Effect Of Impact And Fatigue Test On Cast 6063 Aluminium Rods Produced From Sand And Squeeze Cast Moulds

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Abstract

Experimental investigations were carried out to determine the effect of sand and squeeze cast methods on the impact and fatigue properties of AA6063 Aluminium. Sand and squeeze cast moulds were fabricated and used to produce Aluminium rods. The test samples from cast rods were subjected to impact and fatigue tests. The results obtained showed better impact and fatigue properties, in the squeeze cast samples that were produced under varied pressure. In impact strength analysis, the toughness increased with increase in pressure in squeeze casting, followed by sand casting. The fatigue life also increased with increase in pressure. Conversely, the mechanical properties of the cast products improved from those of sand casting to squeeze casting. Therefore, squeeze cast products could be used in as-cast condition in engineering applications requiring high quality parts while sand casting may be used in as-cast condition for non-engineering applications or engineering applications requiring less quality parts.

Keywords: Sand mould, Squeeze Cast mould, Cast Aluminium Rods, Fatigue Properties, Impact Properties

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 mould material and the pouring method [5].

Sand casting –This 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.

The squeeze casting process combines permanent mould casting and die forging operation. It utilizes punch pressures on the metal metered into a permanent mould to consolidate the metal during solidification; this eliminates defects due to shrinkage cavities and/or gas porosity [7]. Application of pressure improves mechanical properties of squeeze cast products provided the applied pressure exceeds a certain critical value. Some of the advantages of this process are higher casting yield, better mechanical properties, reduction in tooling cost, and higher dimensional accuracy.

Raji and Khan [8] 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.

In a study by Oyetunji [9], 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.

Chatterjee and Das [10, 11] and Frankl and Das [12] 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.

Also, Akpan etal.[13] Investigated the degrading of the fatigue life of 6061 aluminum reinforced with boron fires oriented in the 0, 90 and + 45 degree 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 measured for 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 occured 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 [14] 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.

Abifarin and Adeyemi [15] 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. [7] 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. [16] 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 [17] 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 [18] 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, grain refined 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.

Obiekea etal. [19] work on the mechanical properties and microstructure of die cast aluminium A380 alloy casts produced under varying pressure was investigated experimentally and compared. The results obtained show better mechanical properties i.e. hardness, tensile strengths and impact strengths 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 solidified under different applied pressures varied from 76 to 85 HRN. Also tensile strength, yield strength and elongation of the samples showed an increase with increased pressure. Also the results of SEM and metallography show that at high pressure, structural changes occurred as a fine microstructure was obtained with increase of pressure.

Obiekea etal. [20] 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.tc. 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.

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

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

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

The mould squeeze cast 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

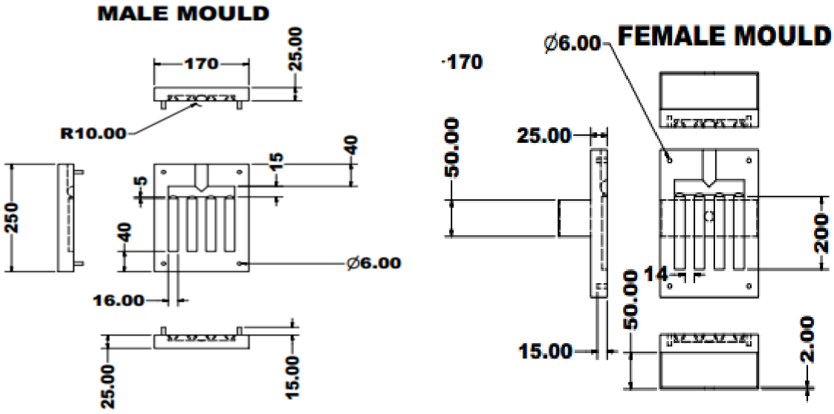


Fig. 1: Male and Female Moulds for Squeeze Cast Moulds

Fabrication of Squeeze Cast Mould

The Permanent and Squeeze Cast 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).

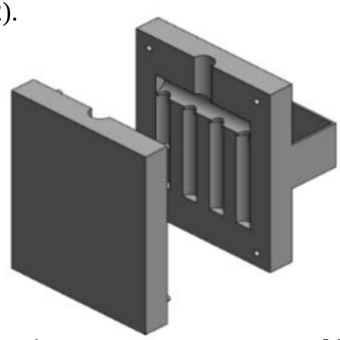
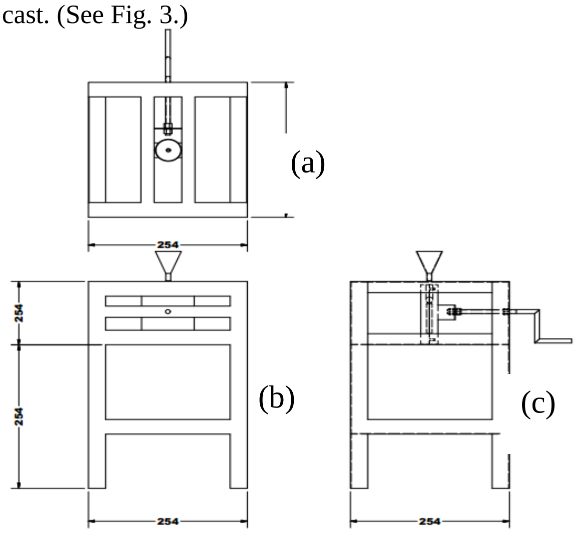


Fig. 2 Squeeze Cast Mould

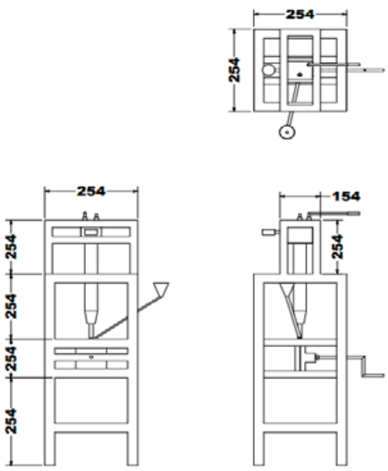
After slicing the steel block, gate and pouring hole were made. A system to hang and house the mould for easy pouring of molten metal and ejection of the solid cast material was constructed. The product of this rig was a permanent cast when no pressure system is attached. (See Fig. 3.). However, the 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.)



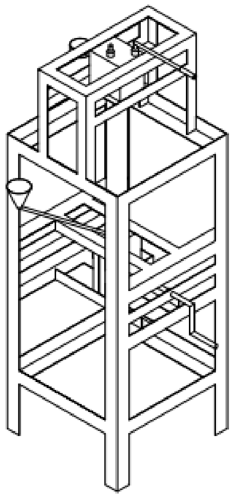
PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Frame	
2	1	Mould Assembly	
3	1	Control Handle	
5	3	Nut	
6	1	Funnel	

Fig. 3 Permanent Mould

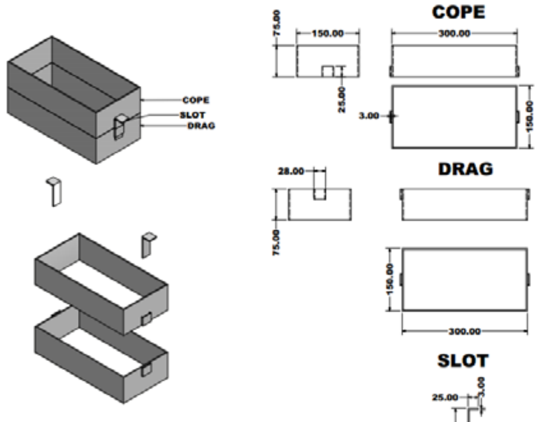


Orthographic View



Isometric View

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).



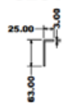


Fig. 4: Sand Cast Flask

Experimental Procedures

The Aluminium ingot was melted using blacksmith open furnace. The hot liquid Al metal was cast into solid rods by sand casting, permanent casting and squeeze casting processes using the fabricated rigs.

In case of squeeze casting, 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 various mould techniques. For simplicity and analysis sake, the samples were designated as shown in Table 1.

Table 2: Sample designation

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

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 (see Plate 3.2) and subjected to fatigue test in accordance to ASTM test method. The fatigue properties obtained are presented in Table 2

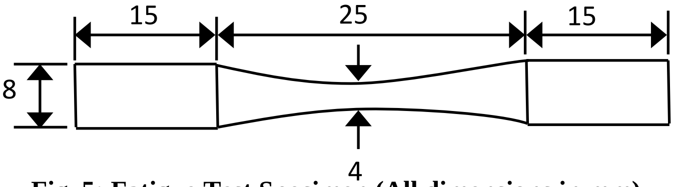


Fig. 5: Fatigue Test Specimen (All dimensions in mm)

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 and subjected to Impact test in accordance to ASTM test method. The Impact properties obtained are presented in Fig. 4

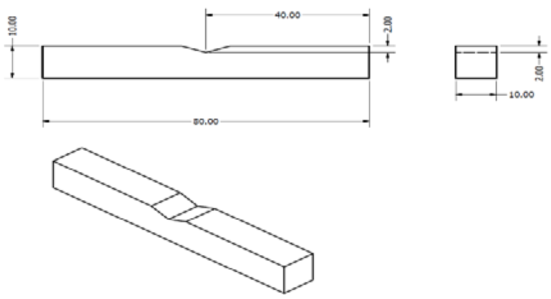


Fig. 6: Impact Test Specimen (All dimensions in mm)

RESULT AND DISCUSSION

Table 4.4: Fatigue Properties of cast Aluminium from various casting moulds

M_S	Stress (MPa)	100.7	198.6	469.8	1008	1680
	N_f	20	10	7	6	5
M_{Sq-1}	Stress (MPa)	106.5	213	497.1	1067	1778
	N_f	25	20	13	10	5
M_{Sq-2}	Stress (MPa)	113	223	527.7	1085.6	1804
	N_f	25	20	15	13	8
M_{Sq-3}	Stress (MPa)	120	240	562.9	1206	2010.7
	N_f	25	21	18	14	9
M_{Sq-4}	Stress (MPa)	127.8	252	596.5	1269	2115
	N_f	25	22	20	15	11

4.2.3 Fatigue Result

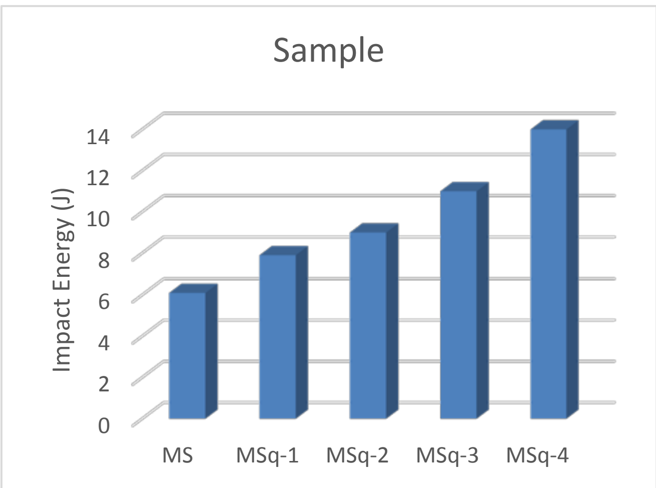


Fig. 4.8: Effect of Various Casting moulds on Impact Energy

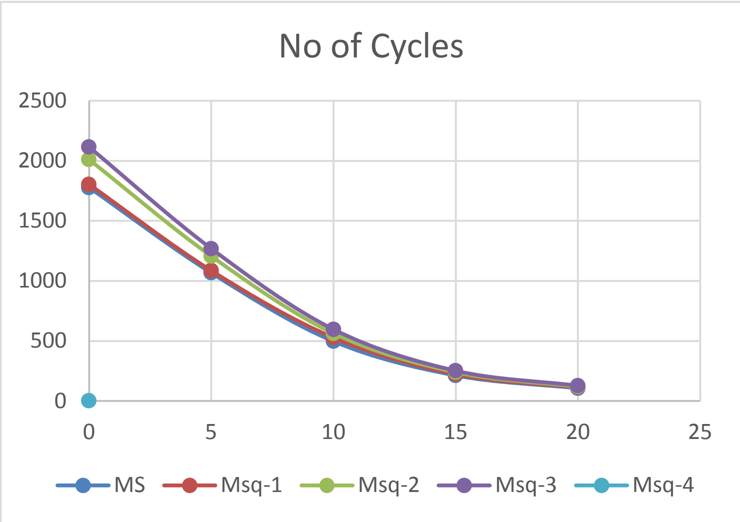


Fig 4.15: Fatigue Stress against Number of Cycle for M_{sq-1}, M_{sq-2}, M_{sq-3}, M_{sq-4}, &M_s

Impact Properties:

Fig. 4.8 shows variation of impact energy for various moulding techniques. It is revealed that Squeeze Castings have highest impact values from 7.9J to 14J and 6.1J in sand and mould. This indicated that increase in pressure improves the toughness of the Cast Aluminium.

Fatigue Properties:

Variation of fatigue properties of the castings from various mould techniques are shown in figures 4. 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 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, Sand Casting has fatigue stress of 1680MPa, N_f of 5. The trend of variation shows that as pressure increases, the fatigue strength increases.

CONCLUSIONS

Impact and fatigue properties of AA6063 Cast Aluminium rods from fabricated rigs of Sand and Squeeze cast moulds were investigated. The impact and fatigue properties of AA6063 are significantly improve in squeeze castings than that of Sand castings. The notable effect is recorded as pressure increases in Squeeze Castings. Squeeze castings can be employed in as-cast condition where high fatigue and impact properties are required in engineering applications.

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