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Assessment of Inorganic Lubricants on Mechanical Properties of ECAE Aluminum 6063

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ABSTRACT

Equal Channel Angular Extrusion (ECAE) is the process of subjecting bulk of metal to Severe Plastic Deformation (SPD) which led to the production of fine grain of that metal in larger quantities. The existing lubricants for this process are organic based and as a result scarce, expensive and not environmental friendly. Hence there is need to investigate alternate inorganic lubricant that can replace the organic ones. Therefore the major focus of this report based on improvement of the mechanical properties of aluminum conditioned to ECAE using jatropha oil as inorganic lubricant for the process. Aluminum alloy bar was annealed at 350^0C for 1hr, machined and cut to billets size of 11.95mm x 11.95mm x 40mm. these specimens for extrusions were machined to the specified dimension. The billets were extruded through ECAE die of 12 x 12mm^2 channel cross-sectional area, the channel angle was 30^0. The punch and container used for the experiment were made of tool steel alloy AISI D2. Two lubricants that were varied for the process include; jatropha oil and kleen mould for inorganic and organic lubricant respectively. The yield, ultimate tensile strengths (UTS), ductility and grain refinement of the material extruded with jatropha oil as lubricant, which gave the least extrusion pressure, produced the maximum yield, ultimate tensile strengths, ductility and best grain refinement and can effectively replace the organic lubricants used in forging operations.

Key words: Aluminum, extrusion, ductility, hardness, lubricants, microstructure.

INTRODUCTION

Equal Channel Angular Extrusion (ECAE) describes a severe plastic deformation (SPD) process a bulk of metal was subjected to in order to produce ultra-fine grained metals in a larger volume [1-6]. The advantage of this type of extrusion is the ability to lessen the time and stresses involved in extrusion process as compared to other methods of extrusion process in which the end result depends on the number of passes before getting a desirable grain size. Another describing characteristic of this method is the shape preservation ability due to special tool geometry that prevents the free flow of material and thereby producing a significant hydrostatic pressure [7]. The presence of a high hydrostatic pressure, in combination with large shear strains, is important in producing crystal lattice defects in higher densities, especially dislocations, which resulted to a significant refining of the grains. The dimensions of the billet otherwise called work-piece particularly do not change in severe plastic deformation operation. Hence, the process can be applied repeatedly so as to impact exceptionally high strains. The main objective of extrusion is to produce high strength and lightweight parts with environmental harmony [8]. In the conventional metal forming processes such as rolling and forging, the imposed plastic strain is generally less than 2.0. When multi-pass rolling, drawing and extrusion are carried out up to a plastic strain of greater than 2.0, the thickness and the diameter become very thin and are not suitable to be used for structural parts. In order to impose an extremely large strain on the bulk metal without changing the shape, many severe plastic deformation (SPD) processes have been developed [9]. The processes exhibit high strength, and thus they may be used as ultra-fine grained metals created by the SPD processes exhibit high strength, and thus they may be used as ultra high strength metals with environmental harmony [10].

Lubricants role cannot be over-emphasized in its performing role in forging processes as tribological systems based strongly on the metal forming process type. There is need of large load for ECAE processes to be carried out successfully which poses a high risk on tool life [11]. As a result of large load involvements, there is need for

different special lubricants which can serves as an anti wear coatings, reduction of heat generated during the process, reduction of extrusion pressure, adding tribological components to the functional surfaces efficiently, maximize tool life and above all improve the mechanical properties of the test piece. Organic lubricant has been the conventional lubricant for this process but very scarce and costly. In addition, the use of conventional, organic-based synthetic oil as lubricants has being an issue due to environmental problems, it has become imperative for researchers to be proactive in establishing safe and healthy working conditions while limiting the strain on the environment and metal forming equipment. Since about a decade ago, many countries such as Europe, Japan and the US have increasingly been restrictive to the industrial application of hazardous lubricants [12]. Regarding cold forging the substitution of zinc phosphate plus soap with environmentally benign lubrication systems is of concern due to sludge accumulation in the baths and its associated content of heavy metals [13].
The focus of the present study based on the assessment of the extrusion process using inorganic lubricant (jatropha oil) that can effectively separate tool and work-piece in ECAE. Such environmentally friendly lubricants become imperative judging from the strength obtained during ECAE but with equally enormous extrusion load which can have dire consequence on tool life. To effectively ameliorate the adverse conditions of high pressure and temperature at the interface between the tool and work-piece, the appropriate lubricant should not only posses the ability to consistently separate the tool and the work-piece but extract heat from the interface to prevent grain growth thereby enhancing and preserving improvement in the mechanical properties of the alloy after ECAE [14].

EXPERIMENTAL PROCEDURE

ECAE Die, Punch and Billet Design

Figures 1, 2 and 3 are the ECAE die, punch and billet (test piece) respectively. From the figure, it is shown that the entry and exit region of the die is 12mm and 12 mm respectively. This is to give little clearance of 0.05 for the billet of size 11.95 mm to enter the die and also to give punch of same dimension as the billet and die allowance to press the billet inside the die. The die was made a split type design in the sense that it can easily be assembled and disassembled into two halves. This is to avoid stress concentration at the exit region of the die, easy maintenance, and ease access of the billet after the extrusion. The die and punch was made of mild steel but was case hardened to improve its strength and later chrome coated to prevent it from rusting so as to allow reuse in further research

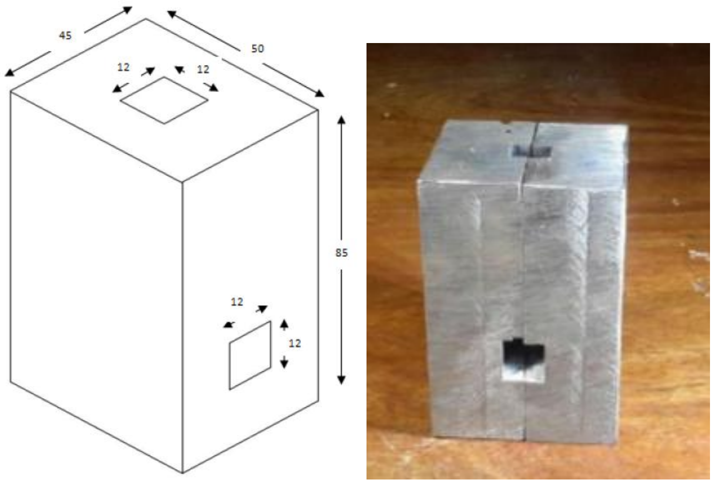


Fig. 1 ECAE Die

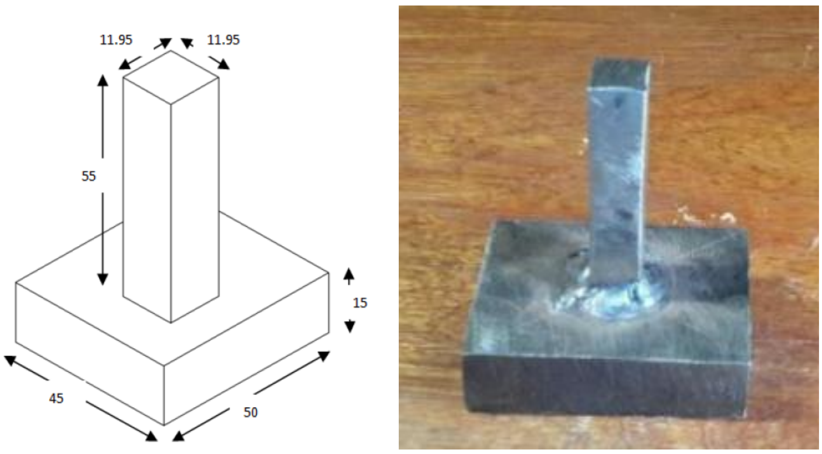


Fig. 2 Punch

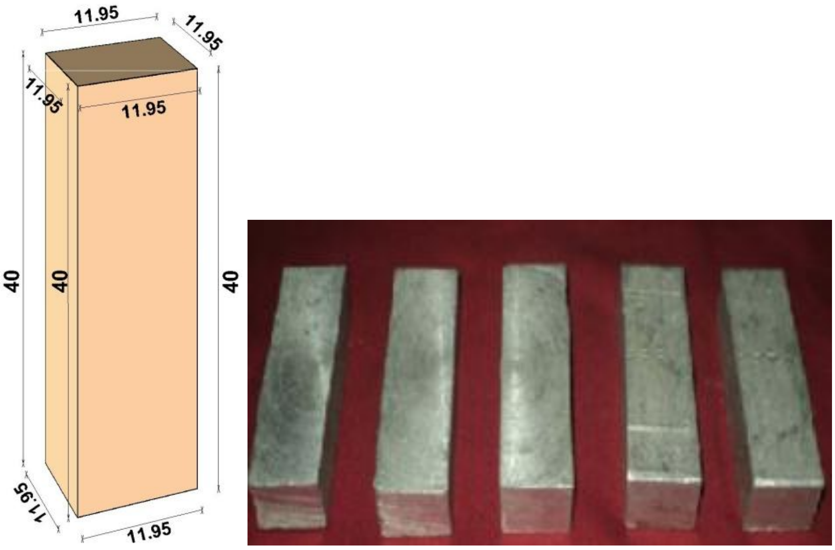


Fig. 3 Billet (Test piece)

ECAE test

Aluminum 6063 that was used as the test piece (billet) in this research was analyzed using spectrometer and the chemical composition by weight was found as thus: Si (0.45), Fe (0.35), Cu (0.03),Mn (0.04), Mg (0.06), Cr (0.007), Zn (0.04), Ti (0.006), Sr (0.005) and Al (base). The sample was machined to size 11.95 × 11.95 x 40 mm^3 (length× breadth × height) and was annealed at 350^0C for 1 hr to soften the billet so as to reduce the extrusion load requirement. Organic lubricant (Kleen mould) and inorganic lubricant (jatropha oil) were analyzed for comparison. The billets were extruded with the use of ECAE die of 12 × 12 × 58 mm^3 channel cross-section using organic lubricants for the first set of extrusions. The wall of the die channel was thoroughly cleansed with mentholated spirit before another set of extrusions using inorganic lubricant. This is to avoid adulteration of lubricant during the test. The channel angle of die used was 30^o. The pressures at which the organic and inorganic samples extruded were noted and recorded from the hydraulic press used. The punch and die used for the experiment were made of tool steel alloy AISI D2, and were chromium coated and polished to prevent rusting. A split die was used to avoid stress concentration at the corners and to facilitate easy removal of the extruded specimen. Specimens were extruded at room temperature at just one pass. All extrusions were conducted using a hydraulic press of 600kN capacity. As the press was operated manually, it was not possible to apply constant strain rate during the test. For each lubricant, four samples were subjected to the extrusion procedure and the average value was used to confirm the repeatability. After the whole process, the extruded samples using organic and inorganic lubricants were subjected to various mechanical test and compare to determine the variation and correlation of these lubricants in terms of mechanical properties after extrusion

Tensile test

A gauge diameter of 5mm and length of 10mm were machined out of the extruded samples using organic and inorganic lubricants. For each of the two lubricants, four specimens were tested and the average value was used for this study. An analog Monsanto tension meter was used, from where the yield strength, ultimate tensile strength and ductility data were derived and recorded.

Lubricants test

The organic lubricant (Kleen mould) and inorganic lubricant (jatropha oil) was subjected to tests such as fatty acid composition, saponification value iodine value using standard analytical test and viscosity test to determine the properties of these lubricants. Viscosity test was conducted on a NDJ-5s Digital viscometer to determine the viscosity of each lubricant. A 200ml volume of each lubricant in a clean beaker placed on a viscometer platform with stirrer which doubles as source to introduce heat was then inserted into the lubricant. The power source was switched on and the monitoring of the viscosity readings and corresponding temperature commenced until the required temperature range was achieved. Before the commencement of the experiment for the next lubricant, the stirrer and beaker were cleaned properly to avoid contamination among lubricants.

Micro-structural test

The extruded billets extruded with organic and inorganic lubricants were slowly grounded on a rotating grinding machine while steady flow of cooling water was maintained to prevent heat-induced. Various grades of emery paper (220, 320, 400 and 600) were used until a fine surface finish was produced. Polishing was done on a rotating polishing machine using diamond paste. The specimens were washed with cold water and immersed in methanol for two minutes to eliminate any stains that might be left by the polishing compound, residue of grease and dirt. The specimens were then cooled in running water, dipped in a mixture of acetic acid (16.66%), nitric acid (16.66%) and glycerol (66.67%) and agitated vigorously for 6 minutes. The samples were quickly transferred to running water to wash away the etchant, and then dried and finally examined in CETI optical metallurgical microscope.

RESULTS AND ANALYSIS

Properties of Organic and Inorganic Lubricants Used

Table 1 shows the properties of the organic and inorganic lubricants used and it was discovered that they both share similar properties in terms of specific gravity as well as viscosity. This may responsible for a very close range in properties (tensile strength and microstructure) of the samples tested after extrusion. It may also responsible for a closer range in value of extrusion load.

Table -1 Lubricants properties

Lubricants	Mass (g)	Saponification value(mg/g)	Iodine Value(mg/g)	Specific Gravity/30°C	Viscosity (100°C)
Jatropha oil	2000	200	88	0.921	8.53
Kleen mould	2200	146	92	0.925	8.96

Extrusion Load Result

Figure 4 depicts force versus ram displacement of extrusion at just one pass using organic and inorganic lubricants (kleen mould and jatropha oil respectively). This indicates that the extrusion pressure increases gradually with increasing ram movement (O to A) in Figure 4. This increase is due to initial easy movement of the specimen in the die after which it decreases to point B. The reason for this behavior may be due to the restriction of the exit channel of the die that leads to the forging of the billet. Obviously, at the start of the material movement, a static frictional condition is applied, but as the deformation proceeds, a dynamic frictional condition becomes prevalent resulting in a slight reduction in force (A to B). From point B, the extrusion pressure increases again to C (B to C), but with slow rate and it continues to the end of the process.

It should be noted that the load requirement for the sample extruded with inorganic lubricant (jatropha oil) at the start and end of extrusion process was lesser as compared to sample extruded using organic lubricant (kleen mould). This is indicated as O to A and B to C for start and end of extrusion process respectively in figure 4. However, the sample extruded with jatropha oil requires higher load as the billet is moving towards angular region (exit region) as compared to sample extruded with kleen mould. The whole illustrations emphasized on the superiority of jatropha oil over kleen mould at the starts and end of extrusion process but its inferiority towards exit region because at the beginning and end of ECAE processes, jatropha oil has load reduction capacity but not towards the exit channel of die.

Above all, the samples extruded with organic and inorganic lubricants exhibits very close and similar response in terms of extrusion load as it is visibly indicated by the two curves in figure 4.

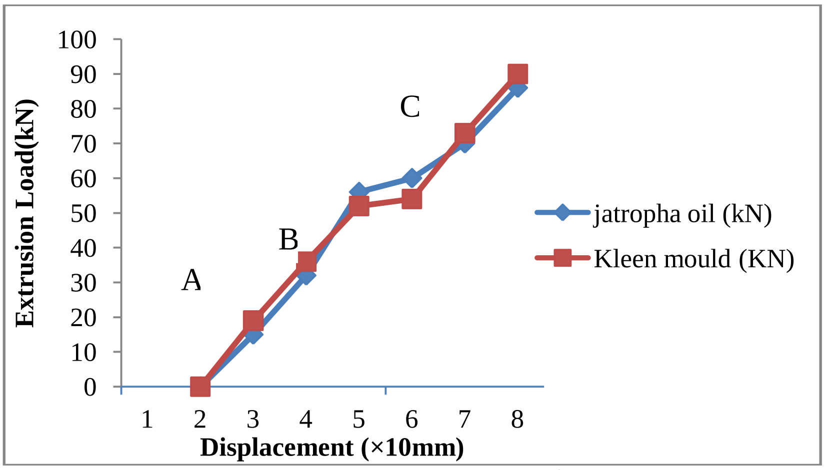


Fig. 4 Effect of lubricant on load-ram displacement curves during extrusion of aluminum 6063 and at a ram speed of 1mm/s

Tensile Stress Yield Stress and Elongation Result

Figure 5 and 6 shows the effect of lubricants on the yield strength and percentage elongation, respectively, of specimens processed by ECAE. Observe from figure 5 that the specimens extruded with the lubricants tested shows significant improvement in the yield strength and ultimate tensile strengths at a very close margin as compared to the un-deformed specimens. Although, samples extruded with jatropha oil has a little tensile and yield strength improvement capacity above the samples extruded with kleen mould has shown in figure 5. However, figure 6 shows that the ductility of specimens extruded with the two tested lubricants exhibits inverse relationship to tensile strength and yield strength because figure 5 and 6 indicated that the higher the tensile and ultimate strength, lower the percentage elongation (ductility)

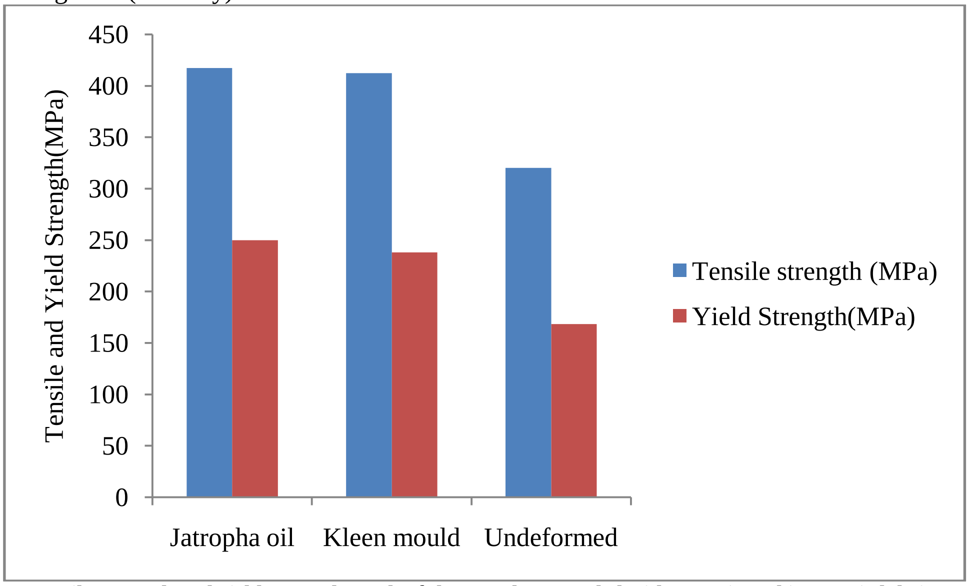


Fig. 5 Tensile strength and yield strength result of the samples extruded with organic and inorganic lubricants

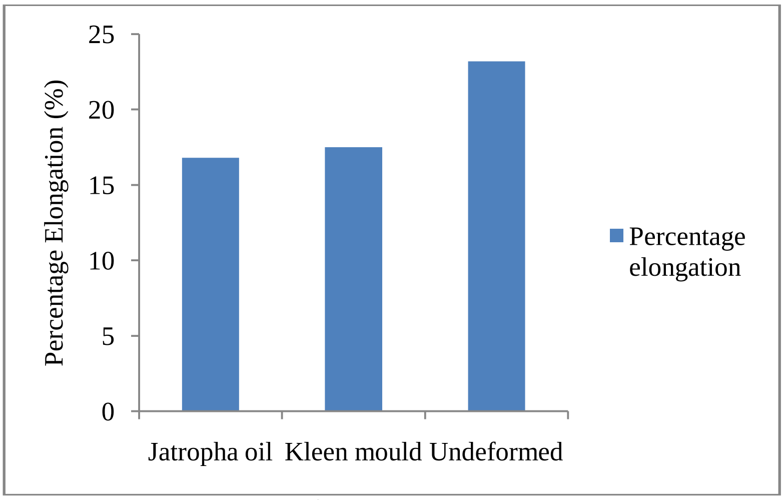
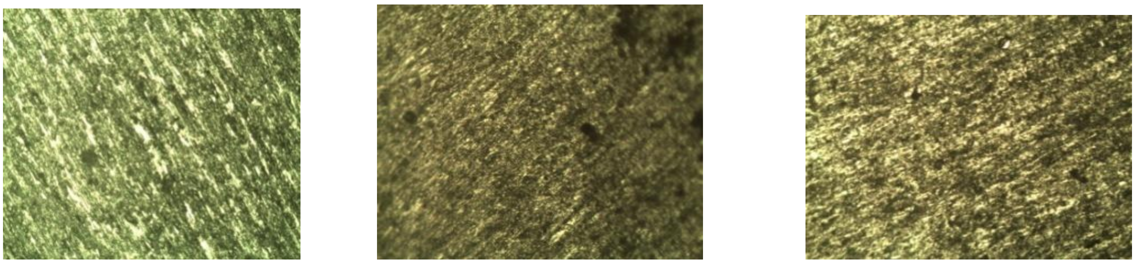


Fig. 6 Percentage elongation result of the samples extruded with organic and inorganic lubricants

Microstructures of the Samples

The microstructure of the sample un-extruded State (before ECAE) and after extrusion using jatropha oil and kleen mould as lubricants is as shown in figure 7. The microstructure of the un-extruded state sample reveals three major components namely α-aluminum matrix (α-Al) which is white in colour, magnesium silicide (Mg_2Si) which possesses grey colour and AlFeSi which is brown in colour. The more pronounced the α-aluminum matrix (α-Al), the less is the hardness of the matrix. When the grey colour predominates it indicates presence of AlFeSi, the more is the hardness. Examining the aluminum at un-extruded state, there is the high density of magnesium silicide (Mg_2Si) phase, follow by large particles of α-aluminum phase and sparsely distribution of AlFeSi phase. This shows that the aluminum sample at un-extruded state is of high ductility but of lesser hardness properties.

The microstructure when using jatropha oil and kleen as lubricant reveals some better refined grains of magnesium silicide Mg_2Si which though are not evenly distributed but are still densely present in the matrix. The α-aluminum phase had drastically reduced in volume fraction as well as in grain size while there is noticeable increased density of brown precipitate of AlFeSi. This shows increasing hardness value without considerable reduction in ductility after single pass. The microstructure using jatropha oil in figure 7 shows that a large volume fraction of fine recrystallized grains of magnesium silicide and more densely precipitate of AlFeSi appeared on this portion of the deformation as compared to sample extrude with kleen mould. The α-aluminum phase has further reduced in this portion than in the microstructure of kleen mould. It was also noticed that the α-aluminum phase is surrounded by AlFeSi along its grain boundaries. This obviously explains the increase in hardness using jatropha oil as lubricant.



Sample at un-extruded state Extruded sample with jatropha oil Extruded sample with Kleen mould

Fig. 7 Microstructures of the sample using organic and inorganic lubricant (Magnification x100)

CONCLUSION

The following conclusions were drawn after Equal Channel Angular Extrusion (ECAE) and mechanical properties assessment of aluminum using organic lubricant (kleen mould) and inorganic lubricant (jatropha oil);

- The two experimented lubricants for this forging process impact significantly the strength, hardness and microstructure of the extrudate.
- Jatropha oil as ECAE lubricant has better load reduction factor as compared to kleen mould. The lubricant's load reduction tendencies are at a closer range.
- Jatropha oil and kleen mould effectively ameliorate the adverse conditions of high pressure and temperature at the interface between the tool and work-piece by consistently separating the tool and the workpiece thereby reducing extrusion load, jatropha oil will be preferable to kleen mould at higher temperature and pressure as seen in the present study. This confirms the result found in literature [15] that jatropha oil performed better than others at room temperature and even beyond the room temperature as seen in this study.
- Finally, it was observed that the specimen extruded using jatropha oil were easier to remove from the die after extrusion than those extruded using kleen mould in this study.

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