Material Science & Engineering

Research Article Open Access

Experimental Analysis for Lubricant and Punch Selection in Shear Extrusion of Aa-6063

Ojo SO[1]*, Erinosho M[2] and Ajiboye JS[3]

[1]*Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, C.so Ducadegli Abruzzi 24, 10129 Torino, Italy*
[2]*Department of Mechanical Engineering Science, University of Johannesburg, Auckland Kingsway Campus, Johannesburg, 2006, South Africa*
[3]*Department of Mechanical Engineering, University of Lagos, Nigeria*

Abstract

Shear extrusion is a forming process which is based on combined backward cup-forward rod extrusion. This extrusion process is attractive due its potential to achieve severe plastic deformation thus enabling texture and microstructural control of materials. Furthermore, the economic potential of shear extrusion for mass production and production of complex shapes provides for numerous applications in automotive, transportation, aero-space and other industries. However, a trending challenge in the use of this method for complex shapes is the design and selection of tools to achieve a high quality product. This paper focuses on deep study of shear extrusion of AA-6063. The process was studied experimentally using variables which affect the forming load as well as the quality of the product. It is concluded from the load-displacement and stress plots that a punch with large diameter and small punch land is desirable for easy forming of the material during shear extrusion. Analysis of the effect of lubricants on deformation load and stress shows that palm oil lubricant remains the best lubricant of the four lubricants examined since its gives the minimum load obtained during shear extrusion.

Keywords: Shear extrusion; Severe plastic deformation; Lubricant; Punch

Introduction

Shear extrusion theory was derived from combined backward cup- forward rod extrusion (BC-FRE) theoryand it involves shearing deformation during the metal forming process, a characteristic which makes the process to be labour saving. Chang and Mousavi showed that the extrusion force in shear-extrusion method of severe plastic deformation for fabrication of metal shapes with ultra-fine structures is far lower than that of simple forward rod extrusion (FRE) or backward cup extrusion (BCE) [1,2]. By using an aluminium billet of various sizes, Chang concluded that decrease of the extrusion force was significant especially when the inner diameter of the cup is less than the outer diameter of the rod such that the directly compressed zone is reduced to zero, and the deformation zone becomes the deformation band. Although differential speed rolling (DSR) and equal speed rolling (ESR) are some of the attractive techniques employed for enhanced plasticity and textural control in metal forming process [3-5]. Hu shows that compound extrusion technology, a combination of extrusion and shear process is capable of effective grain refinement of metals due to accumulation of high strain and low temperature rise [6]. Furthermore, Utsunomiya work on continuous deformation process reveals that shear extrusion can also be used as a textural and microstructural control method for metal strips by introducing shear textures in addition to its capacity of being highly productive [7]. This observation is corroborated by Thomas in where he further highlighted other important advantages of the shear extrusion process [8]. First, this is a one-step technique of severe plastic deformation that does not require strain accumulation during multi-pass processing. Second, long complicated shapes including hollow ones can be formed simultaneously with the structure refinement to the sub-micron scale. Third, severe deformation is performed under high and controllable hydrostatic pressures. Therefore, the structure refinement of usually brittle alloys is possible with significant improvement in their strength and toughness. Fourth, processing characteristics of the shear-extrusion method provide high productivity and low product cost which are comparative to the ordinary extrusion methods. Therefore, shear extrusion provides for numerous applications of structural materials in automotive, transportation, aero-space and other industries [9,10].

Hu performed a coupled thermomechanical finite element simulation on the defect of extrusion and submitted that the use of hyperbolic curve die leads to improved homogeneity of metal flow, increased uniformity and less chance of formation of dead zone whereas parabolic curve may cause continuous cracks on the surface of the extruded rods [11]. The use of shear die in the extrusion of complex shapes leads to a complicated problem of metal flow imbalance that often results in shape defects and to obtain a straight and true product in size, the design of the location of the die orifice and the specification of the die land length is of paramount importance [11-13]. Other die process parameters which may affect the quality of the extrudate are the shape ratio of the billet, extrusion ratio and the capacity of the extrusion press [14]. The flow and movement of a punch during deformation by extrusion process is dependent on the magnitude of the maximum pressure and the geometry of the die coupled with the billet configurations [15]. Murai in his work concluded that the extrusion load increases with the shape ratio of the billet and the forward and backward extruded lengths can be predicted from the diameter, height and flow stress of a billet [16]. To determine the extrusion pressure, Altanperformed a slab method analysis in which he takes account of parameters namely, frictional shear stress at the dead-metal/flowing metal interface and frictional shear stress at the billet-container interface [17]. He proposed the average extrusion pressure as

***Corresponding author:** Ojo SO, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, C.so Ducadegli Abruzzi 24, 10129 Torino, Italy, Tel:39 011 090 6111; E-mail: saheedimran@gmail.com

Received May 13, 2015; **Accepted** May 27, 2015; **Published** June 12, 2015

Citation: Ojo SO, Erinosho M, Ajiboye JS (2015) Experimental Analysis for Lubricant and Punch Selection in Shear Extrusion of Aa-6063. J Material Sci Eng 4: 174. doi:10.4172/2169-0022.1000174

Citation: Ojo SO, Erinosho M, Ajiboye JS (2015) Experimental Analysis for Lubricant and Punch Selection in Shear Extrusion of Aa-6063. J Material Sci Eng 4: 174. doi:10.4172/2169-0022.1000174

$$P_{\text{ave},z=0} = 2\bar{\sigma}\left(1+\frac{cot\alpha}{\sqrt{3}}\right)\ln\ln\frac{D_C}{D_E} \quad (1)$$

where D_C is the equivalent diameter of the billet (container bore diameter) filled in the container after upsetting, where D_E, the equivalent diameter of extruded rod, α is the semi dead-metal zone angle and $\bar{\sigma}$ is the flow stress of the material (Figure 1).

The 6000 (AA-Mg-Si) series alloys have an attractive combination of properties, relevant to both use and production as a result of its strength (150-350 MPa), all with good toughness and formability. With the lower limit of Mg and Si for example, 6060 and 6063 extrude at high speeds with good surface finish, anodizing capability and maximum complexity of section shape can be combined with high section thickness. Their properties made them find wide use in architectural applications where shape and finish are more important than strength [18].

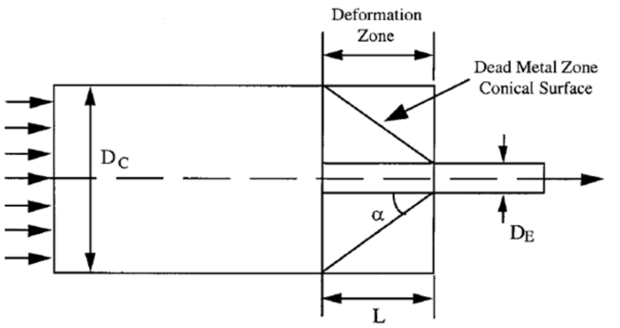

Figure 1: A billet geometry inside a container.

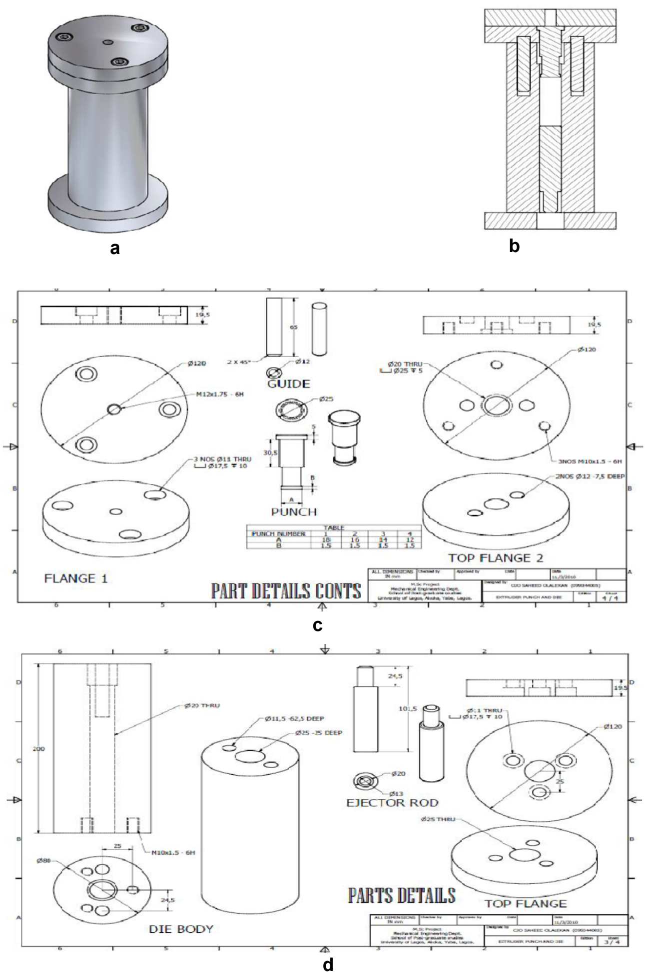

Figure 2: (a) Isometric view of extrusion die (b) sectional view of extrusion die (c) Part details for punch and die flange (d) Part details for die body.

In this paper, experimental analysis for punch and lubricant selection is conducted for shear extrusion process of AA-6063 and it is showed that a careful control of the process parameters can be utilized to obtain better product quality from shear extrusion.

Die Design

Considerations in the choice of equipment and tooling needed for the experiment involves design of extrusion die, punch design, selection of press, and design of fixture and other accessories to be used in the execution of the task [19,20].

The die assembly was designed for easy replacement of punches of varying sizes. The die stack consists of the die body, die shoe and punch plate. The die was constructed as a flat faced die in order to allow metal upon entering the die to shear internally to form its own die angle (Figure 2a-d). A parallel land on the exit side of the die helps strengthen the die and allow for reworking of flat face on the entrance side of the die without increasing the exit diameter.

The diameter of the die bore (D_C) is 25 mm while the die exit area is (D_E) is 20 mm. The areas of the die bore A_C and the die exit are calculated by the formula

$$A_C = \frac{\pi D_C^{\,2}}{4} = 490.9 \text{ mm}^2,$$

$$A_E = \frac{\pi D_E^{\,2}}{4} = 314.2 \text{ mm}^2$$

Punch design

The maximum allowable punch length, L_m is calculated using the formula [21]

$$L_m = \pi \frac{D}{8}\left(\frac{ED}{f_s t}\right)^{1/2} \quad (2)$$

Where D is the punch diameter in mm, f_s is the shear strength of high carbon steel, t is the material thickness and E is the modulus of elasticity of high carbon steel. The value of these parameters used for the punch design is given in Table 1.

D/t= 1.1 or higher

Based on the formula in eq. (2), the calculated maximum punch length for the punch with the smallest diameter is 80 mm. Therefore, the selected punch length is 60.

The extrusion pressure is calculated using eq. (1). mmSince we are using a square die, a dead metal zone exists in the corners of the container against the die. We assume that *a* is equivalent to a semi die angle i.e. α=60°

Punch diameters (mm)				Shear strength (MPa)	Elastic modulus (MPa)
12	14	16	18	758.3	203.4×10^3

Table 1: Parameters for punch design.

Figure 3: Punch samples of various diameters.

Alloying Element (wt%)	Si	Fe	Cu	Mn	Mg	Sn	Pb	Zn	Ti	Al
Al-6063	0.518	0.251	0.007	0.006	0.521	0.007	0.000	0.10	0.013	98.62

Table 2: Chemical composition of AA-6063 .

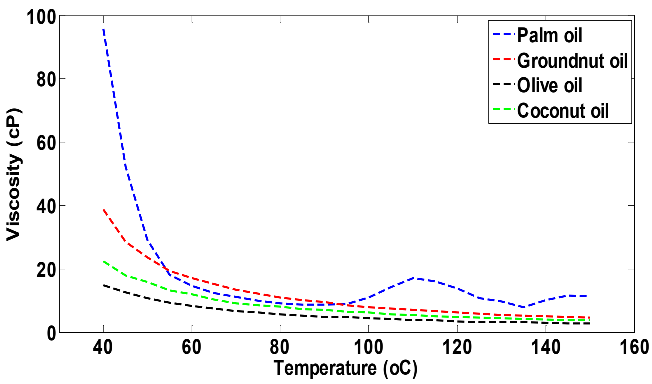

Figure 4: Viscosity of lubricants for the experiment.

Therefore, $P_{AVE} = 455.49 N / mm^2$

The extrusion force is obtained by multiplying the pressure by the area of the bore A_c i.e.

$$F = A_C \times P_{AVE} \quad (3)$$

Where F is the extrusion force.

$$F = 490.9 \times 455.49 = 224kN$$

Consequently, a press of capacity greater than 224 kN (i.e. 600 kN) was selected for the extrusion operation (Figure 3).

Extrusion material

The extrusion material for the experiment is AA-6063 alloy with the chemical composition shown in Table 2. The aluminium samples were machined into small cylindrical billet of size 24.6 × 20 mm. since the aluminium billet was obtained as cast, the billet samples were annealed in an electric furnace and further cooled in the air. This will allow the workpiece to form easily.

Lubricants selection

4 lubricants that were sourced locally were selected for this experiment namely, coconut oil, groundnut oil, palm oil and olive oil. The choice of the lubricants are based reduction of deformation load, control of surface finish, non-toxicity and low procurement cost, favourable wetting characteristics and minimization of pick up on tools and tool wear and cooling of the workpiece and the tool [22]. These local lubricants can function over a wide range of temperature due to their viscous properties (Figure 4).

Experiment

The experiment consists of 48 trials in total. 12 experiments were conducted for each lubricant out of which 3 experiments represent trials for each punch diameter with 3 different punch land thicknesses. An extrusion press of capacity 600 KN is selected for this experiment. Lubricants were applied to the die orifice and tooling to reduce the extrusion force. This is followed by placing the billet sample in the die orifice and the punch was fixed to the punch plate to hold the punch in position. To the punch plate are welded two pins to guide the punch to the billet in the bore during the downward stroke of the punch. The die assembly is then clamped by set of fixtures to hold the die in position. The press ram is then slowly applied on the punch plate which in turn set to deform the billet in the die orifice. By varying the displacement of the ram from 0 to 6.5 mm, readings of the deformation load were then recorded at 0.5 mm intervals of the ram travel. An ejector punch is provided to ensure easy removal of the product as soon as the punch is withdrawn from the billet. The stress experienced by the billet is calculated by the formula

$$\sigma = \frac{F_E}{A_p} \quad (4)$$

Where F_E is the extrusion load while A_p is the punch area in contact with the billet.

Results and Discussion

The results recorded from the experiments are plotted to investigate the effects of lubricants, punch land thickness and punch diameter on the deformation load. Selection of optimum tools for shear extrusion of AA-6063 is based on the combination of parameters which give the lowest deformation load and stress for the extrusion process. In Figures 5-7, it is observed that deformation load using groundnut oil has the highest value while palm oil has the lowest value. In addition, the stress level needed to cause the material to yield is lowest with palm oil lubricant.

Observation from Figures 8-10 shows that lowest deformation load is recorded for 12 mm diameter punch while the 18 mm diameter punch delivers the highest deformation load for groundnut oil and palm oil respectively. However with palm oil lubricant, the stress level needed to cause yielding of AA-6063 is lowest for 18 mm diameter

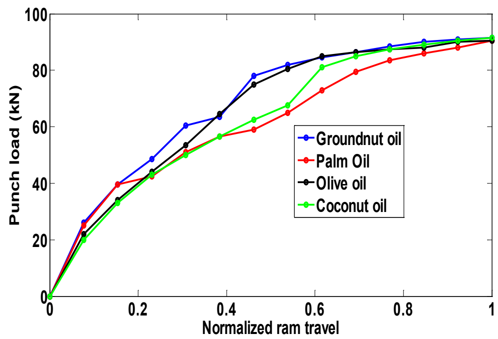

Figure 5: Punch load for different lubricants for a fixed punch diameter of 14 mm and punch land of 4.5 mm.

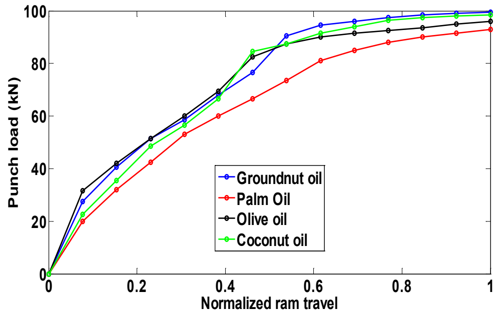

Figure 6: Punch load for different lubricants for a fixed punch diameter of 16 mm and punch land of 4.5 mm..

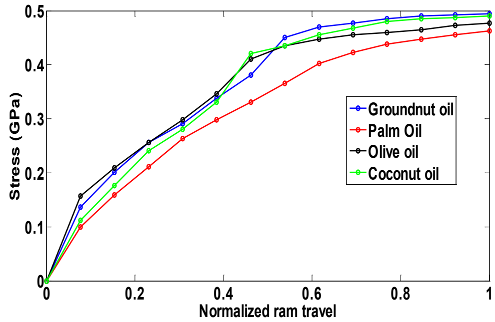

Figure 7: Stress on Al-6063 for different lubricants for a fixed punch diameter of 16 mm and punch land of 4.5 mm.

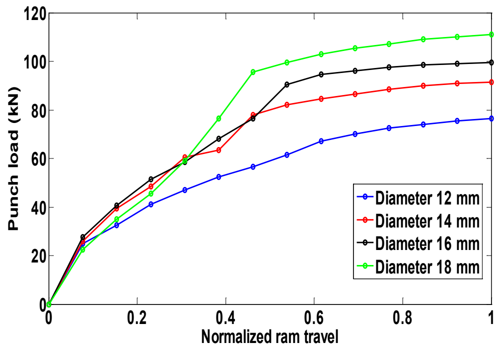

Figure 8: Punch load for different punch diameters for groundnut oil and a fixed punch land of 4.5 mm.

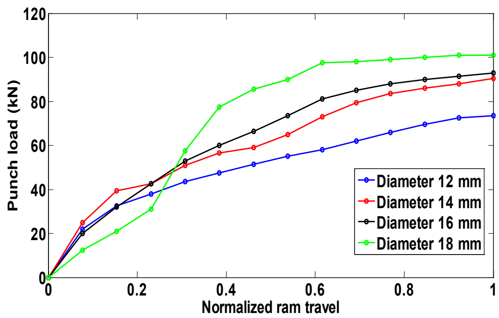

Figure 9: Punch load for different punch diameters for palm oil and a fixed punch land of 4.5 mm.

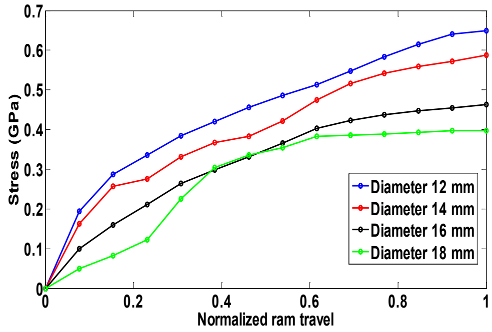

Figure 10: Stress for different punch diameters for palm oil and a fixed punch land of 4.5 mm.

punch and highest for the 12 mm diameter punch. This high stress on the 12 mm diameter punch can cause the deflection of the punch, thus affecting the product quality. On this basis, 18 mm diameter punch is considered most suitable for shear extrusion. This observation is corroborated by the fact that the size of the rod produced during shear extrusion depends on the size of the punch. While a punch of small diameter produces small size rod, a punch of large diameter produces a large size rod for the same ram displacement. Therefore, selection of the optimum punch diameter must be accomplished with the respect to the product specification. The effect of punch land in Figures 11-14 shows that a small punch land is desirable to achieve low deformation and low stress during extrusion. However, since the punch land provides strength for the punch to form the material, the punch land must not be too small to avoid punch deflection during extrusion which in turn affects the product quality.

Conclusion

A detail investigation of optimum process parameters for shear extrusion of AA-6063 has been conducted and results presented. This has been achieved through design and construction of extrusion die and tooling. Specifically, 4 punches of different diameters each made up of 3 different punch land lengths and 4 lubricants were utilized as process variables to optimize the selection of lubricants and punch for the shear extrusion operation. The result indicates that a punch of diameter 18 mm with punch land length of 1.5 mm is most suitable for shear extrusion of AA-6063. In addition, palm oil lubricant gives

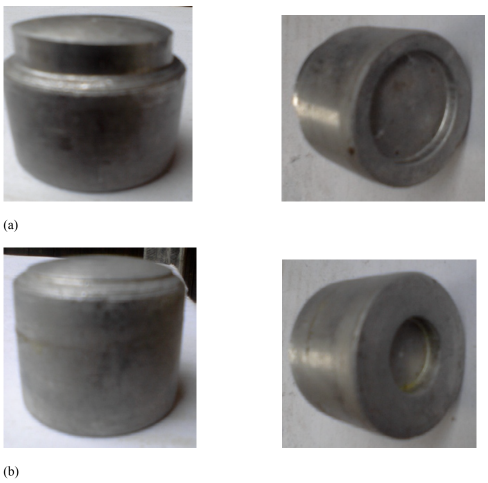

Figure 11: Extrudate rod and cup for (a) 18 mm diameter punch (b) 12 mm diameter punch.

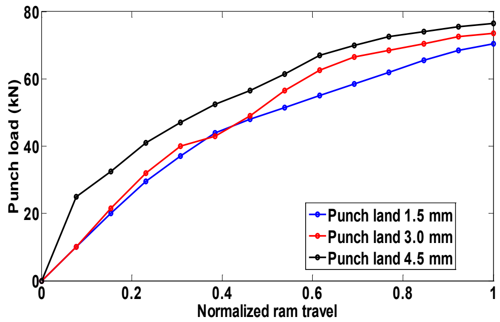

Figure 12: Punch load for different punch lands for groundnut oil and a fixed punch diameter of 12 mm.

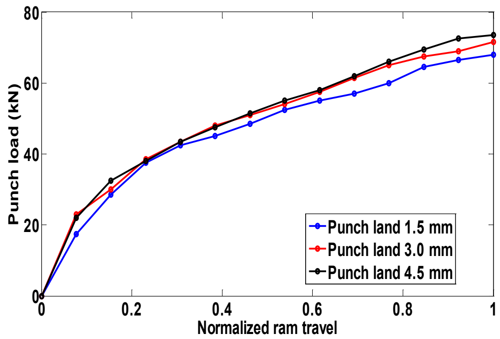

Figure 13: Punch load for different punch land for palm oil and a fixed punch diameter of 12 mm.

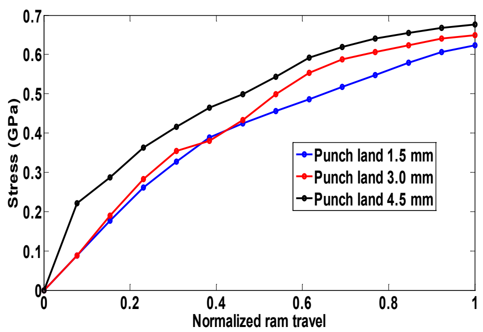

Figure 14: Stress for different punch land for palm oil and a fixed punch diameter of 12 mm.

the lowest deformation load and stress to cause shear extrusion of AA-6063. Therefore, it is concluded that palm oil lubricant gives the best process conditions for this operation. Since extrusion depends on many process parameters which may be too expensive to investigate experimentally, further work in this area should include optimization of process variables through modelling and simulation of the shear extrusion process. This will ensure the best mix of process parameters to obtain quality products.

References

1. Da Chang K, Hong Yi S, Yu C, Honglang Y (2001) Research on the shear extrusion process to form large scale cut-off valve bodies. Journal of Materials Processing Technology 117: 15–20.
2. Akbari Mousavi SA, Shahab AR, Mastoori M (2008) Computational study of Ti–6Al–4V flow behaviours during the twist extrusion process. Material and Design 29: 1316-1329.
3. Gong X, Kang SB, Cho JH, Li S (2014) Effect of Annealing on Microstructure and Mechanical Properties of ZK60 Magnesium Alloy Sheets Processed by Twin-roll Cast and Differential Speed Rolling. Materials Characterization 97: 183-188.
4. Gong X, Li H, Kang SB, Cho JH, Li S (2010) Microstructure and Mechanical Properties of Twin-roll Cast Mg-4.5Al-1.0Zn Alloy Sheets Processed by Differential Speed Rolling. Materials and Design 31: 1581-1587.
5. Gong X, Kang SB, Li S, Cho J (2009) Enhanced Plasticity of Twin-roll Cast ZK60 Magnesium Alloy through Differential Speed Rolling. Materials and Design 30: 3345-3350.
6. Hu HJ, Fan JZ, Zhai ZY, Wang H, Li YY, et al. (2014) Physical fields evolution and microstructures for compound extrusion of AZ31 magnesium alloy. Russian Journal of Non-Ferrous Metals 55: 254-262.
7. Utsunomiya H, Saito Y, Suzuki H, Sakai T (2001) Development of the continuous shear deformation process. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 215: 947-957.
8. Thomas P, Chalupczak J (2008) Experimental research into forward and backward combined extrusion pressure forces for sleeve cylindrical aluminium products. Problems of modern techniques in engineering and education 179-184.
9. Sun H, Chen Y, Kang D (2001) Application on the shear extrusion process to form large size high pressure valve bodies. J Mater Sci Technol 17: 153-154.
10. Kalpakjian S (2009) Manufacturing engineering and technology. (7th Ed), Prentice Hall.
11. Hu HJ, Li YY, Zhai ZY, Gong XB, Wang H, et al. (2015) Comparisons of extruded magnesium rods by hyperbolic curve die and parabolic curve die. Russian Journal of Non-Ferrous Metals 56: 212-216.
12. Xi Y (1997) Theoretical analysis on design of shear extrusion die. Trans. Nonferrous Met. Soc. China 7: 80-85.
13. Chung SW, Kim WJ, Higashi K (2004) The effect of die geometry on the double shear extrusion by parametric FVM simulation. Scripta Materialia 51: 1117-1122.
14. Saha P (2002) Aluminium extrusion technology. ASM International 1-22.
15. Gbenebor OP, Fayomi OSI, Popoola API, Inegbenebor AO, Oyawale F (2013) Extrusion die geometry effects on the energy absorbing properties and deformation response of 6063-type Al–Mg–Si aluminum alloy. Results in Physics 3: 1-6.
16. Murai E, Ono M, Tozawa Y, Sawai Y, Kojima T, Hamaya S (2009) Effect of shape ratio of billet on extruded length and extrusion load in forward can-backward can combined extrusion forging. Japan Society for Technology of Plasticity 50: 847-851.
17. Altan T, Ngaile G, Shen G (2009) Cold and hot forging: Fundamentals and Applications. ASM international 91-93.
18. Ross RB (1992) Metallic materials specification handbook. (4th Ed) Chapman and Hall.
19. Kostic M, Reifschneider L (2006) Design of extrusion dies. Encyclopedia of Chemical Processing 633-649.
20. Arif A, Akhtar S (2010) Fatigue failure of extrusion dies: Effect of process parameters and die features on die life. J Fail. Anal. and Preven 10: 38-49.
21. Danckert J (2004) A new punch design in backward can extrusion. Department of Production, ICFG (International Cold Forging Group) 37th Plenary Meeting 13-15.
22. Bowden FP, Tabor D (1951) The friction and lubrication of solids. Part II, Science 113: 443-444.

Citation: Ojo SO, Erinosho M, Ajiboye JS (2015) Experimental Analysis for Lubricant and Punch Selection in Shear Extrusion of Aa-6063. J Material Sci Eng 4: 174. doi:10.4172/2169-0022.1000174