# MICROSTRUCTURAL ANALYSIS OF CAST 6063 ALUMINIUM RODS PRODUCED FROM SAND AND SQUEEZE CAST MOULDS

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## Abstract:

This paper presents experimental investigations to determine the effect of sand and squeeze cast methods on the microstructural 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 microstructural analysis. The metallographic results obtained showed better properties in the squeeze cast samples that were produced under varied pressure than that of sand cast mould. The result showed that as pressure increases, structural changes occurred as fine microstructure was obtained with increase of pressure in squeeze castings. It was observed that the grain size of the microstructure of the cast products increased from those of squeeze casting, to Sand Casting. 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* — Cast Aluminium Rods, Microstructure, Sand Cast mould, Squeeze Cast mould**

## 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 $\alpha$-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. 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 [13] 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.

Abifarin and Adeyemi [14] 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.

Gaurav [15] 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.

Raji [16] 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.

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 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. [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.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.

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. 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 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

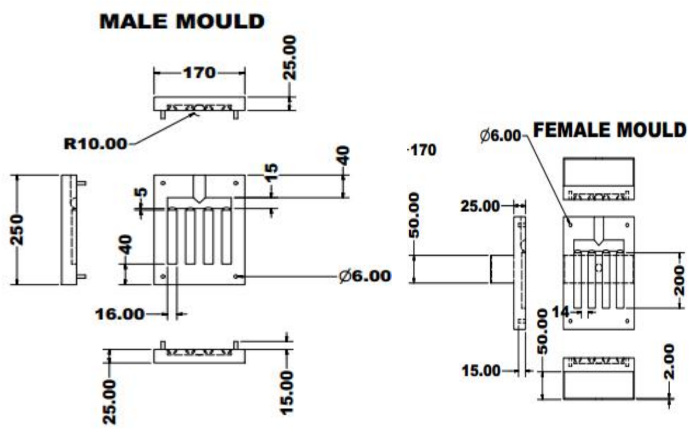



**Fig. 1: Male and Female Moulds for Squeeze Cast Moulds**

### Fabrication of Squeeze Cast Mould

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).

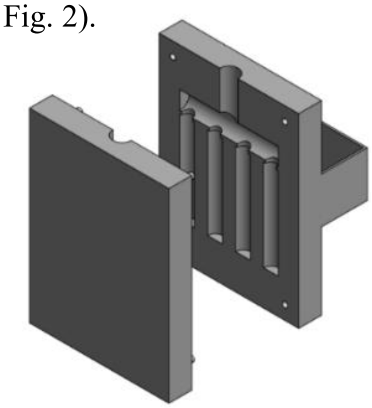
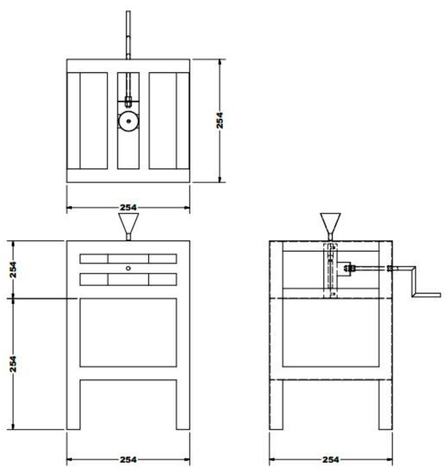
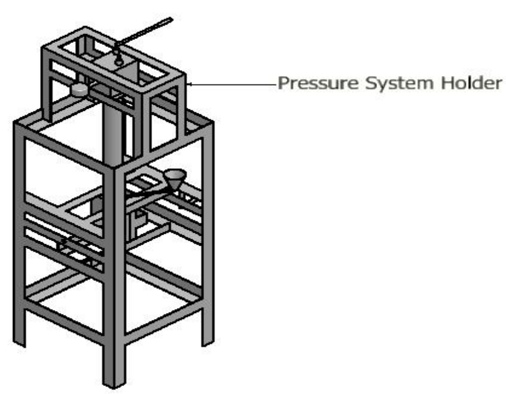


**Fig. 2 Squeeze Cast Mould**

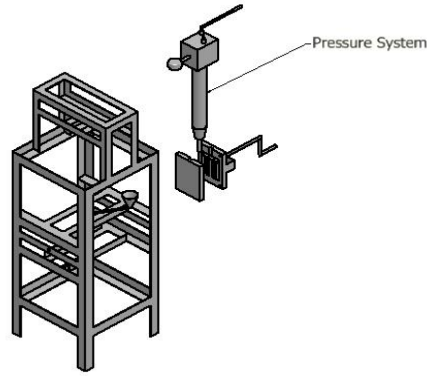
After slicing the steel block, gate and pouring hole were made. A system to hang and house the mould for easy pouring of molten metal and ejection of the solid cast material was constructed. The product of this rig was a permanent cast when no pressure system is attached. (See Fig. 2.). However, the 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.)



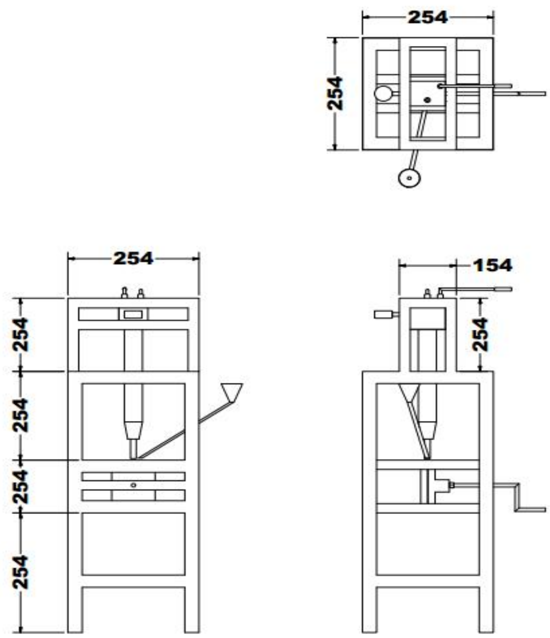

| PARTS LIST | | | |
|---|---|---|---|
| ITEM | QTY | PART NUMBER | DESCRIPTION |
| 1 | 1 | Frame | |
| 2 | 1 | Mould Assembly | |
| 3 | 1 | Control Handle | |
| 5 | 3 | Nut | |
| 6 | 1 | Funnel | |




(a) Assembly




(b) Exploded




Orthographic View

**Fig. 3 Squeeze 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).

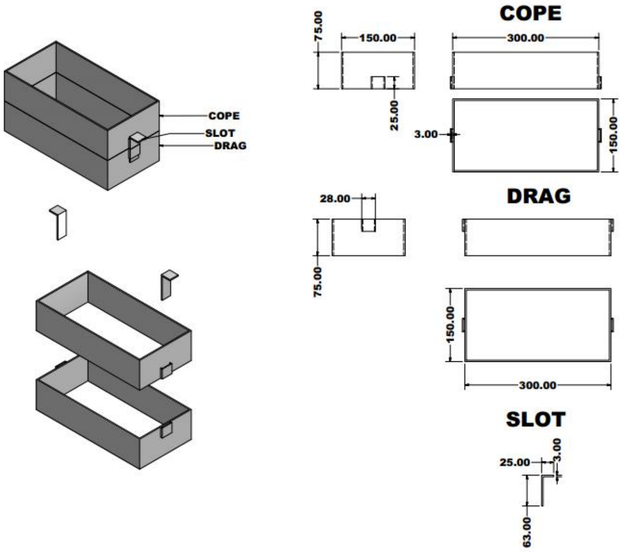



**Fig. 4: Sand Cast Flask**

### Experimental Procedures

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

### Metallographic Examination

Test specimen was first ground on emery paper of different grit sizes from 240$\mu$m to 600$\mu$m. The samples were rotated 90$^0$at 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 6$\mu$m and 1$\mu$m site silicon carbide particles. The polished sample was etched in 3% NaOH and surface observed under a high-power metallurgical microscope at a magnification of 200.

## RESULTS AND DISCUSSIONS

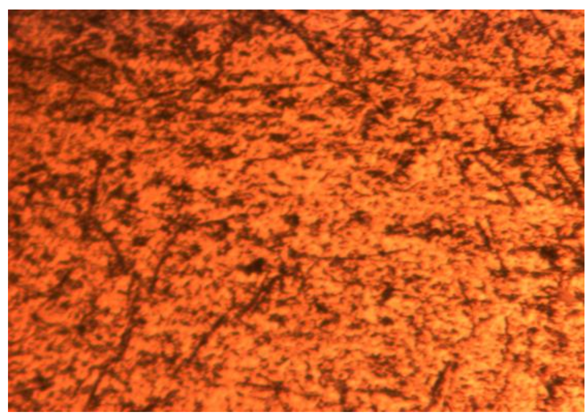


**Plate 1: Micrograph of cast aluminum using sand mould**

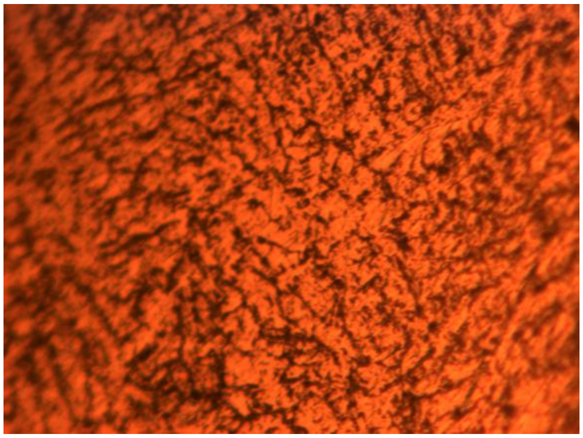


**Plate 2: Micrograph of cast aluminum using squeeze mould at 35N/m$^2$ pressure**

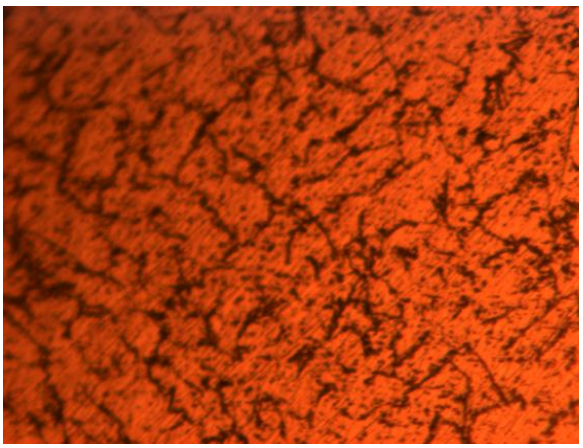


**Plate 3: Micrograph of cast aluminum using squeeze mould at 60N/m$^2$ pressure**

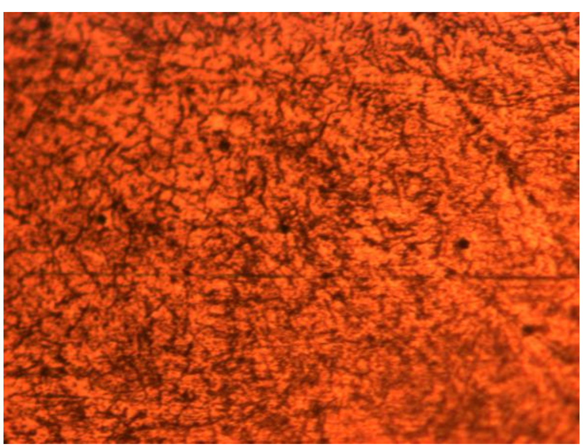


**Plate 4: Micrograph of cast aluminum using squeeze mould at 85N/m$^2$ pressure**

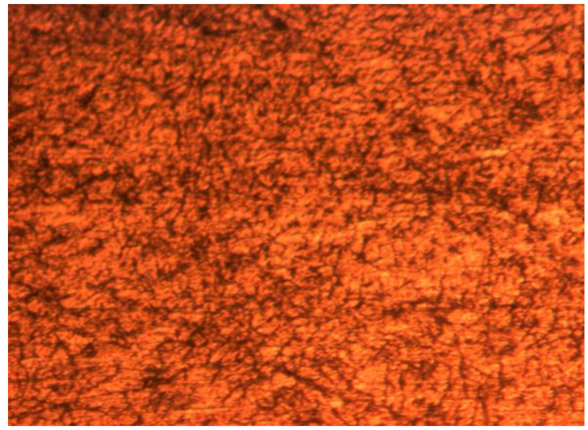


**Plate 5: Micrograph of cast aluminum using squeeze mould at 110N/m$^2$ pressure**

The photomicrographs of the produced Cast Aluminium AA6063 varied techniques are as shown in Plates 1 – 5. This is necessary in order to view the phase morphology of the internal structures of the product Plates 1 shows the micrographs of the Al 6063 produced using sand mould, Plate 2-5 are product of squeeze casting at varied pressures.

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. These are directly responsible for the observed improvement in the mechanical properties of the cast alloy.

When considering the microstructure on the methods of casting used, it was discovered that the grain size of the Aluminium obtained during sand casting is a bit of refinement with the grain size coarse.

## CONCLUSIONS

This experimental investigation of AA6063 Cast Aluminium from fabricated rigs of sand and squeeze cast moulds, shows that microstructure effects of AA6063 are significantly improve in squeeze castings than that of sand castings. The microstructures also show structural changes due to applied pressure as some appeared granular, lamellar, coarse etc. Squeeze Casting can be employed in as-cast condition where finer grain size are required in engineering applications.

## ACKNOWLEDGEMENTS

The authors acknowledge the support of Aluminium Tower Company, Ota, Ogun State, Nigeria. We are also grateful to the authorities of the Olusegun Obasanjo Centre for Engineering Innovation, The Federal Polytechnic Ado Ekiti for providing conducive environment and necessary equipment for the work.

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