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Tensile and Hardness Properties of Cast 6063 Aluminium Rods produced from Sand and Squeeze Casting Moulds

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ABSTRACT

This work presents experimental analysis to determine the effect of sand and squeeze casting methods on the Tensile and Hardness 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 Tensile and Hardness tests. The results obtained showed better Tensile and Hardness properties, in the squeeze cast samples that were produced under varied pressure. The hardness of squeeze casting varied from 72.9 to 82.3Hv, while that of sand casting had 70.0Hv. Also, Ultimate Tensile Strength increased with increased pressure in squeeze castings from 178.01 to 194.04MPa and 161.97 in sand castings. 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.

Key words: Aluminium Rods, Hardness Properties Cast, Sand Mould, Squeeze Casting Mould, Tensile 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.

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]

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] which centred mainly 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.

Abduwahabetal.[13] investigated the effect of chromium addition and precipitation hardening on the mechanical properties of cast Al – Si – Fe alloy. This study revealed how the mechanical properties of Al-Si-Fe-Cr alloy changes with precipitation hardening treatment with the percentages of chromium in the alloy being varied from 0.1 to 0.5% while the Si-Fe ratio was kept constant. The as-cast bars were cut and machined into tensile, impact and hardness test samples and were then solution heat-treated at 490^0C for six hours before quenching into warm water. The solutionized samples were then aged at 200^0C for six hours and air cooled. It was observed that the tensile, impact and hardness properties of the as-cast alloys improved significantly after precipitation hardening for all levels of chromium addition considered. However, at 0.1% Cr addition highest values of impact and ductility for the two categories of the alloy produces cast and precipitation hardening alloy(s) was exhibited.

Adeyemi [6] investigated the mechanical properties of Aluminium produced from sand casting under different pre-heat temperatures and shake-out times. AlsoSowole 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.

Agbanigo and Alawode [16] 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 fibre s. Abubakre and Khan [17] 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 [18] 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 [19] 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.

Obiekeaetal. [20] 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.

Obiekeaetal. [21] 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.

Darguschetal. [22] 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.

Awedaetal.[23] 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.

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 were designed and fabricated. The rigs comprise of squeeze cast 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 of 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

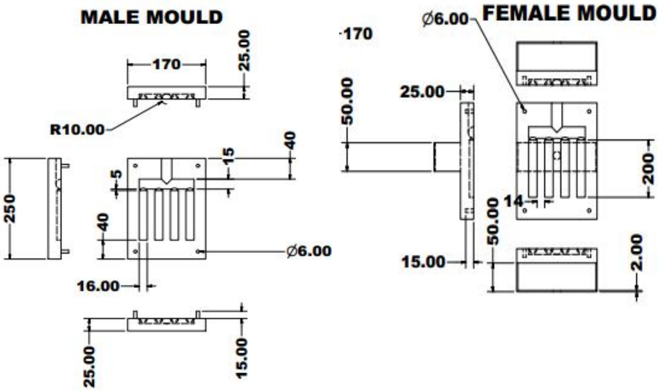


Figure 1: Male and Female Moulds for Squeeze Cast Moulds

Fabrication of Squeeze Cast Mould

The 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).

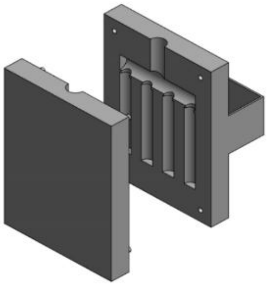
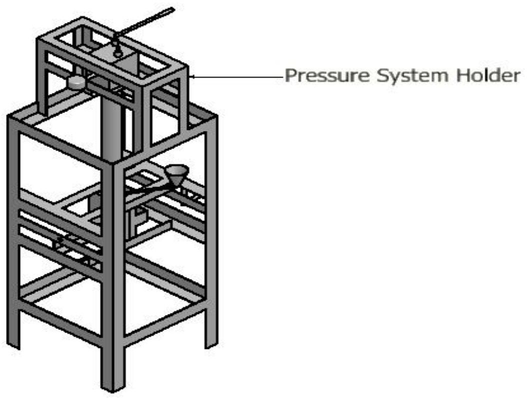
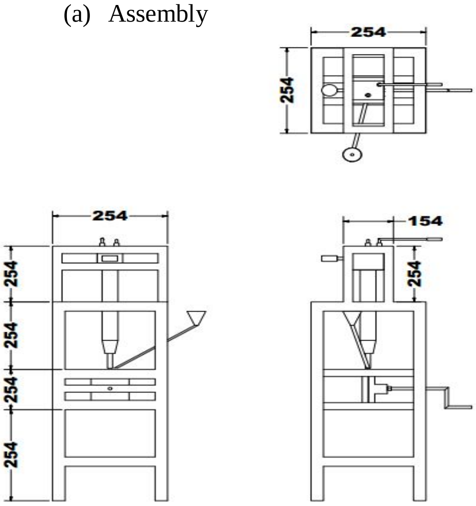


Figure 2: Squeeze Cast Mould

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. 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.)



(a) Assembly



(b) Orthographic View

Figure 3: Squeeze Cast 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).

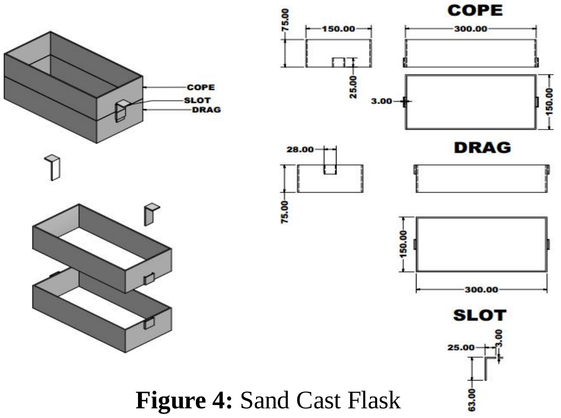


Figure 4: Sand Cast Flask

3.3 Experimental Procedures

The Aluminium ingot was melted using blacksmith open furnace. The hot liquid Aluminium 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 2

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

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 5.

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. 8.

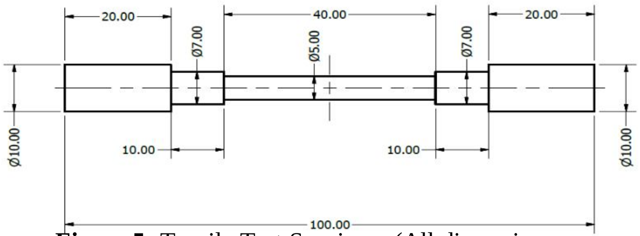


Figure 5: Tensile Test Specimen (All dimensions in mm)

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 6.

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. 7

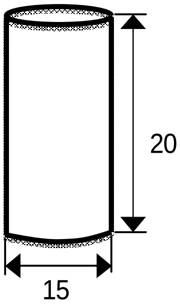


Figure 6: Hardness Test Specimen (All dimensions in mm)

4. RESULTS AND DISCUSSIONS

Table 3: Selected mechanical properties of the cast Aluminum

Sample	**Hardness (Hv)**	**UTS (MPa)**	**Load at break (N)**	**Strain-to-fracture (%)**
M_S	70.0	161.97	3180.27	5.04
M_{Sq-1}	72.9	178.01	3495.31	5.12
M_{Sq-2}	76.2	182.46	3582.67	5.53
M_{Sq-3}	78.2	185.22	3636.1	5.77
M_{Sq-4}	82.3	194.04	3809.99	6.51

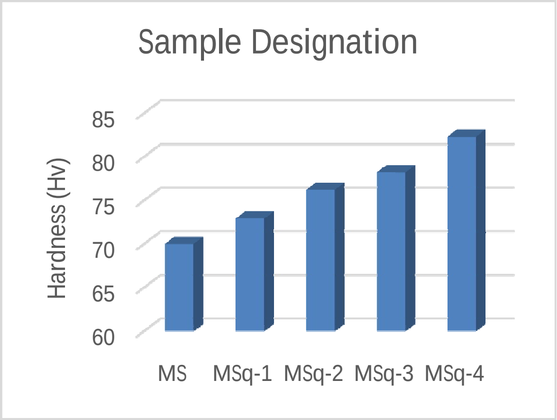


Figure 7: Response of various casting moulds on hardness of aluminium

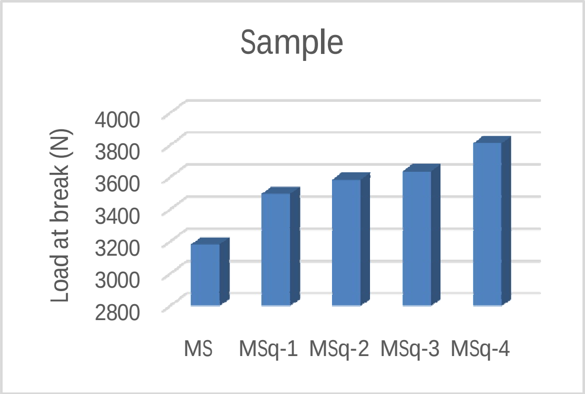


Figure 8: Load at Break

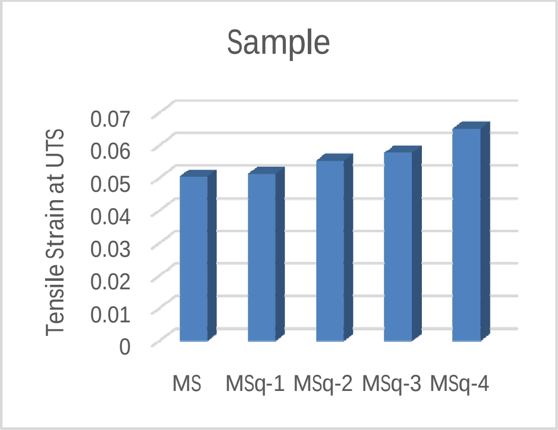


Figure 9: Effect of various casting moulds on Tensile Strain at UTS

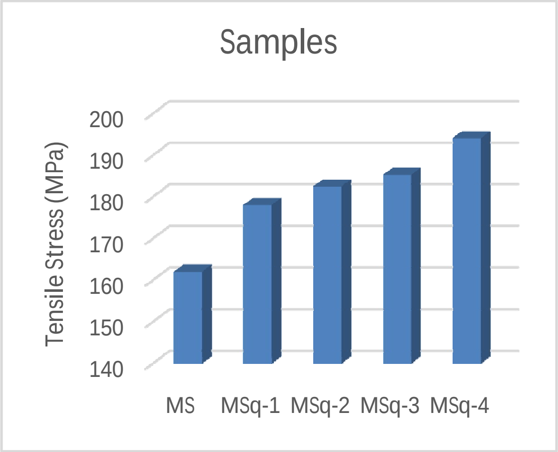


Figure 10: Effect of Sand and Squeeze casting moulds on UTS of Various Samples

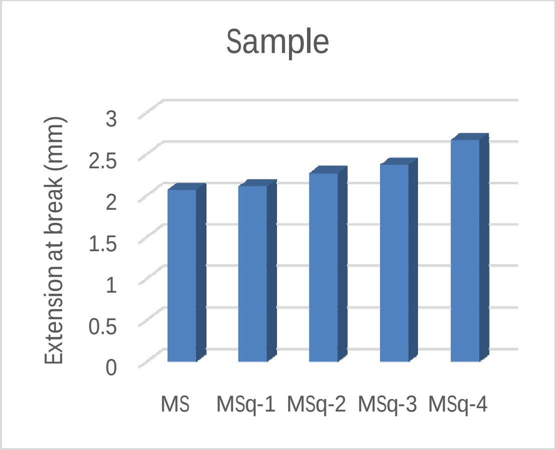


Figure 11: Extension at break

Hardness properties

InFigure 7, it was observed that squeeze casting technique exhibited the highest hardness value of 82.3Hv as against the 70.0Hv exhibited by the product from sand mould. As the pressure increases in squeeze casting, the hardness values also increases.

Tensile Properties

In Figure 10, 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 results of UTS showed that squeeze casting enhances the strength of cast materials while Sand casting has 161.97. The percentage of elongation for the squeeze castings varied between 5.12 to6.51%. The increase in elongation of squeeze cast products is brought about by rapid cooling leading to grain refinement as compared to sand casting of 5.04%.

5.CONCLUSION

This experimental analysis of AA6063 Cast Aluminium from fabricated rigs of Sand and Squeeze cast moulds, show that Hardness and Tensile properties of AA6063 are significantly improve in Squeeze casting than that of Sand Castings. The notable effect is recorded as pressure increases in Squeeze Castings. Squeeze casting can be employed in as-cast condition whose high hardness and Tensile properties are required in engineering applications.

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