Enhancing the Hardness of Al 6063 Alloy Via Equal Channel Angular Extrusion Process

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Abstract-
Hardness of a material is highly important in most architectural and engineering applications, especially considering its direct relationship with strength. As a result of this, methods of enhancing the hardness properties of materials, such as Al 6063 alloy, will of a great benefit to researchers, engineers, and architects. This study presents the effect of Equal Channel Angular Extrusion (ECAE) in enhancing the hardness of Al 6063 Alloys. ECAE is known to develop ultrafine-grained materials, which tend to be characterised by better hardness. Sets of samples made of Al 6063 were obtained, fabricated into the sizes of ECAE specimen, and grouped into seven parts. A part was taken as the control while the other six parts were went through a Sever Plastic Deformation (SPD) Process using the ECAE method. A part was extruded once, another twice, another 4 times, another 5 times and another 6 times. The microhardness values were obtained and reported, likewise, the calculated brinell hardness values were reported. From the results, it was concluded that ECAE increases the hardness of Al 6063 to an extent.

Keywords: Equal Channel Angular Extrusion (ECAE), Hardness, Al 6063 Alloy, Ultrafine-grained Materials.

1. Introduction
To optimise the applications of metals and alloys industrially, it is important to enhance their mechanical properties. One proven strategy to improving material’s mechanical properties is the technique whereby the grains are refined through plastic deformation [1-5]. This technique enables to production of Ultrafine Grains (UFG) and Nanostructured (NS) materials, and it is known as the Severe Plastic Deformation (SPD) technique [6-7]. Some SPD fabrication methods, which have been developed includes Equal Channel Angular Extrusion (ECAE), Cyclic Extrusion Compression (CEC), High Pressure Torsion (HPT), and Accumulative Roll Bounding (ARB) [8-12].

Out of the SPD methods highlighted, Equal Channel Angular Extrusion (ECAE) is the most attractive method. This is not only because the procedure is relatively simple, but it can produce quite large billets, which can be used for numerous structural applications. In addition, the method has a high potential being scaled up for commercial purposes [13-15]. Table 1 shows the four basic routes of the ECAE process, while Figures 1 and Figure 2 show the illustration of these processes.
Table 1: Routes of ECAE Processes [16]

| ROUTES | DESCRIPTION |
|--------|-------------|
| Route A | Billet extruded without any rotation |
| Route B<sub>A</sub> | Billet is rotated 90° in a counter clockwise and counterclockwise manner at alternate passes |
| Route B<sub>C</sub> | Billet is rotated by 90° after each pass |
| Route C | Billets is rotated 180° after each pass |

Figure 1: Illustration of the ECAE Process via route A and route B<sub>A</sub> [7]

Figure 2: Illustration of the ECAE Process via route B<sub>C</sub> and route C [7]

Aluminium 6063 Alloy has found huge applications in engineering and architecture. When heat treated, it provides an excellent resistance to general corrosion, and especially, to stress corrosion cracking [17]. It can be brazed, joined and welded easily through several commercial methods [4]. This alloy has often been referred to as architectural aluminum, and this is because of its ability to produce very smooth surface finish and its relatively low strength and low hardness, which is about half Al 6061 alloy's strength [18].

Hardness is the resistance of materials to localized plastic deformation. These deformations can either be small dents or scratches. Hardness is commonly used, even more than many mechanical properties because the process is relatively inexpensive, easy to carry out, it is non-
destructive and can be estimated from other mechanical properties such as the tensile strength [19]. Since SPD reduces the grain sizes of materials, it is expected to have a positive influence on the hardness of Aluminium 6063. Exposing Al 6063 alloy to ECAE tends to increase the hardness of the material.

The literature showing the direct effect of multiple passes of ECAE on hardness of UFG Al 6063 processed by is limited. Hence, this present study has aimed to studying the hardness behaviour of ultrafine grained Al 6063 alloys after subjected to 6 passes of ECAE. This will allow researchers to establish a trend on how multiple processing of materials through SPD will affect the resistance of that material to local deformation.

2. Methodology
The starting material for this study is Al 6063 alloy, which was obtained from Nigalex Limited, in Nigeria. This material was gotten in a billet form with a dimension of 15 mm. The chemical composition of the Al 6063 alloy was obtained using the spectrometer.

2.1 ECAE Samples Preparation
The as-received billets were then fabricated through machining, in order to get seven sets of samples. The dimension of these samples were 12.75 mm diameter and 75 mm length. This dimension was chosen so as to have a similar diameter with the ECAE die channels that was used for the SPD. A set was taken as the set of control samples and was labelled G. The other six sets of samples were then named as A, B, C, D, E, and F respectively.

2.2 Equal Channel Angular Extrusion Processes
ECAE of the billets in set A was done once. The billet was forced to enter the die through one of the channels (referred to as the entrance), then forced through the channel angle, and was allowed to go out through the other channel (referred to as the exit). The method used is similar to the one shown earlier in Table 1 and Figure 2, which is the Route Bc.

ECAE was done on set B billets twice. A 90° counterclockwise rotation of the billets was observed after the first pass. ECAE was done on set C billets three times. A 90° counterclockwise rotation of the billets was observed after the each of the first two passes. ECAE was done on set D billets four times. A 90° counterclockwise rotation of the billets was observed after the each of the first three passes. ECAE was done on set E billets five times. A 90° counterclockwise rotation of the billets was observed after the each of the first four passes. ECAE was done on set F billets six times. A 90° counterclockwise rotation of the billets was observed after the each of the first five passes. The last set of billets, G, was left unextruded.

2.3 Material's Hardness Testing
In order to study and determine the effects of ECAE hardness of the Al 6063 Alloy, the hardness test was carried out.

2.3.1 Microhardness analysis samples preparation
A sample of length 10mm was cut from each of the unextruded set of samples G and the extruded set of samples A, B, C, D, E and F. Seven samples were therefore obtained altogether. The samples were then mounted so as to ensure that the samples balance on the microhardness tester.
The surfaces of these samples were then prepared via grinding and polishing so as to remove scratches and defects. Intermediate and fine grinding was carried out on emery papers of progressive finer grades to remove all the scratches. The grinding was done using different grit papers ranging from No. 220, No. 320, No. 400 to No. 600 papers from coarse to fine. The special hard-wearing cloth was used to cover the polishing disc.

A constant drip of water was fed to the rotating pad. Light pressure was used and absolute cleanliness was ensured. The specimen was washed to be free of any adhering polishing compound and care was taken in touching the polished surfaces.

2.3.2 Microhardness Test

Using the microhardness tester, the microhardness tests were conducted on the prepared seven Microhardness test samples. The microhardness test was carried out using a Test load of 490.3 mN and the dwell time for the test was 10s. This test was done at 3 different points on each of the sample. The average hardness was then calculated.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition

The Chemical composition of the Al 6063 Alloy is shown in Table 2.

| Element | Si  | Fe  | Ca  | Mn  | Mg  | Zn  | Cr  | Ti  | Others | Al  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|--------|-----|
| Quantity (%) | 0.45 | 0.2 | 0.02 | 0.02 | 0.5 | 0.02 | 0.02 | 0.02 | 0.12   | 98.75 |

The major constituent of the alloy is Aluminium and other major alloy elements re Magnesium, Silicon and iron. This Composition confirms that the material obtained in Al 6063 alloy.

3.2 Microhardness Test

Three microhardness results were obtained from each of the 7 samples tested. The average of this result was computed. The trend of changes in average hardness at each pass of ECAE is shown in Figure 3.
From Figure 3, a gradual increase in the hardness value was observed at every pass of the ECAE was observed. ECAE led to a substantial increase in hardness after the first pass itself. Hardness increased with increasing number of passes due to the strain hardening mechanism which is as a result reduction in grain sizes which thereby increases grain boundary and hence impeded the movement of dislocations.

3.3 Hardness calculated from Tensile Strength
To validate the impact of ECAE on hardness, the Brinell hardness (HB) values were calculated using the tensile values obtained experimentally. The Brinell hardness (HB) values obtained are shown in Figure 4.

![Figure 4: Calculated Brinell hardness (HB) values for 6 ECAE passes](image)

Figure 4 showed a steady increase in hardness in the first 2 ECAE passes, this slightly decreased at the third pass and increased again at the fourth pass, and then started declining from the 5th pass down to the 6th pass. Although each passes lead to decrease in grain sizes, which is expected to lead to increase in hardness, this directly is exactly not the case in this study. The varying trend is presumed to be a result of the route being used, whereby different part of the billet made a contact with the sharp die angle [1,4], leading to a non-uniform ECAE deformation. In this experiment, the sets with 4 passes seem to give the optimum hardness values, considering the effort and resources required for each of the passes.

4. CONCLUSION
Comparing the hardness values before and after deformation, a substantial increase in the hardness values were achieved as a result of ECAE. Therefore, SPD via ECAE is proven to be an effective way of increasing the hardness of Aluminium 6063 alloy, and this should be done at an optimum number of passes.
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