



## Evaluation of Vegetable Based Lubricants on Hardness Property of ECAE Aluminum

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### ABSTRACT

Equal Channel Angular Extrusion (ECAE) is the extrusion method that involves the use of angular die to introduce plastic deformation on any metal especially aluminum which in turn improves its hardness. Lubricant's role cannot be underestimated in the process as it requires reducing the high heat of deformation and extrusion pressure involved. The commonly used lubricants for this process were from organic sources, very scarce and non-environmentally friendly. Hence, it is a great advantage to investigate alternative extrusion lubricant from vegetable source. Four vegetable based lubricants such as jatropha oil, castor oil, neem oil and cottonseed oil were selected for this research. The properties of these selected oils were characterized to its physical and chemical properties. Aluminum rod was machined to 17 billets of size 11.95m x 11.95m x 40m ( $l \times b \times h$ ) each and was annealed. The billet size was selected based on the configurations of the fabricated ECAE die. Four billets were extruded with each lubricant which makes the total of 16billets extruded for the four lubricants and the last billet was used as the control. The hardness of the extruded samples was evaluated after the extrusion and compared to the control. The hardness result was compared to the sample extruded with organic based lubricants from the literature. It was discovered that all the lubricants tested greatly enhanced hardness of the extruded sample but at different magnitude. Jatropha oil exhibits the greatest hardness on extrusion of Aluminum.

**Keywords:** Aluminum, extrusion, hardness, lubricants, vegetable

### INTRODUCTION

Extrusion is defining as the process of subjecting metals to plastic deformation by compressive force which in turn brings about reduction in micro-structural size of such metals and increased hardness [1]. The required pressure to force the billet out of the die channel was supplied by the hydraulic press that rest on the die punch. Equal Channel Angular Extrusion (ECAE) involves the severe plastic deformation that lead to the increased hardness of a material in larger volume at just a single pass [2]. In ECAE deformation, angular die of the same cross sectional area for both entry and exit region that intercept at a particular angle ranges from 90° to 150° is applicable to extrude the annealed billet at high pressure, which lead to the deformation of such material [3]. The extruded products will be of the same cross sectional area when compared to the material before extrusion [4]. Extruded products constitute more than 50 % of the market for aluminium products in Europe of which construction consumes the majority [5]. Aluminium extrusions are used in commercial and dwelling buildings for window and door frame systems, prefabricated houses/building structures, roofing and exterior cladding, curtain walling, shop fronts, etc. Furthermore, extrusions are also used in transport or airframes, road and rail vehicles, aircraft manufacturing and in marine applications [6]. Extrusion by ECAE process impacts large amount of plastic deformation on the material at just a single pass which in turn will improve the mechanical properties such as hardness, yield stress, tensile strength and also reduced the time and energy spent on extrusion [7].

Vegetable oils are highly desired as alternative lubricants for metal working operations but it has limited ability to be utilized in the metal working application because it is mostly utilized in food industries. It was proved that the biodegradability levels of vegetable oils are better compared to organic-based lubricants which makes it environmentally friendly [8]. Furthermore, organic based extrusion lubricants are more expensive as compared to vegetable based [9]. The major disadvantage of vegetable based lubricants is that most of them are edible, which may cause food shortage if introduced as metal working lubricants but has so many advantages. However, if vegetable based

lubricants with little or no edibility value can be discovered, it will be a great advantage to metal working operation because it is cheap, environmentally friendly and readily available.

### Roles of Extrusion Lubricant

Lubricant plays an important role in extrusion process because extrusion cannot be successful without suitable lubricants. Extrusion lubricants help in reduction of deformation load, increase the level of deformation before fracture, control surface finish, minimization of die wear, minimization of punch wear, thermal insulation of tool, thermal insulation of work piece, cooling the tool and the work piece [10]. All these stated functions help in increasing the useful life of die as well as increasing the hardness of the extruded products [11]. Lubrication also influences the metal flow in die cavities because it reduces friction between the surfaces of the dies and forging [12].

### Disadvantages of the Existing Extrusion Lubricants

Existing extrusions lubricants are non-biodegradable because they are organic based and as a result cause pollution to the aquatic and terrestrial life when discharged as a waste [4]. Also, they are very expensive as compared to vegetable based [11]. In order to eliminate the problem associated with these lubricants, there is need to investigate vegetable based lubricants as a replacement for organic based because they are safe and environmentally friendly.

## EXPERIMENTAL PROCEDURE

### Determination of Properties of Lubricants

Viscosity of 20ml each of the four selected lubricants namely jatropha oil, neem oil, castor oil and cottonseed oil was conducted on digital viscometer at different temperature ranges from 40°C to 100°C. Properties such as saponification, iodine contents, peroxide, fatty acid and unsaponifiable matter were determined using standard analytical methods (SAM). Fatty acid contents were obtained by converting the oil to fatty acid methyl esters prepared by the addition of 900: 1 of n-hexane 50mg of oil and 50: 1 of sodium methoxide. The mixtures were vortex for 7seconds and allowed to settle for 5min. The top layer (1: 1) was injected into a gas chromatograph where each content was derived.

### ECAE Die Design

The fabricated die for this research was a split type just to ensure easy removal of billet inside the die after the extrusion with each selected lubricants and to allow thorough cleaning of die channel after each lubricant to prevent reflection of one lubricant property in others. This is possible because split type design allows easy assembly and disassembly of die. The die consists of two equal parts which becomes one after it has been assembled. One of the two parts consist of six holes (diameter 6mm each) bored on it and the other parts consists of four holes of same diameter with two die holder to secure and hold the two parts firmly after the assembly. The entry and exit die channel was  $12 \times 12 \times 58 \text{mm}^3$  (length, breadth, height). The channel angle was 60°. The die material is made of mild steel which was case hardened to withstand pressure from the hydraulic press. The detail configuration is as shown in figure 1 and 2.

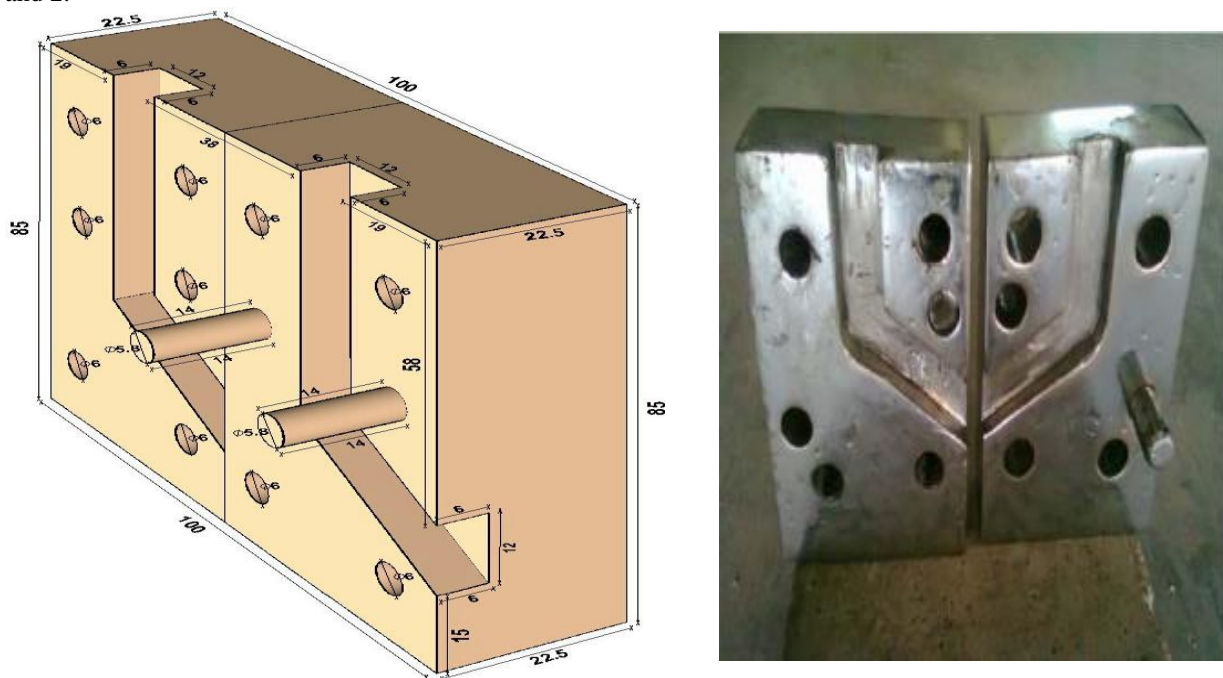


Fig. 1 Designed die in two parts

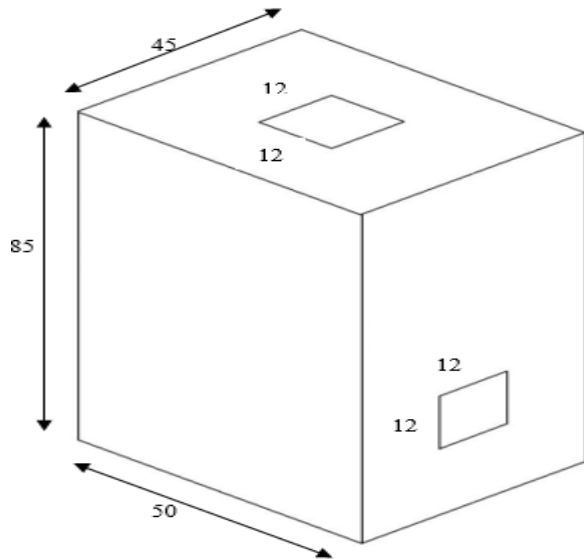


Fig. 2 Assembled design of a die

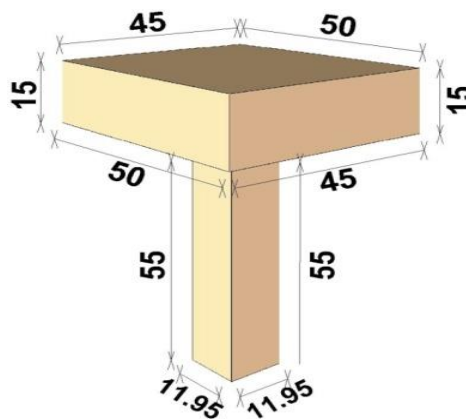


Fig.3 Punch design

### Punch Design

The major requirement for the punch design is the billet diameter, which is the diameter of the punch itself. The punch's height design was 55mm as shown in Figure 3. This is to provide space for an initial advance of the punch to avoid it slipping off, and at the end of the extrusion process the punch was not completely in the die, but some portion of it was outside the die to allow the appropriate contact with ram. The punch was made of mild steel and was case hardened to give enough required strength.

### ECAE Process

Annealed billet that has been machined to size  $11.95 \times 11.95 \times 40 \text{ mm}^3$  each was coated with jatropha 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 (neem oil, castor oil, cottonseed 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.

### Hardness Test

Hardness test was carried out on the extruded samples and were analyzed based on different lubricants experimented using rockwell micro hardness to determine the mechanical properties across the surface of interest, as well as to determine the response of each lubricant to hardness. The hardness of the control billets was also measured for comparison and to know the degree lubricant's response to hardness. The individual indents with each row were spaced at 3mm intervals. This ensured that no residual stresses from previous indents would offset the value of the current indent.

RESULTS AND DISCUSSION

Lubricants Composition Analysis

Lubricants viscosity at different temperature ranges from 40°C to 100°C is as shown in figure 4.

Lubricant Seed Oil Percentage, Saponification, Iodine, Specific Gravity and Fatty acid value

Percentage of oil in the seed, saponification value, iodine value, specific gravity and fatty acid composition of lubricant were shown in table 1 and 2.

Table -1 Percentage of oil in Seed, Saponification, Iodine Values and the Specific Gravity of Local Oil

Lubricants	% of oil	Saponification Value(mg/g)	Iodine Value (mg/g)	Specific gravity
Castro oil	49	181	85	0.955/30°C
Neem oil	48	180	72	0.920/30°C
Jatropha oil	37	200	88	0.921/30°C
Cottonseed oil	23	194	104	0.924/30°C

Table -2 Fatty acid Composition of four Lubricants

Fatty acid	Neem oil	Castro oil	Cotton oil	Jatropha oil
Myristic	1.8	1.5	0.4	1.2
Palmitic	15	2.0	2.0	1.5
Arachidic	2.2	2.1	2.0	0.3
Oleic	5.5	7.0	3.5	5.0
Linoleic	10.0	5.0	4.2	3.2
Stearic	1.0	1.8	2.0	7.5

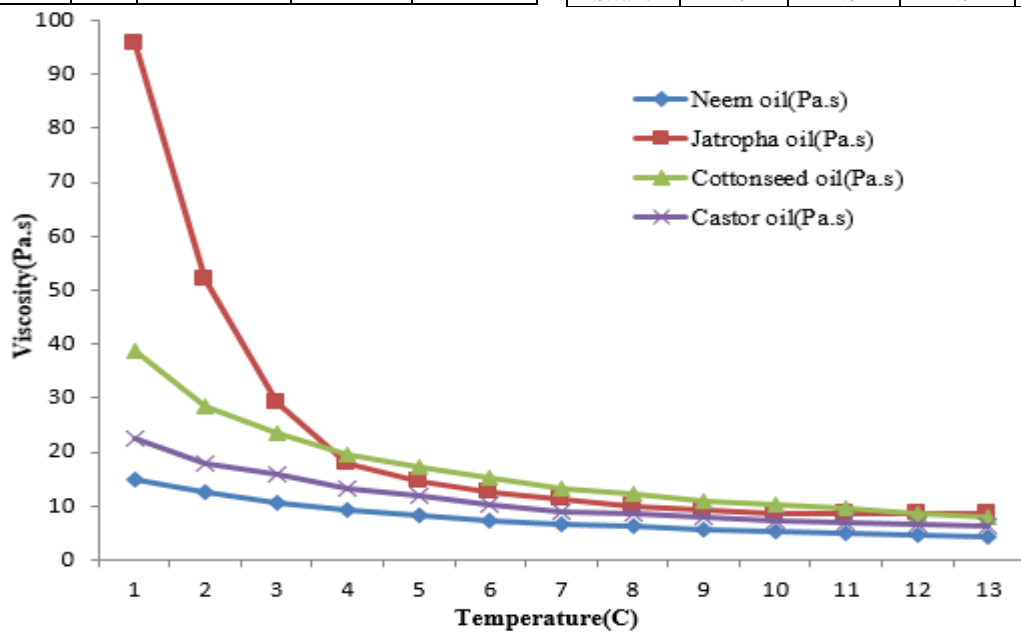


Fig. 4 Lubricant viscosity at different temperature

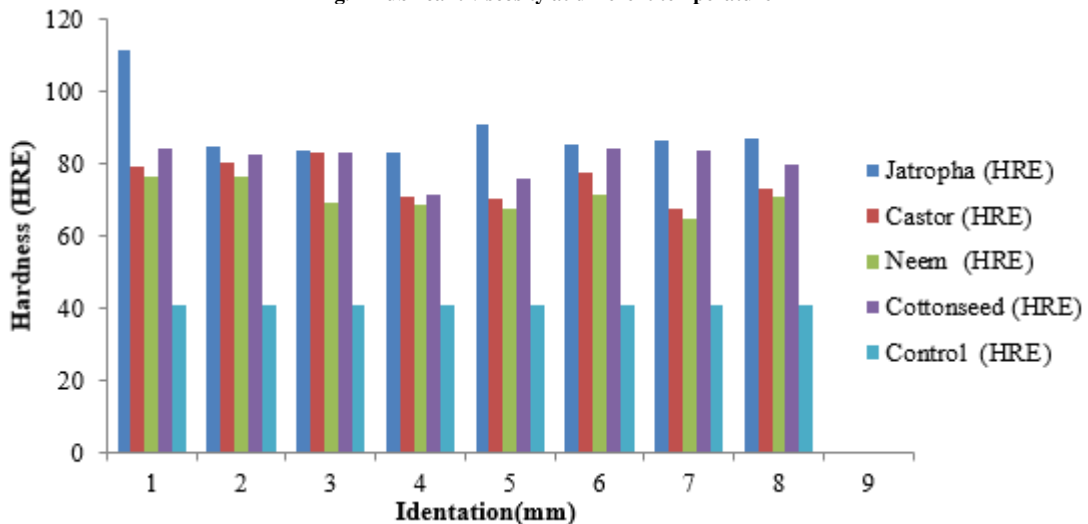


Fig. 5 Hardness test results of the sample

Harness Results of the Sample

The average value of the hardness after extrusion of 16 billet samples with different lubricants were shown in fig. 5. Figure 5 shows that there is a wide hardness improvement after ECAE extrusion considering the fact that the control billet which has not undergone extrusion process at all has the least hardness. Also, the sample extruded using neem oil has the least hardness of all lubricant tested and it has higher hardness when compared to the control sample.

Jatropha oil exhibit the greatest hardness of all the samples extruded with different lubricants, followed by cottonseed oil, then castor oil and least was neem oil. Saponification value in table 1 and stearic content shown in table 2 has direct response to hardness. If the saponification and stearic contents of the oil is very high, higher will be the possibility of hardness. The arachidic content in table 2 exhibits inverse response to hardness. Higher arachidic contents of oil indicate lower hardness.

Lubricants viscosity also plays an important role on the hardness of the extruded samples because figure 4 show that jatropha oil has the highest viscosity while the neem oil has the least. This indicates that if the viscosity of the extrusion lubricant is very high, there is tendency of impacting higher hardness on extruded products and vice versa because sample extruded with jatropha oil was the hardest after extrusion while that extruded with neem oil was the least hard. Table 3 shows hardness comparison between samples extruded with selected vegetable lubricants and samples extruded with organic based. Only samples extruded with jatropha oil amongst other selected lubricants exhibits a little hardness advancement over sample extruded with organic based lubricants

**Table -3 Comparison of Organic Based and Selected Vegetable based Extrusion Lubricant**

Lubricants	Hardness (HRD)	Lubricants	Hardness (HRD)
organic based	112	Castor oil	79.33
Jatropha oil	111.33	Cottonseed oil	76.66
Neem oil	84.33		

## CONCLUSIONS

Four vegetable based lubricants (jatropha oil, neem oil, castor oil and cottonseed oil) were used in extrusion of aluminum grade 6063 and the hardness response of the selected lubricants were evaluated after the extrusion to determine which of the four selected lubricants is most suitable for the extrusion of aluminum. However, the following points were observed:

- Sample extruded with jatropha oil impact better hardness on the extruded samples as compared to organic based and other tested lubricants as shown in figure 5.
- Saponification and stearic contents of the selected lubricants exhibit direct relationship in hardness after extrusion. Jatropha oil has the highest saponification value (200mg/g) and stearic content (7.5) while neem oil has the least saponification value (180mg/g) and stearic content (1.0) as shown in table 1 and 2. This is the reason that enables the sample extruded with jatropha oil to exhibit the largest hardness and the sample extruded with neem oil exhibits its least hardness
- Viscosity of the extrusion lubricants has effect on the hardness of the extruded products. Higher the viscosity of the extrusion lubricants, higher the possibility of hardness. Jatropha oil has the highest viscosity and neem oil has the least viscosity has shown in figure 4.

Therefore, jatropha oil can effectively replace existing organic based extrusion lubricants which are scarce, costly and not environmentally friendly.

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