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Effect of Vegetable Based Lubricants on Equal Channel Angular Extrusion Pressure

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Authors' contributions

This work was carried out in collaboration between all authors. Author TMA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors IU and OLR managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This research aimed at investigating vegetable based lubricant as a replacement for chemical based lubricants on extrusion pressure of equal channel angular extrusion of Aluminum. In the process, aluminum alloy (Al 6063) was heated at 350℃ for one hour, machined and cut to billets size of 11.95 m x 11.95 m x 40 m (l × b × h). The billets were extruded through die of 12 mm x 12 mm channel cross-section area, the channel angle was 60°. Four vegetable based lubricants namely jatropha, neem, castor and cotton seed oils were used. The die was centrally located on the bed of vertical hydraulic testing machine and the billet was inserted into the entrance channel. Lubrication was applied to the billet to decrease its friction and with the channel inner wall. The ram displacement per plunger speed was 1 mm per 1 second respectively. For each lubricant, four samples were extruded through ECAE die to confirm the repeatability of the results and the average values of the extrusion pressure were computed. The results were compared to the sample extruded via conventional lubricants. It was discovered of all the extruded samples, jatropha oil gave the least extrusion pressure of 83 kN, cottonseed oil extruded at 104 kN and

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castor oil at 151.4 kN while neem oil require the highest pressure at 220.9 kN. The chemical based lubricants that serve as the control from the literature gave the extrusion pressure of 81 kN. It can be concluded that the oil from jatropha seed is the best in terms of extrusion pressure and can effectively replace the chemical based lubricants.

Keywords: Extrusion; lubricants; pressure; aluminum.

1. INTRODUCTION

Extrusion is the process of forcing out metal through a die with the aid of punch and hydraulic press at a particular pressure [1]. In a broad sense, it is a manufacturing process in which a block of metal is subjected to plastic deformation, and it undergoes a reduction and elongation during the process [2]. There will be significant improvement in mechanical properties of material when compared the sample before and after the extrusion process [3].

Extrusion by Equal Channel Angular Extrusion (ECAE) enables to obtain a fine grain structure in larger volume. It is another type of severe plastic deformation (SPD) that has gained an attention recently [4]. ECAE deformation involves a die with two channel of equal cross sectional area that intercept at an angle usually between 90° and 150°. Deformation occurs when a sample of the material (otherwise called billet) is forced through the angled channel in the die under high pressure [1]. The material that emerges from the die after extrusion process is of equal cross sectional area when compared to the material that was inserted into the die [5]. This can be extremely useful in many different industrial applications that require a material to have a refined grain structure with a certain texture developed while still in bulk form. Severe plastic deformation process (SPD) such as ECAE may be defined as a metal forming process in which an ultra-large plastic strain is introduced in a bulk metal in order to create ultra-fine grain metals [6].

Lubricant plays significant role in extrusion as every other forming operation. There is need for selection of adequate lubricant that can thermally insulate the die and the work-piece, prevent wear of the die as well as lowering the stress and time required for the extrusion by reduction of extrusion pressure [7]. These lubricants may be liquid or gasses and has the capacity of removing heat. In most cases they are chemical based lubricants which make it non biodegradable, expensive, scarce and in its exploration process, both the aquatic and terrestrial life will suffer because since they are not biodegradable, pollution will be impacted on soil and water when discharged [8,9]. It was earlier asserted that vegetable based (palm oil) could be a perfect replacement for chemical based lubricants because it is biodegradable, cheap, higher flash point, natural viscosity and readily available as compared to the conventional ones [10]. Much emphasis should be given to non edible oil such as jatropha oil, neem oil, cottonseed oil and castor oil as a replacement for chemical based because recommending edible vegetable oil as a replacement will cause food shortage as there is tendency of the price of the selected one amongst them to rise abnormally.

2. MATERIALS AND METHODS

The items required in carrying out this ECAE extrusion process are: Angular die, Punch, hydraulic press of 600 kN, die holder allen key, Jatropha oil, Neem oil, Castor oil, cottonseed oil, mentholated spirit, hexane (solvent), Viscometer, Hydrochloric acid, Aluminum (billet), Electric furnace and tool steel (die and punch construction). All the materials were sourced locally and the oils were extracted from its seed using solvent extraction method.

2.1 Viscosity Test on Lubricants

Viscosity test was conducted on an NDJ-5s Digital viscometer to determine the viscosity of each lubricant at different temperature. A 200 ml volume of each lubricant in a clean beaker was placed on the viscometer platform with stirrer, which was double as a source to introduce heat, was then be inserted into the lubricant. The power source was switched on, and the monitoring of the viscosity readings and corresponding temperature commences until the required temperature range was achieved. Before the commencement of the experiment for the next lubricant, the stirrer and beaker was cleaned properly to avoid contamination among lubricants.

2.2 Determination of Chemical Properties of Lubricants

Standard analytical technique was used to determine parameters such as specific gravity, free fatty acid, saponification values, and iodine contents. Determination of Percentage relative fatty acid was calculated based on the peak area of a fatty acid species to the total peak area of all the fatty acids in the oil sample. Atomic absorption was used to determine the mineral which was extracted from ash by adding 15.0 ml of 2% Hydrochloric acid, heated in a steam bath to bring down the contents to approximately 5.0 ml, latter transferred to a 50 ml volumetric flask. Deionised water was diluted to the volume of it to about 50 ml.

2.3 ECAE Die Design Sketches

In carrying out the design, the entry channel dimension where the billet is to be placed before extrusion was chosen in respect to the billet dimensions. The Aluminum was machined to dimension 11.95×11.95×40 mm^3 (length, breadth, height) as billet, hence the entry channel of the die was 12 mm×12 mm×58 mm. Size 12 mm for the die will be taken against 11.95 mm for billet so that the clearance between the billet and the entry channel of the die allows sliding. Height 40 mm for billet against 58 mm for entry channel of the die is to allow proper punch guidance and initial contact between the punch and the billet. Die design is as shown in Figs. 1 and 2.

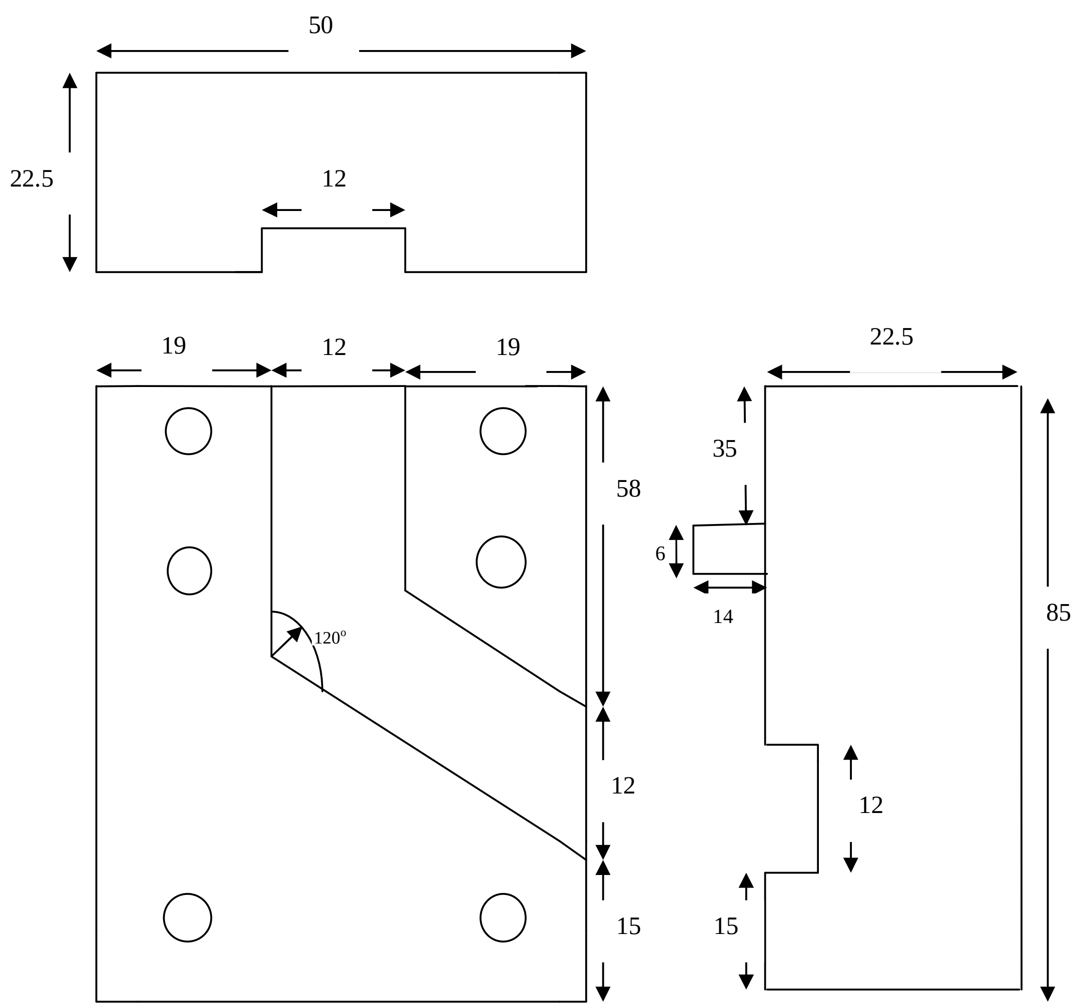

Fig. 1. 2D design drawing of ECAE die with die holder (front, side and plan view)

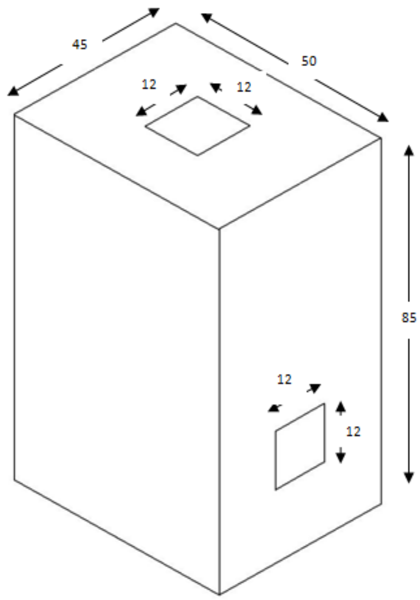

Fig. 2. Extrusion die dimension (3D view)

2.4 Design of Die Holder

As mentioned in the foregoing section, the die holder primarily holds the die in place and gives support against the high pressure applied by the ram. Its dimensions were chosen bearing in mind the high pressures it would be subjected to. The die holder was threaded on the outside along its length and M40 × 4 threading was used.

2.5 Punch

The main data required for the design of the punch is the billet dimension, which is the diameter of the punch. The punch's height chosen was 55 mm. This is to allow for an initial advance of the punch to avoid it's 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 later carburized and case hardened to impart the required hardness to withstand the high applied pressure. Fig. 3 shows punch design.

2.6 Sample of Control Billet, Die and Extruded Billet

The first pictures from the left in Fig. 4. is the billet before extrusion while the middle picture is the ECAE die that was constructed for the test and the last is the extruded billet.

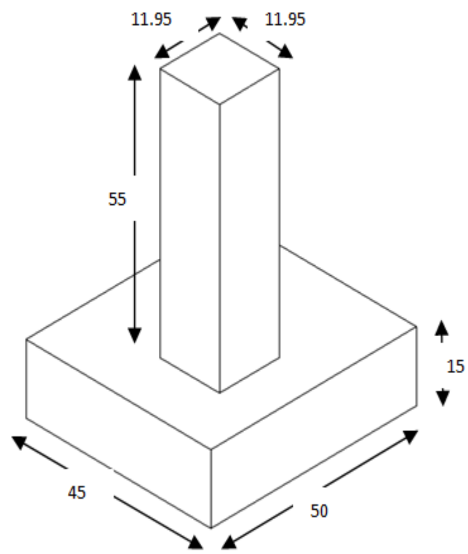

Fig. 3. Punch dimension

Fig. 4. Control billet, die and extruded sample

2.7 ECAE Test

Commercial 6063 aluminum-magnesium was casted and used in this research. The percentage by weight of chemical compositions are; Si (0.45), Fe (0.35), Cu (0.03), Mn (0.04), Mg (0.6), Cr (0.007), Zn (0.04), Ti (0.006), Sr (0.005) and Al (Base). Before extrusion, the specimen was heated at 350℃ for 1 hour. The billet size was machined to 11.95×11.95×40 mm^3 based on entry die channel. The constructed die with 14×14 mm^2 channel cross section was used; the channel angle was 60°, the punch and die material consideration for the experiment were made from high carbon steel alloy AISI D2, which was electroplated with chromium. A split die was used to avoid stress concentration at the corners and to facilitate easy removal of the ECAEed specimen. Specimens were ECAEed at room temperature in one pass. All extrusions were conducted using a hydraulic press of 600 kN capacity. As the press was operated manually, it was not possible to apply constant strain rate during the test.

2.8 Experimental Procedure

During extrusion, the die was first centrally located on the bed of vertical hydraulic testing machine; the billet was then be inserted into the entrance channel. Before a billet was inserted into the ECAE entry channel, lubrication was applied to the billet to decrease its friction with the channel inner wall. The ram/plunger speed was about 1 mm/second. Before applying each lubricant, the surfaces of the punch and dies was cleaned by a wiper soaked with methylated spirit to avoid adulteration among lubricants. For each lubricant, four samples were equal channeled extruded to confirm the repeatability of the results and the average value of pressure that was determined for analysis.

3. RESULTS AND ANALYSIS

The result of percentage of oil in the seed, saponification value, iodine value, specific gravity and fatty acid composition of lubricant were shown in Tables 1 and 2.

3.1 Viscosity of the Lubricants at Different Temperature

The viscosity of the lubricant used for the experiment was tested at different temperature was tested ranges from 40℃ to 100℃. The results are as shown in Fig. 5.

3.2 Extrusion Load Results of the Sample

Fig. 6. shows the load displacement curve recorded during ECAE. It shows that deformation during the ECAE takes place in different stages. In the first stage (O to A), sample fills the entire die by upsetting, which can be observed from the load displacement curve reaching the peak load position.

In the second stage (A to B), as the material enters the exit channel of the die, elastic recovery take place because of which the force lowers gradually as the deformation progresses.

In the third stage (B to C), force increases monotonously as the ram displacement

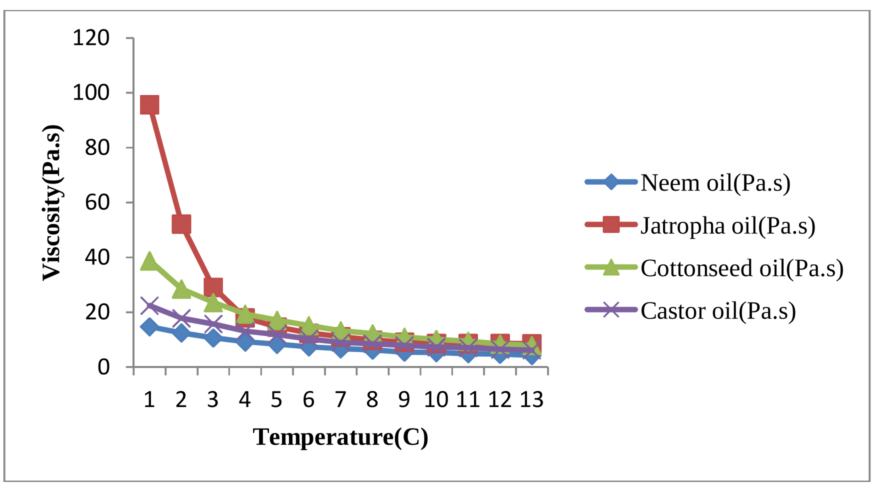

Fig. 5. Viscosity of lubricants at different temperature

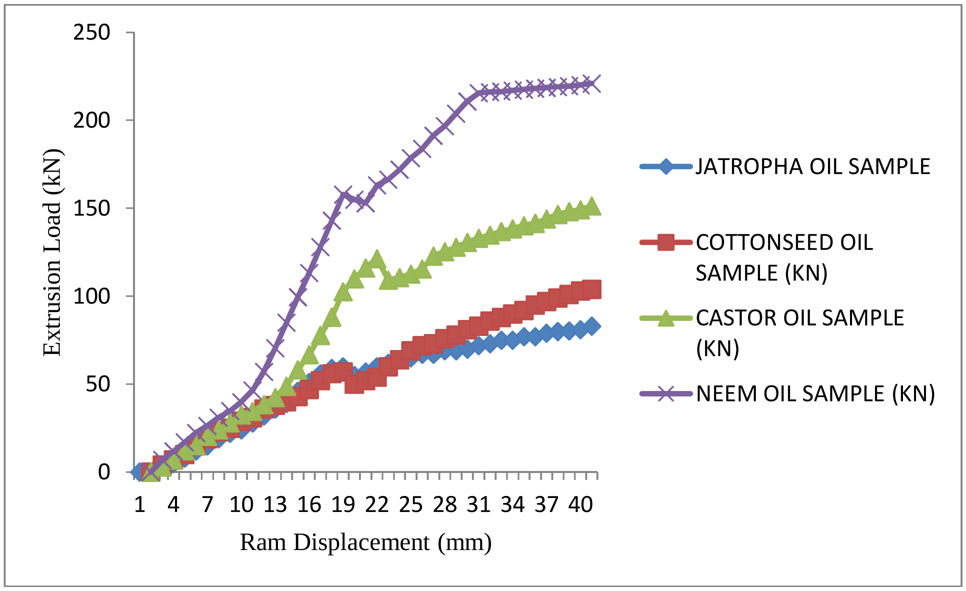

Fig. 6. Load displacement curve recorded during ECAE

continues. This is due to the increase in the frictional resistance with the increase in the contact area between the sample in the exit channel and the inner surface of the die.

Lastly, the decrease in the load at the end of the deformation (fourth stage C to D) is due to the reduction of tri-axial stress state as the end of the bulk material is pushes close the die diagonal.

It should be noted that stage D to E only visible in neem oil which shows abnormality of that oil as extrusion lubricant.

From the same graph we can also deduce the effect of lubricant on the extrusion pressure as thus:

1. The least pressure of extrusion (83 kN) was observed in sample extruded using jatropha oil as a lubricant. This indicates that using jatropha oil as the extrusion lubricant will reduce time and stress required for extrusion process. The lesser the extrusion pressure, the greater the advantage.
2. Sample extruded using cottonseed oil require lesser pressure of extrusion when compare with sample extruded with castor oil but greater pressure than jatropha oil. This indicates lesser advantage to jatropha oil but greater advantage over castor oil.
3. Sample extruded using castor oil requires more extrusion pressure when compared with sample of jatropha oil and cottonseed oil lubricant but lesser pressure than neem oil. This indicates greater advantage over neem oil but lesser advantage over cottonseed and jatropha.
4. Sample extruded using neem oil as lubricant requires the greatest extrusion pressure and indicates its poor performance in extrusion pressure.

Possibly, the saponification value as well as the stearic and arachidic content of the fatty acid of lubricant may have effect on this. The saponification value of the lubricants tested shows that jatropha oil has the highest value followed by cottonseed oil, castor oil and neem oil in that order. In other words, the result indicated that the higher the number of saponification value, the lower the extrusion pressure. Also, stearic contents of fatty acid of lubricant may have similar effect on the extrusion pressure. Jatropha oil has the largest percentage of stearic, follow by cottonseed oil, castor oil and neem oil in that order. In other word, the higher the contents of stearic in fatty acid of lubricant, the lower the extrusion pressure. Arachidic acid content of fatty acid of jatropha oil is the lowest, follow by cottonseed oil, castor and neem oil in that order. In other word, the lower the contents of arachidic acid, the lower the extrusion pressure.

The viscosity of the lubricants also plays an important role in determining the extrusion pressure. The viscosity of jatropha oil is the highest followed by that of cottonseed oil while

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
Castor oil	49	181	85	0.955/25℃
Neem oil	48	180	72	0.920/30℃
Jatropha oil	37	200	88	0.921/15℃
Cottonseed oil	23	194	104	0.924/15℃

Table 2. Fatty acid composition of four lubricants

Fatty acid	Neem oil	Castor oil	Cottonseed 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
Strearic	1.0	1.8	2.0	7.5

that of neem oil is the lowest. Therefore, the lubricant with highest viscosity has the lowest extrusion pressure and vice versa.

Table 3. Comparison of chemical based and selected vegetable based as extrusion lubricant

Lubricants	Extrusion load (kN)
Chemical	81
Jatropha oil	83
Neem oil	220.9
Castor oil	151.4
Cottonseed oil	104

3.3 Comparison between the Samples Extruded with Chemical Based and Selected Lubricants

Table 3 compares the sample extruded using conventional lubricant [11] and the sample extruded using selected lubricant (jatropha oil, neem oil, castor oil and cotton seed oil). The results indicated that jatropha oil as a lubricant extruded the sample at a pressure of 83 kN against 81 kN for chemical based. This portrays jatropha oil as a perfect replacement for chemical based because of its close value in the two extrusion pressures.

4. CONCLUSION

A commercial 6063 aluminum-magnesium-silicon alloy billets were ECAEed extruded using four environmentally friendly lubricants such as jatropha oil, castor oil, cottonseed oil and neem oil. The extrusion pressure for each lubricant was determined. The following conclusion may be drawn.

1. Jatropha oil as extrusion lubricant has best load reduction ability.
2. Jatropha oil has the least friction factor, followed by cottonseed oil, then castor oil while neem oil has the highest friction factor in extrusion of aluminium by equal channel angular method.
3. Although jatropha oil and cottonseed oil effectively ameliorate the adverse conditions of high pressure and temperature at the interface between the tool and workpiece by consistently separating the tool and the workpiece thereby reducing the extrusion load. Jatropha oil will be preferable to neem oil at higher temperature and pressure.
4. Finally, the specimen ECAEed extruded using jatropha oil were easier to remove from the die than those extruded using other selected lubricants (neem oil, castor oil and cottonseed oil) tested in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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