes occurred as different morphologies of grains size and numbers were observed under the different applied pressures in the castings as some appeared granular, lamella, coarse e.t.c. Also the mechanical properties like the tensile, impact strength and hardness all showed variations under different pressures in the castings as the hardness increased with applied pressure from 77 to 86 HRN and tensile, yield strengths and elongation of the cast samples varied as maximum values were observed with applied pressures of 1400kg/cm^2 and the impact strength increased with applied pressures from 3.98 to 4.44 joules. Microstructure refining caused by more number of grains and finer grain sizes was observed in the micrograph in the sample at applied pressure of 1400kg/cm2 and porosity was not found due to microstructure refining as compared with those obtained at 0 kg/cm^2 and 700kg/cm^2 These results illustrate how the influence of pressure on the grain refinement and mechanical properties can be used to improve the qualities of die cast products.

Dargusch etal. [19]Investigated the relationship between mechanical properties and microstructure in high pressure die cast binary Mg-Al alloys.As-cast test bars produced using high pressure die casting were tested in tension in order to determine the properties for castings produced using this technique. It was observed that increasing aluminium levels results in increases in yield strength and a decrease in ductility for these alloys. Higher aluminium levels also result in a decrease in creep rate at 150^{0}C. It was also observed that an increase in aluminium levels results in an increase in the volume fraction of eutectic $Mg_{17}Al_{12}$ in the microstructure.

MATERIALS AND METHODS

The material used for the study was AA6063 Aluminium ingot obtained from Aluminium Tower Company, Ota, Ogun State. Thechemical 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

MATERIALS AND PREPARATION

The material used for the study was AA6063 Al ingot obtained from Al 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.

Design and Fabrication of Experimental Rigs

The experimental rig used in this research work was designed and fabricated. The rig comprises of squeeze cast mould and pressure hydraulic system.

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

The mould of squeeze cast are 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

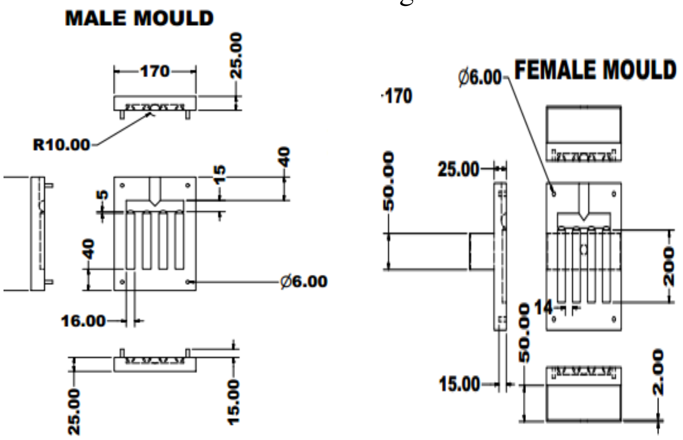


Fig. 1: Male and Female Moulds for Squeeze Cast Moulds

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).

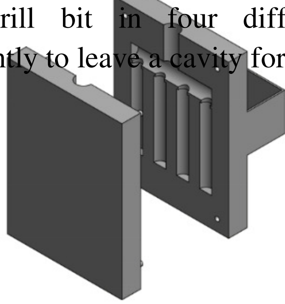


Fig. 2 Squeeze Cast Mould

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 squeeze cast mould rig was similar to the permanent rig only that a system was attached to exert pressure on the cast material. This was done with the aid of hydraulic Jack incorporated with pressure gauge to measure the pressure exerted on the cast. (See Fig. 3.)

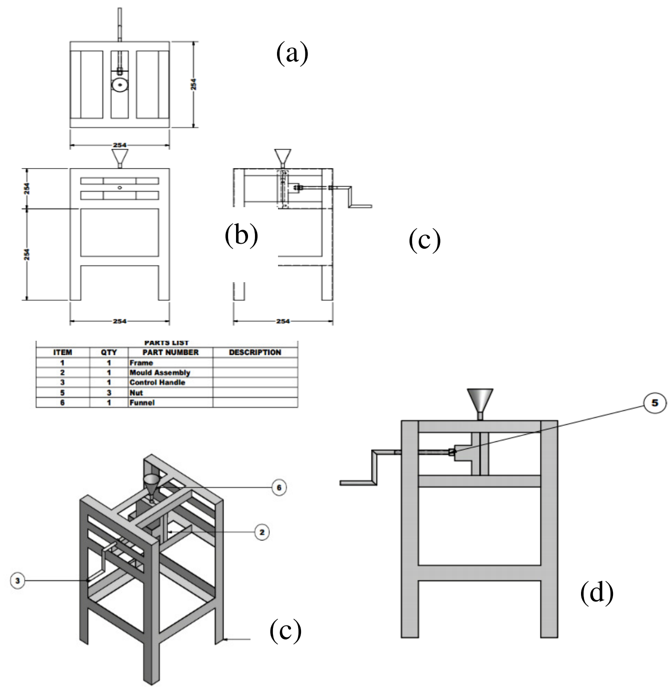
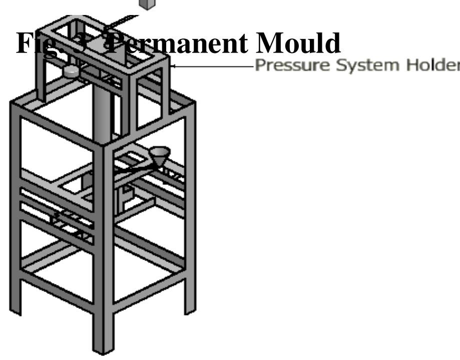
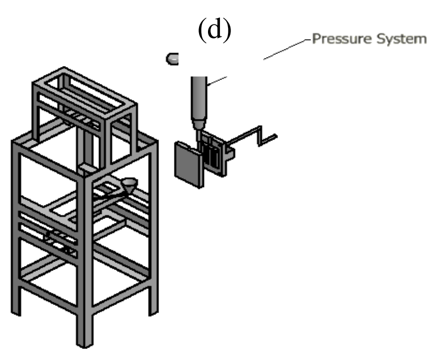


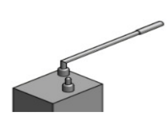
Fig. 3 Permanent Mould



(a) Assembly

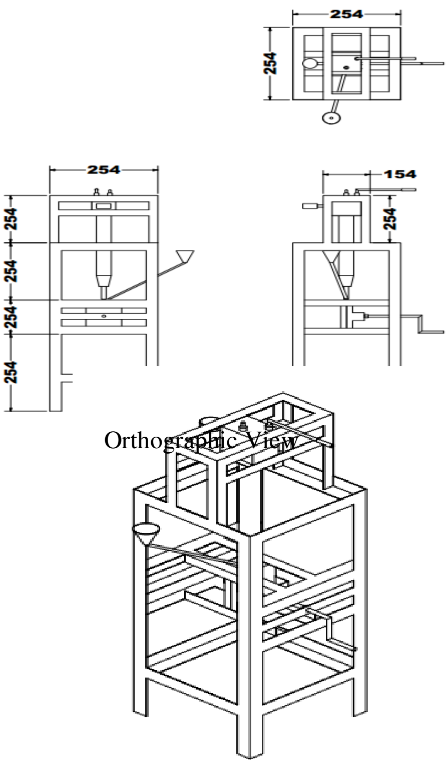


(b) Exploded



(c) Hydraulic Press and Mould

Fig. 4:Pressure System for Squeeze cast mould



Orthographic View

Isometric View

Fig. 5: Squeeze cast mouldViews

EXPERIMENTAL PROCEDURES

The Aluminium ingot was melted using blacksmith open furnace. The hot liquid Aluminium metal was cast into solid rods by squeeze casting processes using the fabricated rig.

The casting pressure was varied from $35N/m^2$ to $110N/m^2$ in order to determine the effect of cast pressure on the properties of cast Aluminium.

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 using squeeze cast mould techniques. For simplicity and analysis sake, the samples were designated as shown in Table 2.

Table 2: Sample designation

S/N	Symbols	Interpretation
1	M_{sq-1}	Squeeze casting @ $35N/m^2$ pressure
2	M_{sq-2}	Squeeze casting @ $60N/m^2$ pressure
3	M_{sq-3}	Squeeze casting @ $85N/m^2$ pressure
4	M_{sq-4}	Squeeze casting @ $110N/m^2$ pressure

Tensile Test

Tensile test specimens were machined from the bulk specimen in accordance with America Society for Testing and Materials E8(ASTM E8) as shown in Figure 6.

The machined specimens were loaded into Universal Testing Machine (UTM) and subjected to tensile load in accordance to ASTM test method. The test was monitored in a computer system and result presented in Fig. 10-15

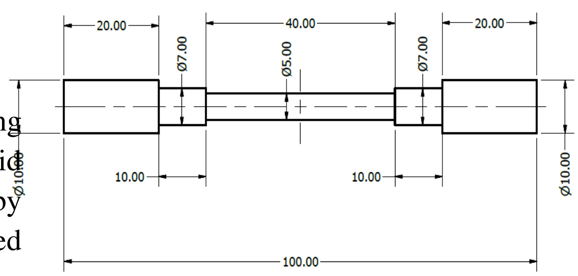


Fig 6. Tensile Test Specimen(All dimensions in mm)

Hardness Test

Hardness test specimen were machined from the bulk specimen in accordance with American Society for Testing and Materials E18 (ASTM E18) as shown in Figure 7.

The machined specimens were loaded into the Vickers Hardness Testing Machine (VHT) and subjected to hardness test in accordance to ASTM test method. The hardness properties obtained are presented in Fig. 16

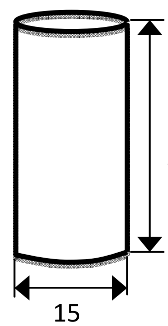


Fig. 7: Hardness Test Specimen (All dimensions in mm)

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 8

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 presented in fig. 18

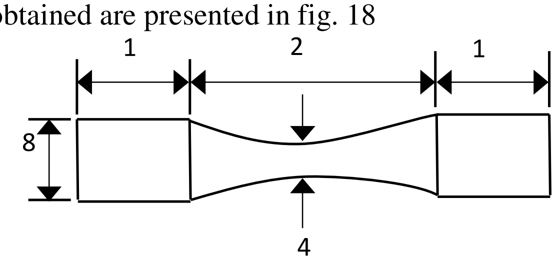


Fig. 8: Fatigue Test Specimen (All dimensions in mm)

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 9

The machined specimens were loaded into the Izod Impact Machine and subjected to Impact test in accordance to ASTM test method. TheImpact properties obtained are presented in fig 17

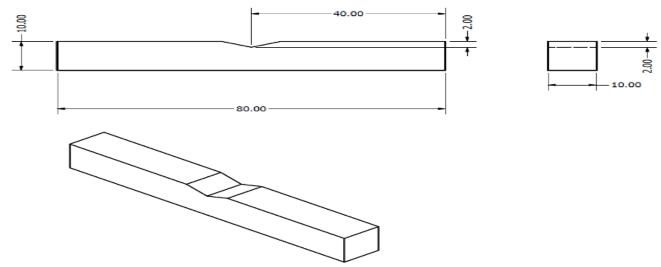


Fig. 9: Impact Test Specimen (All dimensions in mm)

Metallographic Examination

Test specimen was first ground on emery paper of different grit sizes from 240μm to 600μm. The samples were rotated 90^0at each turn of the emery paper in order to remove the scratch produced at previous grit size using strip grinder. During grinding, water was added to remove chips from the surface of emery paper and to cool the sample. The grinding process was continued until a mirror-like surface was obtained. The sample was subsequently polished in succession with cloth sprinkled with 6μm and 1μm site silicon carbide particles. The polished sample was etched in 3% NaOH and surface observed under a highpower metallurgical microscope at a magnification of 200.

RESULTS AND DISCUSSIONS

4.2.4 Graphical Presentation

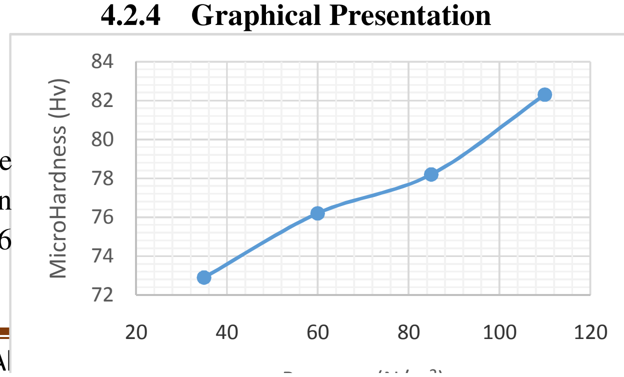


Fig. 10: Effect of pressure on Hardness of squeeze cast aluminium alloy rods

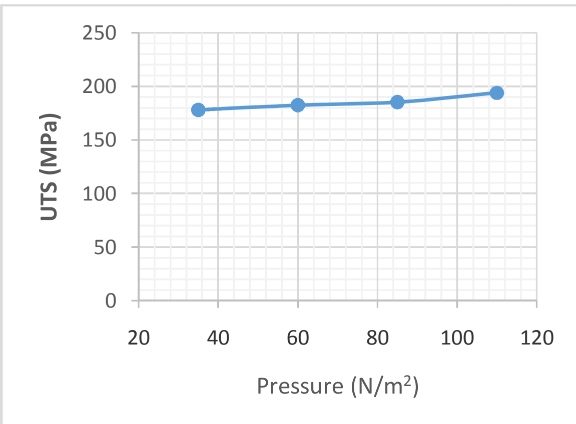


Fig. 11: Effects of pressure on UTS of squeeze cast aluminium

Fig. 12: Load at Break

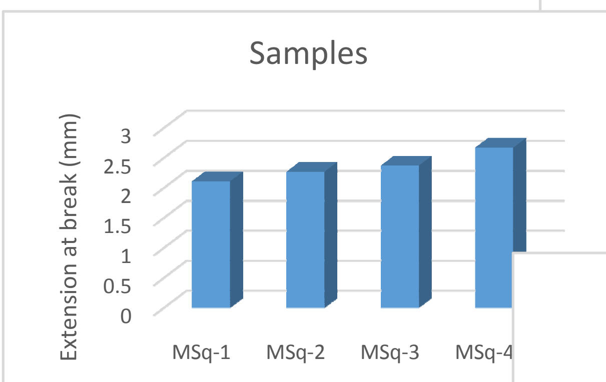


Fig. 13: Extension at break

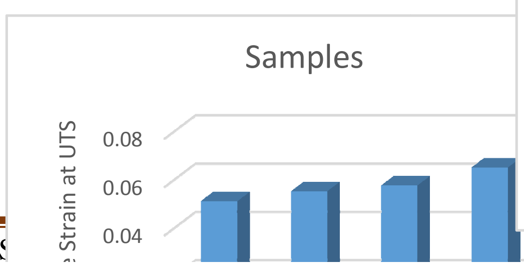


Fig. 14: Effect of Squeeze casting moulds on Tensile Strain at UTS

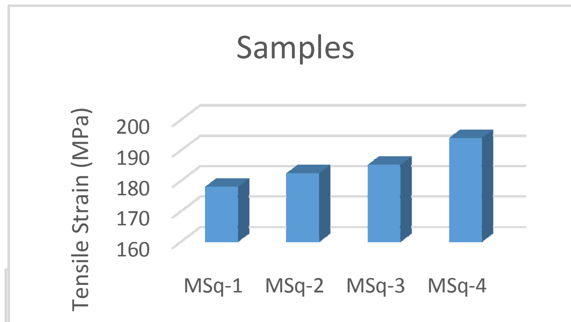


Fig. 15: Effect of Squeeze casting moulds on UTS of Various Sample

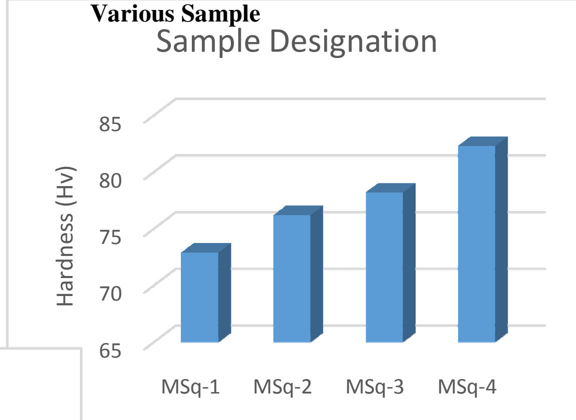


Fig. 16: Response of squeeze casting moulds on hardness of aluminium

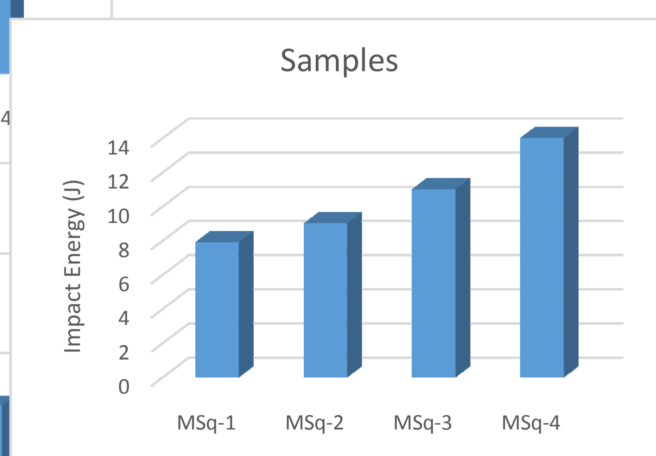


Fig. 17: Effect of Squeeze casting moulds on Impact Energy

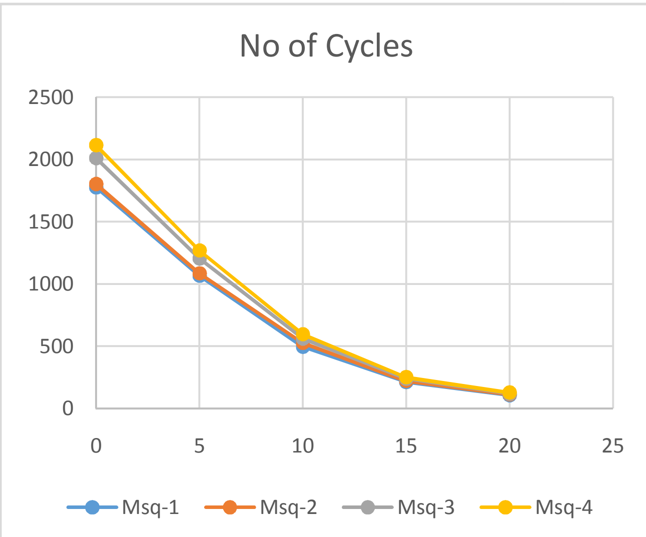


Fig 4.15: Fatigue Stress against Number of Cycle for M_{sq-1}, M_{sq-2}, M_{sq-3}, M_{sq-4}

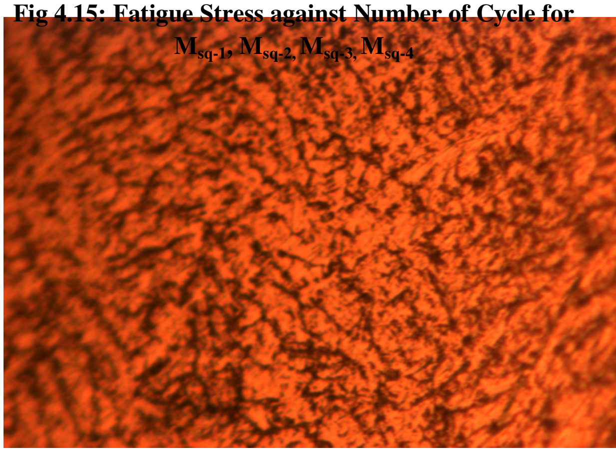


Plate 1: Micrograph of cast aluminum using squeeze mould at 35N/m^2 pressure

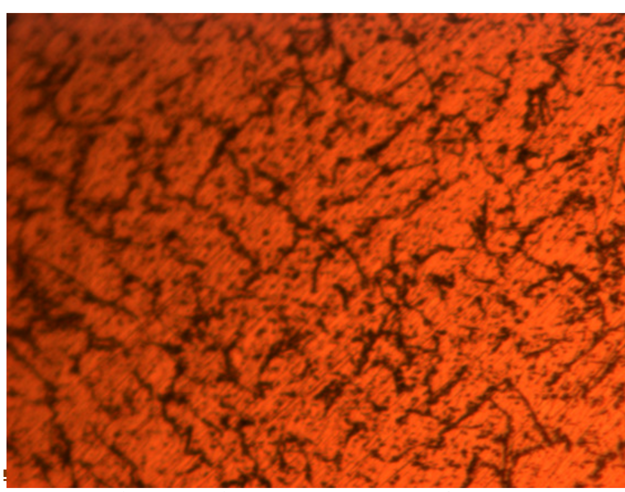


Plate 2: Micrograph of cast aluminum using squeeze mould at 60N/m^2 pressure

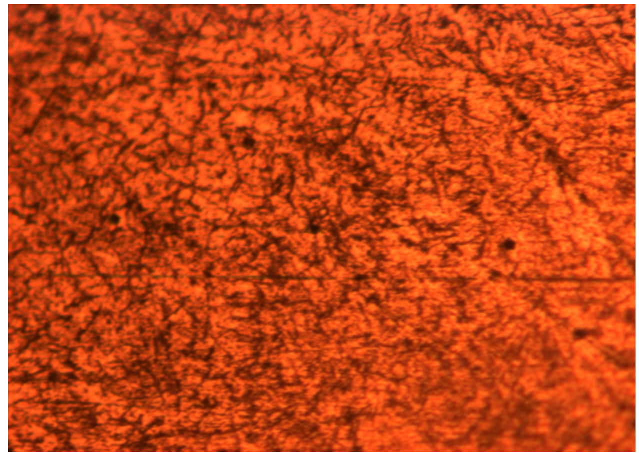


Plate 3: Micrograph of cast aluminum using squeeze mould at 85N/m^2 pressure

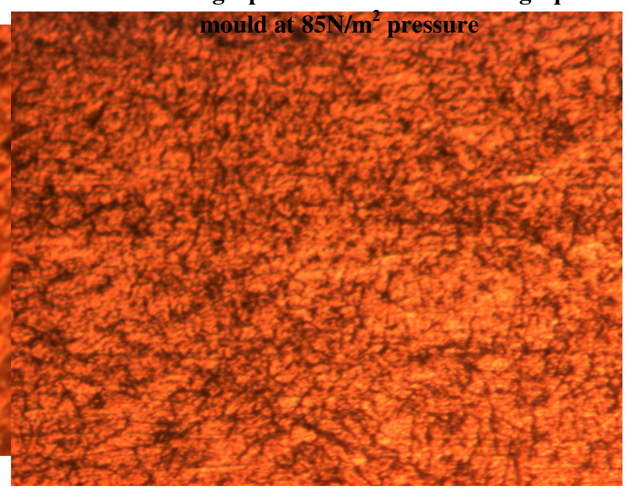


Plate 4: Micrograph of cast aluminum using squeeze mould at 110N/m^2 pressure

Hardness properties

The pressure values selected for the production of this product was observed to have significant influence on the hardness property of Aluminum. Figure 4.1 shows variation of microhardness with the pressure values used during squeeze casting operation. An almost perfect straight line trend was observed that explains the direct relationship between the two parameters. Here, a load of 490N was applied over a dwell time of 10 seconds. When aluminum was cast using squeeze mould at $35N/m^2$, it displays the least observed hardness value of 72.9Hv; these values continue to increase as the pressure at cast is increased until when hardness value of 82.3Hv was displayed by the squeeze casting produced at $110N/m^2$.

Tensile Properties

In Figure 4.2, increment in values was also observed when the Ultimate Tensile Strength of the Cast Aluminium AA6063 was examined. UTS of squeeze casting varied from 178.0.1MPa to 194.04 MPa as the pressure increased from $35N/m^2$ to $11035N/m^2$. The reduction in the grain size leads to increase in the number of grains and hence, increase in the amount of grain boundary. The results of UTS showed that squeeze casting enhances the strength of cast materials. The percentage of elongation for the squeeze castings varied between 5.12 to 6.51 %. The increase in elongation of squeeze cast products is brought about by rapid cooling leading to grain refinement.

Impact Properties

Fig. 4.8 shows variation of impact energy for squeeze casting techniques. It is revealed that Squeeze Castings have highest impact values from 7.9J to 14J as pressure increases. This indicated that increase in pressure improves the toughness of the Cast Aluminium.

Fatigue properties

Variation of fatigue properties of the castings from squeeze cast mould are shown in figures 4.9. Increase in fatigue stress was found to shorten the fatigue life of the respective castings. The number of cycle-to-failure is a measure of the fatigue life of the test materials. Castings from squeeze casting of varied pressure exhibited longest fatigue life with fatigue stress of 2115MPa, and corresponding N_f of 11 to fatigue stress 1778 MPa and N_f of 5. The trend of variation shows that as pressure increases, the fatigue strength increases.

Effects ofPressure on the microstructure of cast AA6063

The photomicrographs of the products ofCast Aluminium AA6063using squeeze casting techniques are as shown in Plates 1 – 4 under varied pressure. This is necessary in order to view the phase morphology of the internal structures of the product.

It has been established that the pressure exerted during squeeze casting causes a reduction in porosity of the microstructure and an increase in the heat transfer coefficient. This result is refined grain structure closer dendrite arm spacing and more finely dispersed second phase particles. All these are directly responsible for the observed improvement in the mechanical properties of the cast alloy.

The results of microstructure in respect to changes in pressure show that pressure has effect on the properties of material selected. The grain size looked finer as the pressure increases.

CONCLUSION

This experimental investigation of AA6063 cast Aluminium from fabricated rigs of squeeze cast moulds, show that properties of AA6063 are significantly improve in squeeze castings. Squeeze casting can be employed in as-cast condition where high mechanical properties are required in engineering applications.

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