

Effect of Vegetable Based Lubricants on Equal Channel Angular Extrusion

Pressure.

ABSTRACT

The aim of this work is to establish the effect of various vegetable based lubricants on extrusion pressure of aluminum 6063 after processing with equal channel angular extrusion (ECAE) using four environmental friendly lubricants. All aluminum 6063 bar was heated at 350°C for 1 hour, machined and cut to billets of dimension 11.5 × 11.5 × 40 mm³. These billets were extruded through ECAE die 12 × 12 mm² channels cross sectional area; the channel angle was 120° and the angle of outer arc of the channel was 240°. The punch and the die were made from high carbon steel. It was electroplated with chrome to prevent it from rusting and make it durable. Four vegetable based lubricants such as jatropha, neem, cottonseed and castor oils were used in this study. The extrusion pressure after the extrusion process was determined after the extrusion process based on different lubricants used. The pressure at which billet was extruded for each lubricant was different. All these results were evaluated and analyzed in order to recommend the most suitable from four selected vegetable based lubricant is best for ECAE. Jatropha oil was discovered to be most suitable out of four experimented lubricants.

1.0 Introduction

Extrusion is the process of forcing out metal through a die with the aid of punch and hydraulic press at a particular pressure (Weartzman, 2002). 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 (Hill, 1997). When compared the sample of the material called billet before and after the extrusion process, there will be a significant change in mechanical properties of the material and grain structure (Rusz and Malanik, 2007).

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 (Murty and Ramulu 2009). 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 (Weartman, 2002). 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 (Parshikovet *al*, 2012). 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 (Valiev *et.al*, 2000; Rosochowski and Olejnik, 2004; Rosochowski, 2005). SPD can further be defined as a technique in which preservation of shape is achieved due to special tool geometries which prevent the free flow of material and thereby produced a significant hydrostatic pressure.

Lubricant's functions cannot be neglected for the role they perform in forming operations, as these operations cannot be carried out efficiently without the appropriate lubricants. Lubricants are generally found in the liquid or gaseous state and are applied to the working surface to facilitate smooth extrusion of the billet and to remove the possibility of folding which usually results in deposit in the dead region of the container. These benefits extrusion in many ways, especially as it acts as a heat remover. It also helps to remove defects such as internal piping of the thin billet skin that is extruded into the extruded rod. Conventional lubricating fluids are usually petroleum based, and since they are not biodegradable they pollute and contaminate water and soil when discharged as waste to the ground thereby having detrimental effect on

health and environment. In order to alleviate the health risk associated with the petroleum based lubricants and the need to make the extrusion process more ecologically friendly, there is the need to develop an alternative safe and environmentally friendly lubricant. Vegetable oils among other options could be investigated in developing a new lubricating fluid where high performance in forming operations with good environmental capabilities could be achieved. The most important characteristics of vegetable oil are their safety and biodegradability. Compared to petroleum based oil (mineral oil), Vegetable oil has been shown to replace mineral oil as lubricants in previous researches carried out (Syahrullail *et. al*, 2011),. Also it has higher flash point and natural viscosity than mineral oil, thus improving the surface finish and extending tool life. It also does not contribute to health hazard via toxic mist and skin cancer and does not pollute the environment (Manawweret. *al*, 2014)

2.0 Choice of Materials

In order to carry out extrusion, the main components needed include the main power supply unit which is the press, die, container, die holder, punch, mild steel and aluminum (billets). All these except the universal testing machine was designed and produced in the workshop using available materials (mild steel) for the construction of the tools (dies, punch, containers); hence a case hardening process was applied to the dies and the punch.

3.0 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.

4.0 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. atomicabsorption spectrophotometry 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 50ml.

5.0 General Concepts of ECAE Die Design

The design is a rectangular shaped block made from high carhon steel(tool steel). The function of which is to provide an angular channel for the billet to pass when pressed by the punch and the hydraulic press. Hence there will be severe plastic deformation impacted on the die as a result of triaxial stress on the angular region of the ECAE die and this greatly enhance the mechanical properties of the billet and consequently reduce the time spent on extruding more than one pass when compared to conventional types of extrusion .

6.0 ECAE Die Design Sketches

The design is the split type whereby there is male and female part. The male part is the one with the two die holders and four holes, the female is the one with six holes. 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 x40mm³ (length, breadth, height) as billet, hence the entry channel of the die was

12×12×58mm³. Size 12mm for the die will be taken against 11.95mm for billet so that the clearance between the billet and the entry channel of the die allows sliding. Height 40mm for billet against 58mm for entry channel of the die is to allow proper punch guidance and initial contact between the punch and the billet. There are six numbers of holes (diameter 6mm each) on the female part of the die. Four out of the holes are bolt holes to fasten together the two parts with allen bolt and the other two holes is to allow the two die holes from its male counterparts to fit , secure them together and locks the die in place.(See figure 1a and 1b)

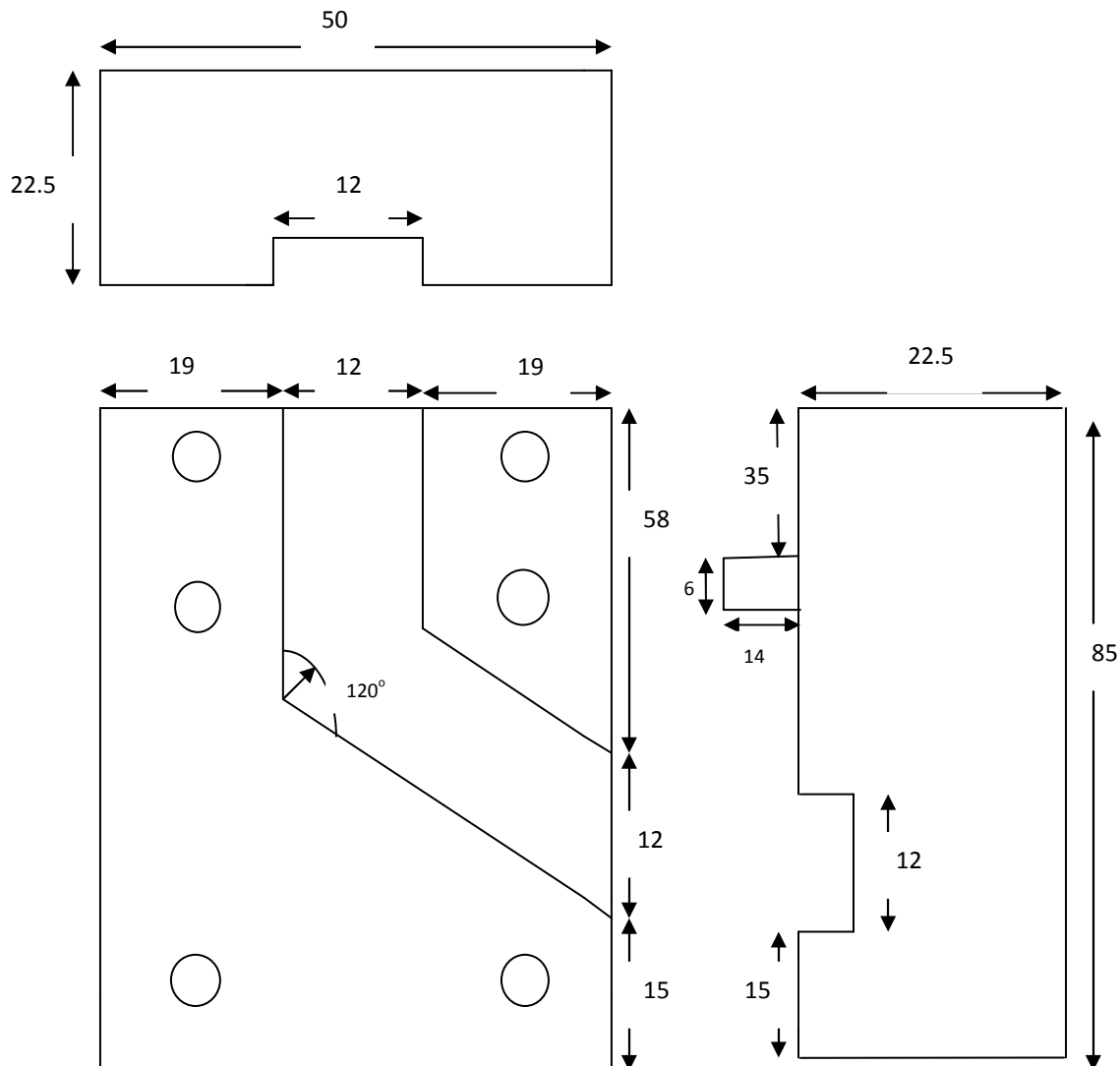


Figure 1a: 2D design drawing of ECAE die with die holder (front, side and plan view)

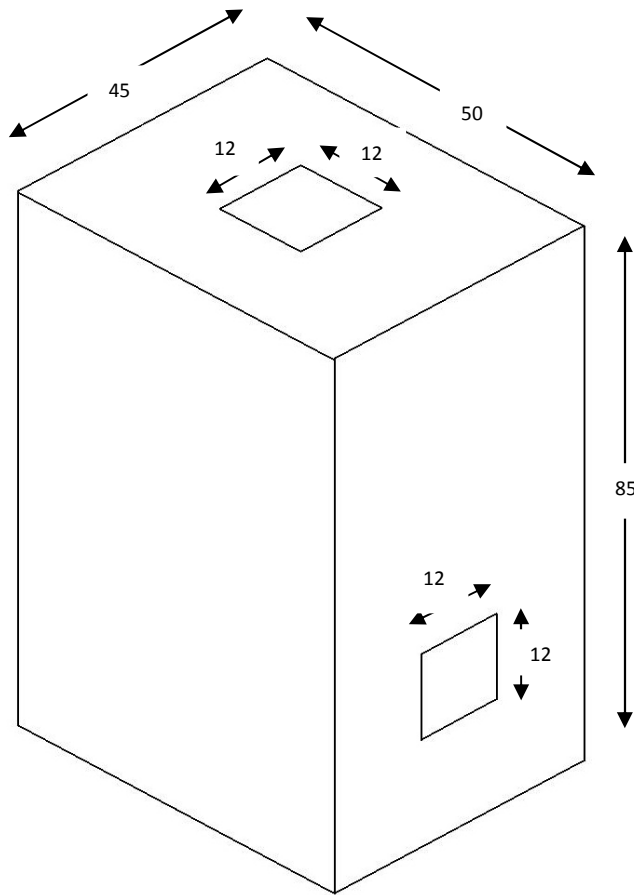


Figure 1b: Extrusion die dimension (3D view)

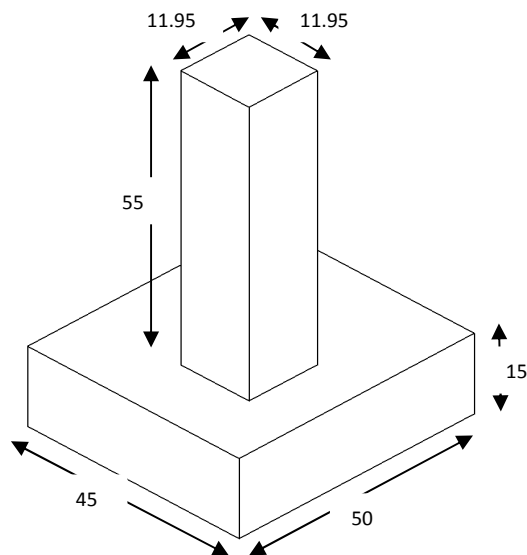
6.1 Design of Die holder

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. The M40 x 4 threading was used

6.2 Punch

130 The main data required for the design of the punch is the billet diameter, which is the diameter of
 131 the punch. The punch's height chosen was 55mm. This is to allow for an initial advance of the
 132 punch to avoid it's slipping off, and at the end of the extrusion process the punch was not
 133 completely in the die, but some portion of it was outside the die to allow the appropriate contact
 134 with ram. The punch was made of mild steel and was later carburized and case hardened to
 135 impart the required hardness to withstand the high pressures applied to it.(Seefigure 2)

136



137

138 **Figure 2: Punch dimension**

139 **6.3 Billet**

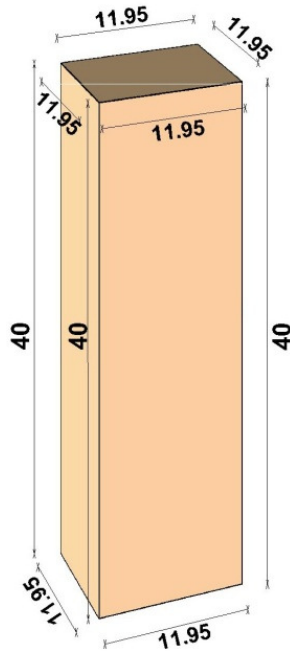


Figure 3: Billet dimension

7.0 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°C for 1 hour. The billet size was machined to 11.95×11.95×40 mm³ based on entry die channel. The constructed die with 14×14 mm² 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 600kN capacity. As the press was operated manually, it was not possible to apply constant strain rate during the test.

8.0 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 methyated 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.

9.0 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 table 1 and 2

Table1: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	0.955/25 ^o c
Neem oil	48	180	72	0.920/30 ⁰ c
Jatropha oil	37	200	88	0.921/15 ^o c
Cottonseed oil	23	194	104	0.924/15 ^o 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

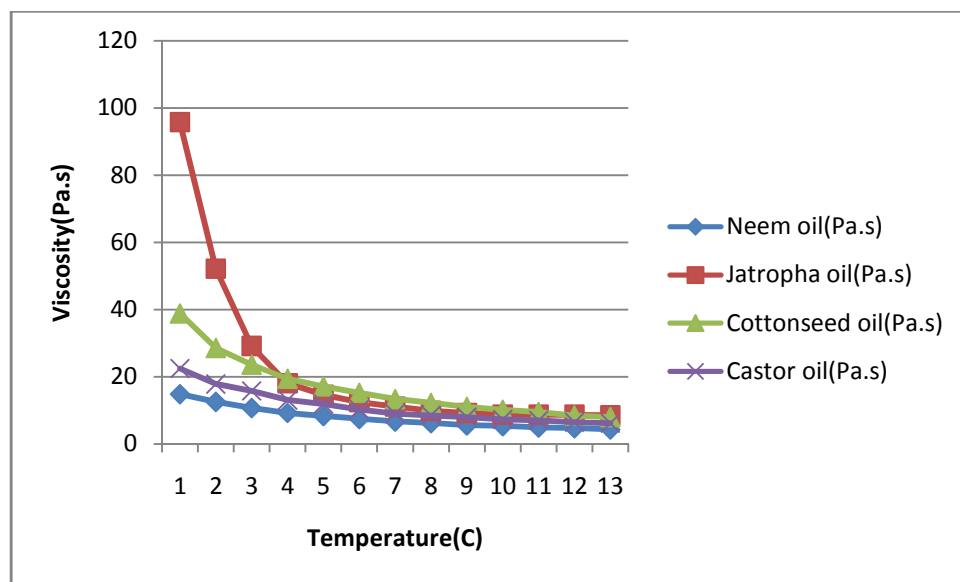
177	Arachidic	2.2	2.1	2.0	0.3
178	Oleic	5.5	7.0	3.5	5.0
179	Linoleic	10.0	5.0	4.2	3.2
180	Stearic	1.0	1.8	2.0	7.5

181

182 11.0 Viscosity of the lubricants at Different temperature.

183 The viscosity of the lubricant used for the experiment was tested at different temperature was
 184 tested ranges from 40°C to 100°C. The results is as shown in Figure4.

185



186

187 Figure 4: Viscosity of lubricants at different temperature

188 12.0 Extrusion Pressure Results of the sample

189 Fig 4.1 shows the load displacement curve recorded during ECAE. It shows that deformation
 190 during the ECAE takes place in different stages. In the first stage, 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, 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, force increases monotonously as the ram displacement 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) is due to the reduction of tri-axial stress state as the end of the bulk material is pushed close the die diagonal.

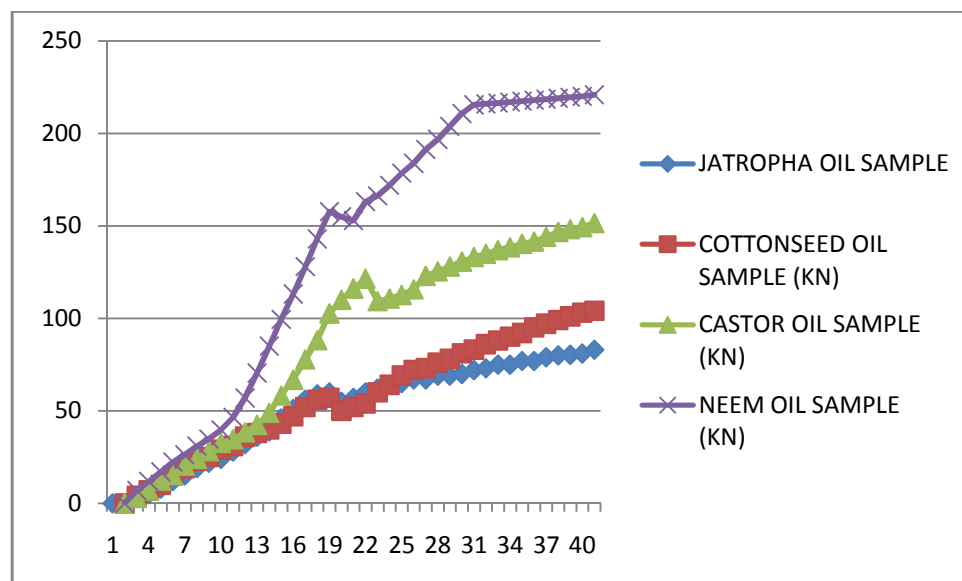


Figure 4.1: Displacement curve recorded during ECAE.

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

- 206 1. The least pressure of extrusion was observed in sample extruded using jatropha oil as a
207 lubricant.
- 208 2. Sample extruded using cottonseed oil require lesser pressure of extrusion when compare
209 with sample extruded with coconut oil.
- 210 3. Sample extruded using castor oil requires more extrusion pressure when compared with
211 sample of jatropha oil and cottonseed oil lubricant.
- 212 4. Sample extruded using neem oil as lubricant requires the greatest extrusion pressure.

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

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

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

13.0 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 reduces extrusion load best
2. Jatropha oil has the least friction factor, followed by cottonseed oil, then castor oil while neem oil has the highest friction factor extruding alluminum alloy processed by equal channel angular extrusion
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 lubricants tested in this study

14.0 References

- Hill, R. (1997): "The Mathematical Theory of Plasticity", first edition, Oxford University Press, new York, 101-105.

- 247 Hyunok, K and Nimet, K (2012). “Friction and Lubrication” Sheet Metal Forming.7 (90-98).
 248
 249
- 250 Jumat, S., DinaAzleemaMohdNoor, A.T. Nazrizawati, M.Y and Noraisha (2010). A “Fatty Acid
 251 Composition and Physicochemical Properties of Malaysian Castor Bean
 252 *Ricinuscommunis*L. Seed Oil” SainsMalaysiana. Vol.5. 39(761–764).
- 253 Manawwer, A., Deewan, A., Eram, S.,Fahmina, Z and Sharif, A (2014). “Vegetable Oil Based
 254 Eco-Friendly Coating Materials”. Arabian Journal of Chemistry 7(469–479).
- 255 Murty, D.V and Ramulu, M. (2009): “Deformation Study of Dual Equal Channel Lateral
 256 Extrusion”. International Journal of Engineering Studies, 3(161- 168).
- 257 Parshikov, R.A., Rudskoy, A.I., Zolotov A.M. and Tolochko O.V (2012).“Technological
 258 Problems of Equal Channel Angular Pressing”. Advance Material Science. 24(26-36)
- 259 Rusz, R.S and Malanik, K. (2007): “Using Severe Plastic Deformation To Prepare Ultra Fine
 260 Grained Material by ECAE Method”, Journal of Achievement In Material Science and
 261 Engineering, 28(683 -684).
- 262 Syahrullail, S., Zubil, B.M., Azwadi, C.S and Ridzuan, M.J (2011). “Experimental evaluation of
 263 palm oil as lubricant in cold forward extrusion process”.International Journal of
 264 Mechanical Sciences.53(549-555).
- 265 Valiev, R.Z., Alexandrov, I.V., Zhu, Y.T and Lowe, T.C. (2000): “Paradox of Strength and
 266 Ductility in Metals Processed by Severe Plastic Deformation”. Journal of Materials
 267 Research:1(1-4)
- 268 Weartman, J.K. (2002): “Hall-petch Strengthening in Nanocrystalline Metals”, Material Science
 269 Engineering, 161-167.