# Investigation of Some Mechanical Properties of Al-6063 Alloy Using Multi Axial Forging

**S. Pranesh, A. Gowtham, M. Jeyasuriya, S. Dineshbabu, B. Karthickraja**

***Abstract: Multiaxial Forging is one of the main deformation process which is used to refine the size of the grain material.In the present work AA 6063 alloy has been processed through MAF die with a different number of forging cycles. From the microstructural analysis of the forged samples,it is observed that the grain refinement was obtained with increasing number of forging cycles.. The mechanical property in terms of hardness and compressive stress was also investigated and reported.***

***Keywords:Multiaxial Forging, AA 6063 alloy, Microstructural analysis.***

## I. INTRODUCTION

Plastic deformation(PD) techniques are been used mostly for their ability to refine the grain size of working metals. The overall objective of PD process is to fabricate a lightweight parts with high strength. Various metal forming methods such as forging, rolling and extrusion, the forced plastic strain of metal is normally less than or about 2.0. The presence of hydrostatic pressure, can be used to reduce the grain size of the metals[1]. One of the distinctive character of these ultrafine grained metals is that they enclose a very high fraction of grain boundaries and also having a high angles of disorientation [1-2].

### Plastic deformation

When the applied stress is enough to change the metal deform permanently , it is been called as a plastic deformation. Sometimes it is been said as simply as plasticity, and this type of deformation can be processed under controlled conditions [6]. Both the plastic deformation as well as metal deformation involve changes to the working material by itself[4]. Generally heat is been applied often to shape the items into the desired form. When the metal cools, and the structure is been retained and becomes stable to the required shape[3]. For this main reason, plastic deformation is been applied in the manufacturing of components which involves constant use of heat and pressure, which allows the material to adapt a new working condition and make it very flexible until the desired shape is achieved [5].

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### Multiaxial Forging (MAF)

Multiaxial forging (MAF) is an exclusive deformation process in which the working is been done at a warm temperature, where there will be a transformation in strain path due to the forging pass, and is been characterized by the larger deformation rates to obtain a large samples[7]. MAF has been recently used for making of ultrafine grain microstructure samples. Plastic deformation by using a simple shear by pressing the sample through a die[8]. There wont be any change in cross sectional area, so it is viable to continue the pressing process for a more number of times to achieve a high strength.

## II. LITERATURE REVIEW

### Multiaxial forging (MAF)

Over the past decade the ECAP has seen many experimental studies and developments. Initially, it can be applied to large samples. Second, it is a relatively simple procedure which can be done on a wide range of metals and alloys[9]. Third, good homogeneity is attained in the material provided the forging are continued to a higher strain. Fourth, the process can be used widely without any limitations on size (private/commercial). MAF process can be either with a single or multi pass. Various parameters can be varied in MAF process with each one referring to a mechanical property and even in emission techniques[10]. The MAF process can be continuous or discontinuous.

### Essential parameters in MAF

The MAF procedure is a metal flowing process working in shear method and characterized by many parameters such as the strain which is imposed in each stain steps[11].

### Heat treatment

The forging temperature is a main factor in MAF. The results from various experiments exposed that there was an

increase in the strength due to the grain refinement that takes place with increasing temperature.

### Speed of pressing

Pressing by MAF is typically done using high capability tensile machine that run normally with high speeds. Usually, the processing speeds will be in the range of 1–20 mm/s. [13].

**Load**

MAF process is being conducted by universal testing machine (UTM) with the help of multi axial forging die-set which consisting of a female die, plunger and stud. To press the material through the die chamber, the constant load is been applied throughout the pressing process and the press capacity maintained for this work is 200KN in order to avoid jamming or crack induced in the workpiece and also inside the die [12].

## III. RESEARCH OBJECTIVES

1. The ultimate aim of the MAF process is to improve the strength and also various as properties like toughness, ductility of Aluminium based light metals, wear resistance.
2. Improved mechanical properties can be achieved without any defects along with plastic deformation for the material.

## IV. RESEARCH METHODOLOGY

**Design and fabrication of die**

**Selection of material**

The die material for MAF has to be strong and should resist deformation. A natural choice was high carbon with high chromium tool steel (D3 steel). Both the die and plunger are made on the same material. General application of D3 steel is stamping of dies, shearing blades, tools, etc.... It is heat treated and it will provide hardness in the range 57-65 HRC.

**Design of die and plunger**

The designing of the die is required the consideration of different types of design. After some research it was decided to produce a split-pattern die. This design was chosen because the process involved constant insertion and removal of the work material. However for removing work material it can be used but this lead to complications in the design of die. Thus a split pattern was chosen for making the Die.

**Fabrication of die and plunger**

The designed die and plunger were fabricated as per the selection of material and its properties. First of all, both the die and plunger were roughly machined as per the basic dimension. Normally the die inner and outer surfaces were machined by wire cutting and then by milling cutter. The plunger was machined by surface grinding center in order to get accurate dimension and for smoothness.

**Experimental work**

**Selection of material and its size**

The selected material is aluminum 6063.This material is selected because of extensive studies carried out on aluminum have shown that MAF is well suited for producing ultra fine grain structured aluminum. The aluminium material is square shape solid rod and its cross section is diameter of 19mm.

**MAF process for using UTM machine**

To process the MAF process, an die was designed and fabricated. The schematic diagram of MAF die was shown in fig.4 which is the split pattern type die, the die consisted of two blocks. These two blocks were then bolted together to form a single internal cavity. The pressing were conducted by universal testing machine (UTM) with the help of plunger. Fig.4.1 is show the MAF die assembly fitted in the UTM machine. To press the billet through the die channel, the constant load is applied throughout pressing process that the press capacity maintained for this work is 200KN in order to avoid jamming or crack induced in the material and also inside the die. The MAF die was housed in room temperature and the samples were pressed at a speed of 10mm/s, plunger attached to UTM machine. Thus the numbers of passes of billet material were carried out at 160°C temperature. For each separate pressing, the billet sample material& inside the channel of die was coated with a solid lubricant of Graphite in order to reduce the friction between the die and sample walls during processing.

**Fig. 4.1 MAF die assembly fitted in the UTM machine**

## V. RESULTS AND DISCUSSION

Aluminium metals and its alloys are good materials for use in various structural applications whose weight to be minimized and strength to be enhanced. Therefore, it is necessary to modify or improve the mechanical and factigue strength of Al and its alloys. To achieve the above said objective, the formation of fine-grained structure would be very useful. In the present work, the mechanical properties in terms of hardness and compressive strength; and microstructural examination were carried out and reported.

**Hardness evaluation for MAFed AA 6063 Al alloy**

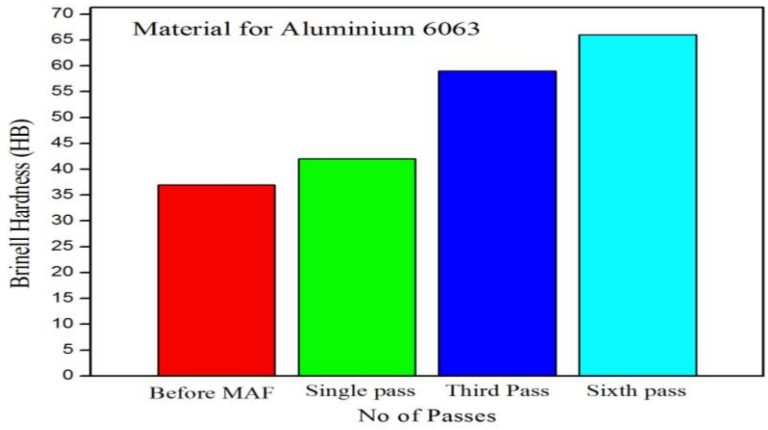



**Fig. 5.1 Bar chart showing the variation in Brinell hardness with the number of MAF Strain steps**

**Table. 5.1 Brinell hardness values of various number of Warm MAF Strain steps**

| S.NO | BRINELL HARDNESS (HB) | | | |
|---|---|---|---|---|
| | BEFORE MAF | SINGLE PASS | THIRD PASS | SIXTH PASS |
| 1 | 37 | 43 | 59 | 67 |
| 2 | 35 | 41 | 60 | 66 |
| 3 | 39 | 45 | 58 | 69 |
| 4 | 38 | 42 | 61 | 68 |
| 5 | 36 | 44 | 57 | 65 |

The effectiveness of the consolidation process of multi axial forging (MAF) was evaluated and reported in terms of hardness values (Fig.5.1 and Table 5.1). Brinell Hardness values were taken after applying each pass of the MAF. Fig.5.1 shows the average hardness measurements for each sample after each pass. As shown in Fig.5.1the hardness value of the samples was increased with the number of passes increases. It was observed that the hardness value for AA 6063 alloy was increased up to 43HB after single pass, 59HB after third pass and 67HB after sixth pass.The increase in hardness was due to the increase in grain refinement of each sample passes through MAF. So this result indicates that improvement of grain refinement due to severe plastic deformation takes place.

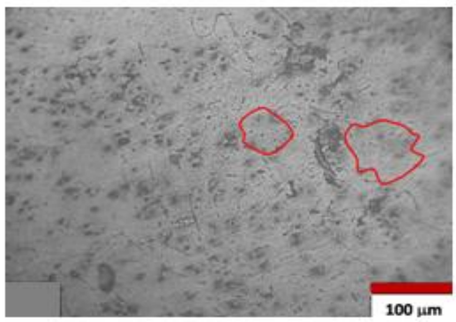
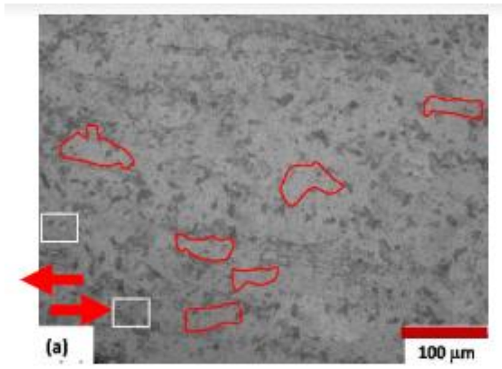



**Fig. 5.2 Microstructure of as received AA 6063 alloy**

**Microstructural examination for AA 6063 alloy**

Fig.5.2 to 5.5 shows the optical microstructures of as-received AA 6063 alloy and MAFed alloys up to 6 passes. Initially, the unpassed AA 6063 Al alloy (Fig.5.2) composed of large and very coarse grains. The average grain size value of AA 6063 alloy based on several microstructural images is 98 □ m.



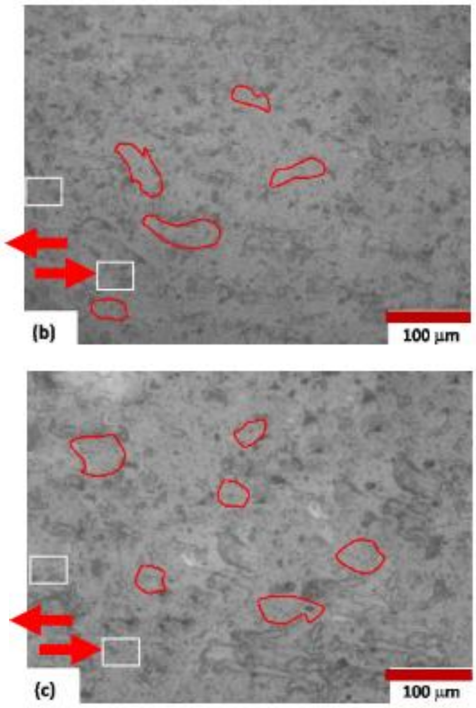
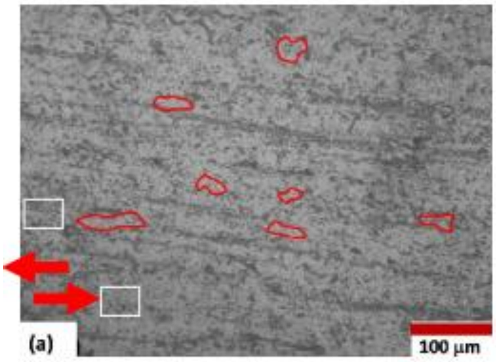



**Fig. 5.3 Microstructures of 1 cycle MAFed AA 6063 alloy perpendicular to: (a) X-axis, (b) Y-axis and (c) Z-axis**

Fig. 5.3(a)-(c) shows the optical microstructure of single passed MAF of AA 6063 alloy. The sample was polished in perpendicular to X, Y and Z-axis and the grain morphology was observed. Before processing, the three directional axes were marked on the sample. During single pass the sample was subjected to forging along the direction of Z-axis. Fig. 5.3(a) shows the grain morphology along perpendicular to X-axis where almost equi-axed and elongated grain boundaries were observed. Similarly, almost equi-axed and elongated grain morphology was observed along perpendicular to Y-axis (Fig. 5.3(b)).These extraction techniques could be employed in vehicle plate identification approaches[14].

However, along the direction of Z-axis or perpendicular to Z-axis, only equi-axed grain morphology (Fig.5.3(c)) was observed. These results evidenced that as the sample subjected to single pass forging, the materials were subjected to deform in two directions other than load direction.



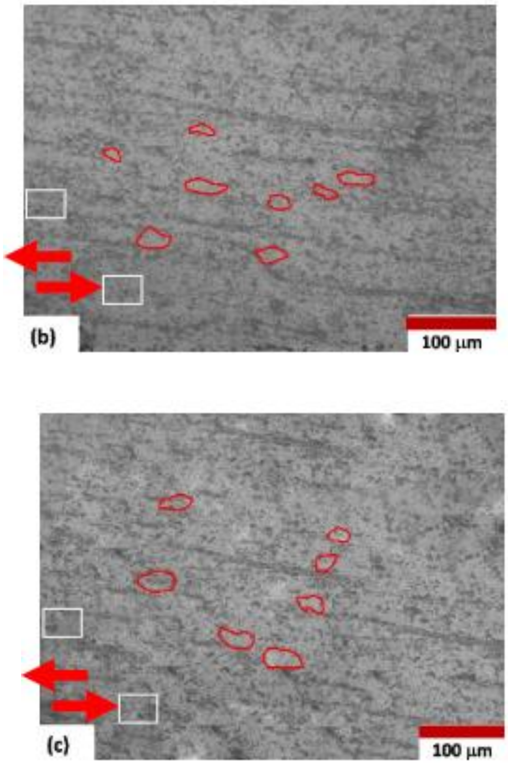
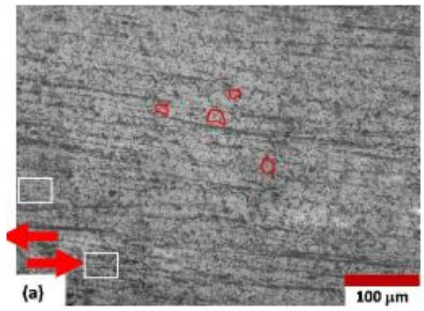




**Fig. 5.4 Microstructures of 3 cycles MAFed AA 6063 alloy perpendicular to: (a) X-axis, (b) Y-axis and (c) Z-axis**

Fig. 5.4 (a)-(c) and Fig. 5.5(a)-(c) shows the optical microstructure of multi axially forged AA 6063 alloy after third and sixth passes in all the axes respectively. It can be clearly seen that the observed grain morphology and size of AA 6063 alloy was started to decreases drastically and finally it reached very fine grained one. Further, almost equi-axed grain size was observed in all the axes after three and six passes (see red encircled). Fig. 5.6 shows the variation of grain size with number of forging cycles. From Fig. 5.6, the grain size of AA 6063 alloy is 98 m, 45□ m and 20 □ m for un-forged, 3 cycles forged and 6 cycles forged samples respectively. The grain size was decreased by a factor of ½ and ¼ after 3 cycles and 6 cycles forged one. These results revealed that more grain refinement was observed as the number of cycles of multi axial forging increases consequently it increases the dislocation density and strength of the materials.





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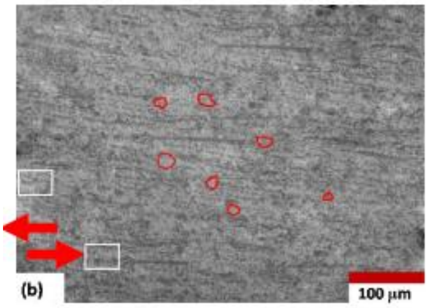


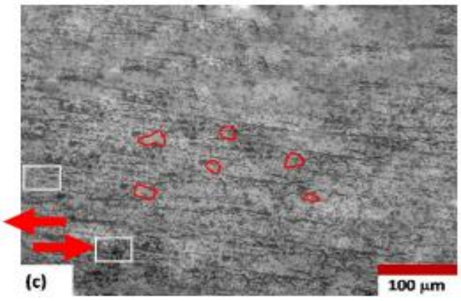


**Fig. 5.5 Microstructures of 1 cycle MAFed AA 6063 alloy perpendicular to: (a) X-axis, (b) Y-axis and (c) Z-axis**

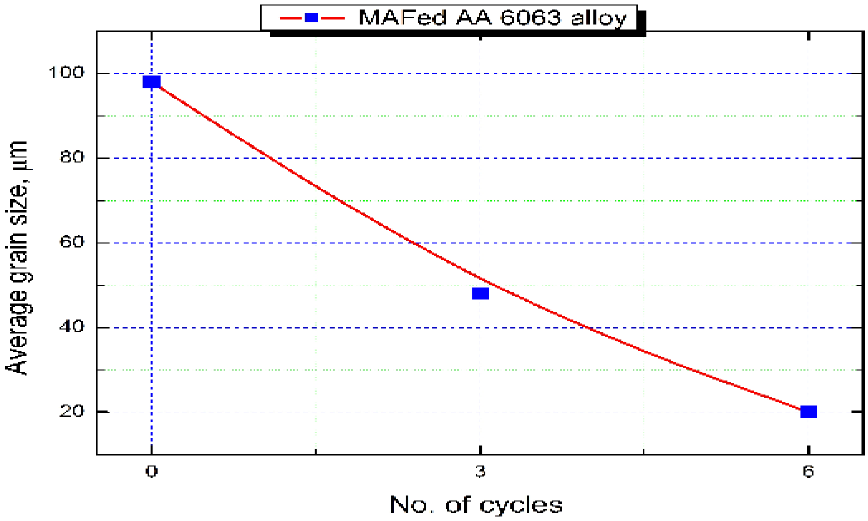


**Fig. 5.6 Variation of grain sizes with number of cycles during MAF of AA 6063 alloy**

**Compression test for MAFed AA 6063 alloy**

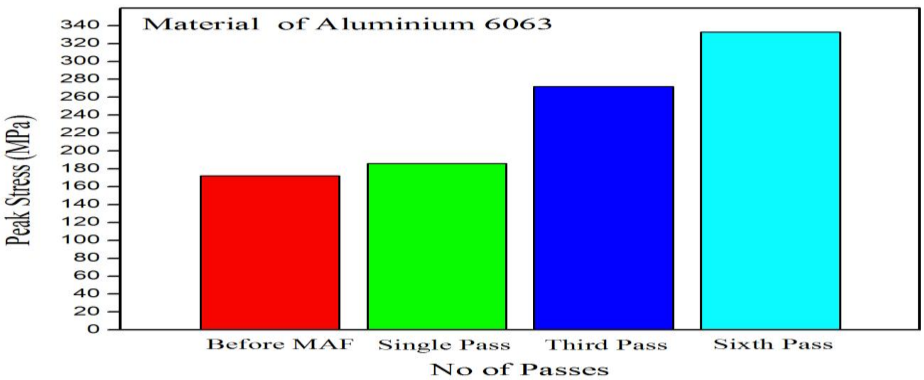


**Fig. 5.7 Bar chart showing the variation in peak compressive stress with the number of cycles of MAFed AA 6063 alloy**

The mechanical property in terms on compression test for MAFed AA 6063 alloy is shown in Fig. 5.7. It can be clearly observed that the compression strength of MAFed AA 6603 alloy was started to increase steadily with number of cycles during MAF (namely, 0, 1, 3 and 6 passes). The compression strength of 0 pass sample exhibited 175MPa peak compressive stress and the compressive strength of 1 passed MAFed sample exhibited around 187MPa and the compressive strength of 3 passed MAFed sample exhibited around 272MPa and the compressive strength of 6 passed MAFed sample exhibited around 333MPa. Thus the compressive strength was increased around 1.85 times than the non-MAFed samples. From these results, it can be concluded and evidenced that the grain refinement during MAF process played more role towards the improvement of mechanical property. It can be clearly noticed that the grain refinement was occurred during MAFed process which contributed more on compressive strength of the material

**Table. 5.2 Compression test values of MAFed AA 6063 alloy**

| S.NO | BEFORE MAF | | SINGLE PASS | | THIRD PASS | | SIXTH PASS | |
|---|---|---|---|---|---|---|---|---|
| | Peak load (KN) | Peak stress (MPa) | Peak load (KN) | Peak stress (MPa) | Peak load (KN) | Peak stress (MPa) | Peak load (KN) | Peak stress (MPa) |
| 1 | 70 | 176 | 79 | 186 | 154 | 271 | 243 | 332 |
| 2 | 69 | 174 | 76 | 189 | 150 | 274 | 242 | 331 |
| 3 | 67 | 177 | 78 | 187 | 152 | 272 | 243 | 335 |
| 4 | 71 | 173 | 77 | 185 | 151 | 270 | 239 | 334 |
| 5 | 68 | 175 | 79 | 188 | 153 | 274 | 240 | 333 |

## VI. CONCLUSION

The multi-axial forging (MAF) die for processing of AA 6063 Al alloy has been successfully designed and fabricated. Further AA 6063 alloy has been processed through MAF die with different number of forging cycles successfully. From the optical microstructural analysis it was observed that the refinement of the grain was obtained with more number of forging cycles. After 6 number of forging cycles, the observed grain size was almost equi-axed and very fine grained one. The mechanical property in terms of hardness and compressive stress was also investigated and reported. The measured hardness and compressive stress were increased steadily as the number of forging cycles increased from 0 to 6. This was due to more grain refinement occurred in the materials during MAF and consequently it increased the dislocation density. It can be concluded based on these results that an improved mechanical property can be achieved through MAF process.

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