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Assessment of Vegetable Lubricants On Microstructural Analysis of Aluminum Produced By Ecae

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ABSTRACT
Micro-structural evaluation of aluminum 6063 extruded by equal channel angular extrusion (ECAE) method is the purpose of this research. Aluminum alloy (AA6063) bar was annealed at 350^0C for 1hr, machined and cut to billets size of 14mm x 14mm x 44mm. these specimens for extrusions were machined to the specified dimension to a visibly good finish. The billets were extruded through ECAE die of 14 x 14mm^2 channel cross-section areas, the channel angle was 120^0 and the extrusion pressures at which samples with different lubricants extruded were noted and recorded. The punch and container used for the experiment were made of tool steel alloy AISI D2. Four lubricants used in this study include; palm oil, olive oil, coconut oil and groundnut oil. The micro structural analysis of the material extruded with palm oil as lubricant, which gave the least extrusion pressure, produced best grain structures followed by groundnut oil and coconut oil while olive oil was the least. However, palm oil and olive oil has better load reduction than other lubricants. All the lubricants tested greatly enhanced microstructures of A1 6063 and can effectively replace the chemical based lubricants used in forging operations.
Keywords: *Aluminum, extrusion, lubricants, microstructure.*

INTRODUCTION
Equal Channel Angular Extrusion (ECAE) may be defined as metal forming processes into a bulk metal in order to create ultra-fine grained metals [1][2][3][4][5][6]. It is a form of Severe Plastic Deformation (SPD) techniques that preserves the of shape material due to special tool geometrics which prevents the free flow of material and thereby produce a significant hydrostatic pressure. The presence of a high hydrostatic pressure, in combination with large shear strains, is essential for producing high densities of crystal lattice defects, particularly dislocations, which results in a significant refining of the grains. As the dimensions of the work-piece particularly do not change in an SPD operation, the process may be applied repeatedly to impose exceptionally high strains. The main objective of a SPD process is to produce high strength and lightweight parts with environmental harmony. In the conventional metal forming processes such as rolling, forging and extrusion, the imposed plastic strain is generally less than 2.0[5]. 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 SPD processes have been developed [7]. 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 ultrahigh strength metals with environmental harmony [8]. The yield stress of polycrystalline metals is related to the grain diameter by the following Hall–Petch equation:

$$\sigma_y=\sigma_o+ Ad^{-1/2} \quad (1)$$

where σ_y is the friction stress and A is a constant. Eq. (1) means that the yield stress increases with decreasing square root of the grain size. The decrease grain size leads to a higher tensile strength without reducing the toughness, which differs from other strengthening methods as heat treatment. To accomplish this, a very large extrusion force is often involved resulting into adverse interface conditions which can lead to tool wear and consequent failure. Tribological systems depend strongly on the kind of metal forming process. Cold forging operations, especially, SPD requires a very large load which poses a high risk on tool life [9]. This large load illustrates the need for different special lubricants, anti wear coatings and additional tribological components such as functional surfaces, to efficiently maximize tool life. Quality and type of lubrication which are required to realize tool work-piece separation and friction reduction depend strongly on the tribological loads that appear in a specific process. By this separation reduced tool wear is achieved because the risk of adhesion is minimized. Additionally, in most cases friction forces are reduced. The use of conventional, petroleum-based synthetic oil as lubricants 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 [10]. 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 [10].

MATERIALS AND METHODS
Viscosity Test
Viscosity test was conducted on a NDJ-5s Digital viscometer to determine the viscosity of each lubricant. A 200ml volume of each lubricant in aclean 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.

ECAE Test

Aluminum billet was annealed and machined to size 11.95×11.95×40 mm^3 each then coated with palm oil. Also the die channel was as well coated with the same the same oil. The billet was then inserted into the die channel and allows punch to rest on it. The set up was placed on the hydraulic machine (60kN capacity) for extrusion to take place and plunger speed was about 1 mm/second. Also, four samples were extruded for each of the lubricants to determine the repeatability of the result and average values of the results were computed. The same processes were repeated for other extrusions using three other selected lubricants (groudnut oil, olive oil, coconut oil).It must be noted that after extrusion with a particular lubricant, the die channel was thoroughly cleansed with cotton wool soaked with methylated spirit to prevent reflection of one lubricant property in other tested ones. At the end of all extrusions with all selected lubricants, the hardness property of all extruded product were evaluated.

Micro-structural Test

Test samples were slowly grounded on a rotating grinding machine while maintain a steady flow of cooling water to prevent heat-induced modification of the microstructure. 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 DISCUSION

Lubricants Analysis

In order to have a better insight to lubricant behavior and performance under severe plastic deformation that ECAE is known for, figure 1 reveals the relationship between viscosity and temperature. Expectedly, increasing temperature leads to decreasing viscosity. Within the range of extrusion temperature in this study, palm oil is observed to demonstrate highest lubricity, follow by groundnut oil, coconut oil with olive oil showing the lowest viscosity. Notice that between the temperature range of 55°C and 95°C the viscosity of palm oil falls below that of groundnut. Foaming was observed at the temperature of 100°C during the test for the viscosity of palm oil. This is probably due to the presence of water. It was noticed that viscosity increases with increasing temperature from this point and this is probably due to the increase of the concentrate of fatty acid. The fluctuation seen from 100°C notwithstanding, palm oil will certainly perform better than any of the tested lubricants under increasing pressure and temperature. Figure 1 gives clue to excellent extrusion load reduction seen with palm oil as lubricant during ECAE process and goes further to assert that red palm oil will function better even at temperature well above room temperature.

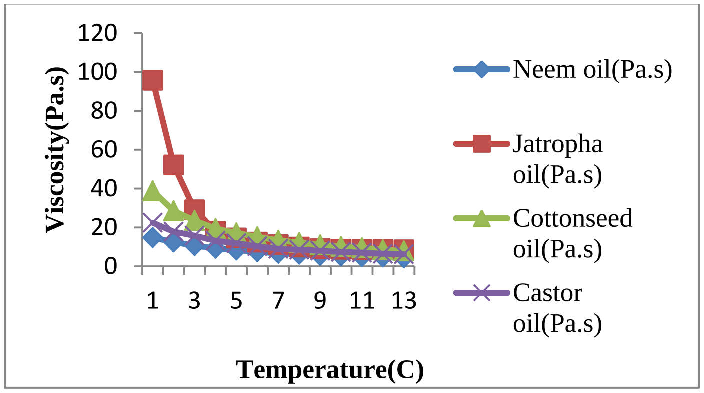


Figure 1: Lubricants viscosity at different temperature ranges from 40°C to 100°C

The ECAE Die and Punch Used for the Experiment

Figure 2 and 3 shows different views and positions of ECAE die used for this research and punch respectively

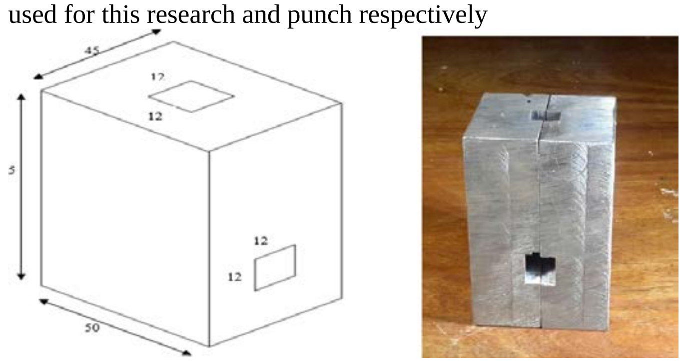


Figure 2: The ECAE die

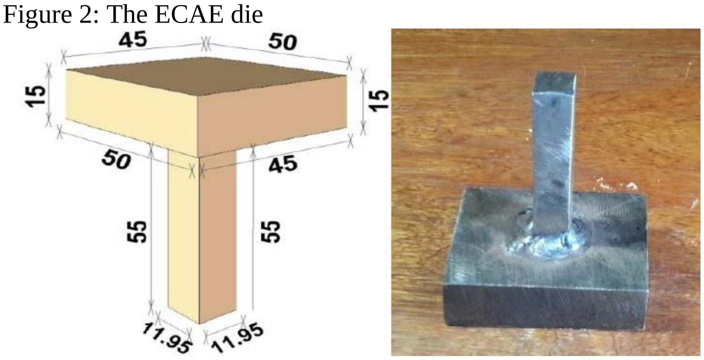


Figure 3: Punch

Extrusion Pressure versus Ram Displacement

Figure 4 shows a typical ECAE force versus ram displacement curves for one pass using different lubricants. Referring to this figure, 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. Then the rate of increase in pressure intensifies (A to B) until the pressure reaches a local maximum B, after which it decrease to point C. 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 (B to C). From point C, the extrusion pressure increases again (C to D), but with slow rate and it continues to the end of the process. The lager flow stress of the work-hardened material in the exit channel against the un-deformed material in the entry channel imposes the increase of the extrusion pressure with the development of ECAE process (D to E).

It should be noted for palm oil and olive oil, that the maximum value (point B) is not as pronounce, not easily observable and differentiable from the rest of the curve. This underlines the effectiveness of these lubricants in extrusion load reaction during ECAE. It was observed that the specimen extruded using palm oil is easier to remove from the die than when using other lubricants tested in the study. Also, point D to E is almost non-existence for palm oil, olive oil and coconut oil compared to that of groundnut oil. This is probably due to low frictional load obtained using palm oil as lubricant thereby impeding filling, since friction favors and improves the degree of filling in ECAE.

Furthermore, it is observed that point A to B is only visible for coconut oil and groundnut oil but for palm oil and olive oil, the pressure simply continues the rise gradually from point O to local maximum (point B).

Since it has been pointed out that this increase is due to the initial easy movement of the specimen in the die, it must be due to the good lubricity of these lubricants. Friction coefficient has a very small effect on variation factor and then on the rate of filling (i.e. existence of unfilled region or not) [11]. However, as seen in Figure 4, the load required to achieve the extrusion process is really sensitive to friction. Even before reaching the maximum point (B), the peak load is higher accounting for higher friction load. The difference or disparity in terms of peak load is magnified or widened by the poor coconut oil as lubricants during ECAE. Obviously, the load corresponding to the steady state is sensitive to the friction parameter. Indeed, the higher friction factor, the higher the load. From the forging, therefore, it can be deduced that palm oil has the least friction factor, followed by olive oil, then coconut oil while groundnut oil has the highest friction factor for aluminum alloy processed by equal channel angular extrusion. In ECAE, friction favors and improves the degree of filling; this probably explains the reason why only the curve for groundnut oil as lubricant got to the steady state within the ram stroke considered. Since the contact areas increase, the required load to extrude the material is increased.

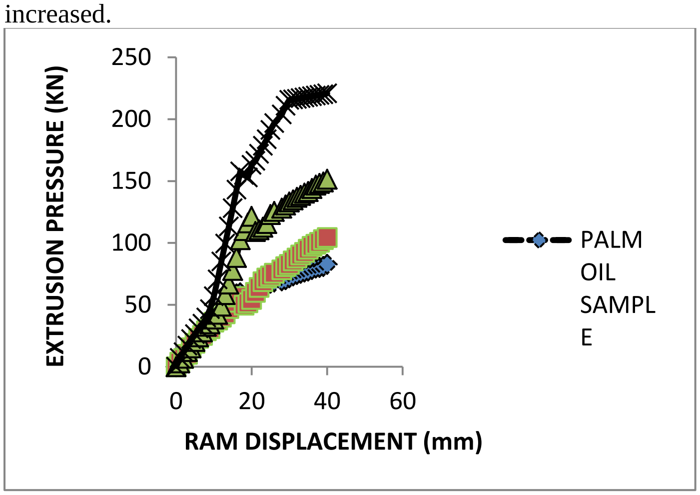


Figure 4: ECAE force versus ram displacement curves for one pass

Initial Micro-Structural and Texture

The original microstructures of the as-received billets before ECAE and the ECAEedextrudates with palm oil and olive oil as lubricants are shown in Figure 5. The microstructure of as-received aluminum 6063 before ECAE reveals three major components namely α-aluminum matrix (α-Al) which is white in colour, magnesium silicide (Mg2Si) 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. Looking at the as-received microstructure, there is the high density of magnesium silicide (Mg2Si) phase, follow by large particles of α-aluminum phase and sparsely distribution of AlFeSi phase. This shows that the as-received billet is of high ductility but of lesser hardness properties.

Microstructure and Texture of Extruded Specimen with Palm Oil as Lubricant

The microstructures of position marked A on the extrude (Figure 5) using palm oil as lubricant reveals some better refined grains of Magnesium silicide 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 the noticeable increase density of brown precipitate of AlFeSi. This shows increasing hardness value without considerable reduction in ductility after single pass. The microstructure marked b using palm oil is from the position marked B on the extrudate. A large volume fraction of fine recrystallized grains of Magnesium silicide and more densely precipitate of AlFeSi appeared on this portion of the deformation. The α-aluminum phase has further reduced in this portion than in the microstructure of the position marked Aon the extrudate. Notice also that the α-aluminum phase is surrounded by AlFeSi along its grain boundaries. This obviously explains the increase in hardness value of this portion. The grains are seen elongated in the direction inclined about 45^o with respect to the x-direction of ECAE samples, being about parallel with the shear direction. In the microstructure of the position marked C on the extrude, represented as c, the α-aluminum and Magnesium phases predominate the matrix with AlFeSi phase sparsely distributed and aligned along the grain boundaries. The particles of these phases are fairly larger than those of microstructure taken at the position marked B on the extrudate, represented as b.

Microstructure and Texture of Extruded Specimen with Olive Oil as Lubricant

The microstructures of the position marked A on the extrudate (Figure 5) using olive oil as lubricant reveals a high volume fraction of better refined grains that as-received of α-aluminum and sparsely distribution of Magnesium silicide Mg2Si which though are not evenly distributed but are still fairly present in the matrix. The α-aluminum phase had drastically reduced in grain size compared to as-received while there is the noticeable increase density of brown precipitate of AlFeSi. This shows increasing hardness value without corresponding reduction in ductility after single pass. The microstructure marked b using olive oil corresponds to the position marked B on the extrudate. A large volume fraction of fine recrystallized grains of Magnesium silicide and a more densely precipitate of AlFeSi appeared in this portion of the deformation. The α-aluminum phase has further reduced in volume fraction with few scattered large grains in this portion than in the microstructure of the position marked ‘A’ on the extrudate. Notice also that the α-aluminum phase is significantly present in this matrix compared with the same position using palm oil. This probably account for the decrease in hardness value of this position compared with the specimen extruded with palm oil. In the microstructure of the position marked C on the extrudate, represented as c, the α-aluminum and Magnesium phases predominate the matrix with AlFeSi phase sparsely distributed and align along the grain boundaries. The particles of these phases are fairly larger than those of microstructure of portion marked B on the extrudate, represented as b. This matrix is of lesser hardness.

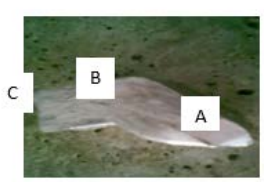
Microstructure and Texture of Extruded Specimen with Coconut Oil as Lubricant

The microstructures of the position marked A on the extrudate (Figure 5) using coconut oil as lubricant reveals fairly refined grains of Magnesium silicide Mg2Si, compared to as-received. The ɑ-aluminum phase is densely present though reduced in grain size while there is appreciable increase density of brown precipitate of AlFeSi. This shows a gain in hardness value without reduction in ductility after single pass. The microstructure marked b using coconut oil corresponds to the position marked B on the extrudate. A large volume fraction of fine recrystallized grains of Magnesium silicide and a more densely precipitate of AlFeSi appeared in this portion of the deformation. The ɑ-aluminum phase has drastically reduced in particles size as well as volume fraction in this portion than in the microstructure of the position marked ‘A’ on the extrudate. Notice also that the ɑ-aluminum phase is surrounded by AlFeSi along its grain boundaries. This obviously explains the increase in hardness properties of this portion. In the microstructure of the position marked C on the extrudate, represented as c, the ɑ-aluminum and Magnesium phases predominate the matrix with AlFeSi phase sparsely distributed and align along the grain boundaries. The particles of these phases are fairly larger than those of microstructure of portion marked B on the extrudate, represented as b. This matrix is of lesser hardness.

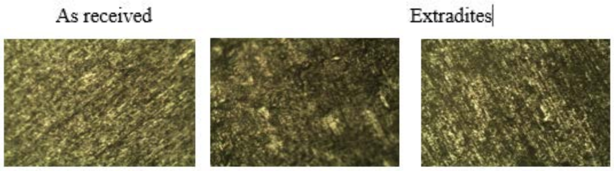
Microstructure and Texture of Extruded Specimen with Groundnut Oil as Lubricant

The microstructures of the position marked A on the extrude (Figure 5) using groundnut oil as lubricant reveals a high volume fraction of well refined grains of ɑ-aluminum and sparsely distributed Magnesium silicide Mg2Si which though are not evenly distributed but are still considerably present in the matrix with some fine crystals of (AlFeSi) in the boundaries. This shows increasing hardness value without a significant reduction in ductility after single pass. The microstructure marked b using groundnut oil is from the position marked B on the extrudate. A large volume fraction of large crystallized grains of Magnesium silicide (Mg2Si) are observed in this phase. There are less precipitate of AlFeSi appeared in this portion of the deformation. The ɑ-aluminum phase dominates with larger particles size compared to position A and C. with enormous force used with this lubricant, it is possible there is grain growth in this portion during deformation. Very similar to A, the microstructure of the position marked C on the extrudate using groundnut oil as lubricant , reveals high volume fraction of well refined grains of ɑ-aluminum phase. However, some of the Mg2Si were observed to have segregated with the matrix in side A with few crystals of AlFeSi found aligned in the boundaries. This shows increasing hardness and ductility after single pass.

As received



Extradites



a b c

Palm oil

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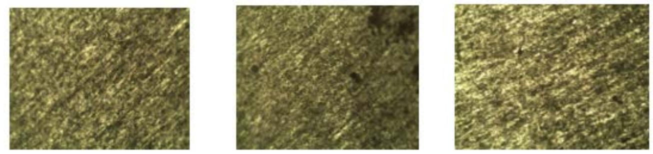
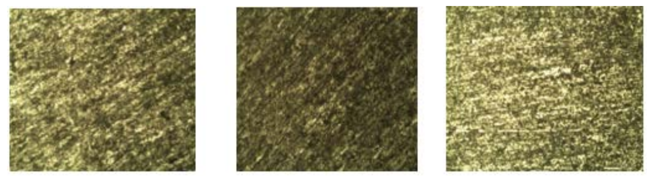


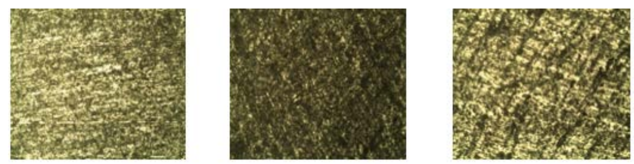
a b c

Olive oil



a b c

Groundnut oil



a b c

Coconut oil

Figure 5: Optical micrograph of the position indicated (A,B,C) on the extrudates showing how the morphology of as-received (prior particles) changes with palm oil, olive oil, groundnut oil and coconut oil as lubricants (magnification: 100x).

CONCLUSION

A commercial 6063 aluminum-magnesium-silicon-alloy billets were extruded using four environmentally benign lubricants such as palm oil, olive oil, coconut oil and groundnut oil. The as-received microstructures and textures were analyzed and compared to the same properties after extrusion. The following conclusion may be drawn.

- All lubricants used during metal forming process significantly improved microstructure of the extrudate with the sample extruded with palm exhibits finest grain structure.
- There is unusual mechanical behavior caused by the unique fine structures generated by SPD processing and the effective heat extraction by the lubricant from deformation zone thereby reducing grain growth that could have evolved from excessive heat generation during deformation.
- Palm oil has the least friction factor, followed by olive oil, then coconut oil has the highest friction factor extruding aluminum alloy processed by equal channel angular extrusion.
- Palm oil has the least friction factor, followed by olive oil, then coconut oil has the highest friction factor extruding aluminum alloy processed by equal channel angular extrusion.
- Palm oil and olive oil 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 work-piece thereby reducing extrusion load, palm oil will be preferable to olive oil at higher temperature and pressure as seen in the present study.
- It was observed that the specimens extruded using palm oil

were easier to remove from the die than those extruded using other lubricants tested in this study.

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