International Journal of Engineering and Technology Volume 4 No. 2, February, 2014

Effect of Die Entry Angle on Extrusion Responses of Aluminum 6063 Alloy

S. O. Adeosun, O.I. Sekunowo and .O.P. Gbenebor
Department of Metallurgical and
Materials Engineering, University of Lagos, Nigeria

ABSTRACT

Mechanical properties response of extruded 6063 aluminum alloy at varied die entry angle has been investigated. Plain carbon and tool steel dies with entry angles of 15º, 30º, 45º, 60º, 75º and 90º were simulated. Extrusion on the alloy was done at ambient temperature (37ºC) and the extruded samples from the various angles were subjected to selected service related mechanical tests and microstructural analysis. Results show that maximum extrusion pressure and extrudate hardness increase with increasing die entry angle. Contribution to extrusion pressure increase may have come from obtuse changes in the extrudates' crystal slip system in relation to extrusion direction. Improved deformation was observed in plain carbon steel die in the order 45º, 90º and 75º entry angles. However, maximum lateral deformation index of 2.1 was observed with the plain carbon steel die at 45º entry angle against 1.8 of tool steel die. The disparity in the lateral deformation index was attributed to varied responses along longitudinal elongation on load application.

Key words: *Extrusion, die entry angle, extrusion pressure, lateral deformation*

1. INTRODUCTION

Mechanical working processes such as rolling, forging, extrusion, drawing, pressing, etc are the major engineering devices component requirements. This is based on the permanent changes in the shape of the material under the action of external forces. Therefore, optimization of metal flow is very important as it directly affects extrusion speed, mechanical properties and surface finish of the extruded products [1]. Metal flow during extrusion can be affected by factors such as material flow properties, die profile, friction conditions, and container work piece heat transfer characteristics [2].

Extrusion appears to be a means of breaking down the as- cast structure of billet being subjected to only compressive forces during the process. In cold extrusion, punches and dies are made of wear resistant tool steels such as high alloy chromium steels which are subjected to severe working conditions in order to impart dimensional stability and good surface finish.

Cold extrusion models to verify parameters that influence the process have been investigated. Qamar [3], through a Finite Element Method (FEM) studied extrusion complexities and dead metal zone using numerical simulations extrusion to validate experimental observations. Dies of three different profiles made of H13 steel were used on lead and Al- 6063 alloy. Fluctuations in metal distortion during plastic flow and dead metal zone size were observed. This occurrence was attributed to the variation in die profile symmetry and extrusion ratio. .Tiernan et al. [4] used two different lubricants namely: zinc stearate and oil based lubricant containing lead and copper additive. The experiment was configured to analyze effects of reduction ratio, die angle and die length on the extrusion force. Data obtained from experimental measurements and by computations using FEM predictive simulation were compared. The highest extrusion force obtained by experiment was 1260kN. The force was measured when extruding the aluminum billet using a die with exit diameter, die angle, and land height of 5 mm, 150°and 4 mm, respectively. In comparison of results, reasonable correlations were observed to exist between FEM and experimental values of extrusion forces.

In an attempt to curb shrinkage cavity defects and surface cracks posed by non – homogenous flow of metal during extrusion, Yuan, et al [5] proposed a method by using a guiding angles 5º – 30º.This was done on the premise that the metal in the deforming area will be extruded twice with a lower extrusion ratio, which usually result into significant changes in metal flow at the die orifice thereby reducing extrusion defects. It was observed that the minimum load was applied on 15º die angle compared to that whose die angle was 0º. The stress state at the bottom of the die with the guiding angle was observed to be different from that without the guiding angle. The overall result showed that metal flow was more homogeneous and the tendency to generate dead zone was greatly reduced. Shrinkage cavity elimination was attributed to the transition of axial stress in the metal from tensile to compressive. Similarly, evaluation of the effect of die land on the extrusion pressure was carried out by [6]. The study showed that the extrusion pressure contributions due to die land are found to increase with die land length for any given percentage extrudate reduction. The extrusion pressure also increases with die land length for any given percentage sample reduction. The extrusion of copper feed materials and the Rheological property test showed that extrudable feed materials exhibited pseudoplastic behavior and the viscosity values of feed materials decreased with increasing shear rates [7]. Cold extrusion is often employed for the manufacture of special sections as the metal is made to flow under cold conditions (room temperature) of high pressure which imparts improved mechanical properties and good surface finish on the work piece.

However, the mechanism of extruding a billet above recrystallization temperature (hot extrusion) engenders pressure decrease along the container as the ram/punch advances and when the ram speed increases, a fine structure of high integrity devoid of coarse grains ensued [8]. For simulation purpose, Chaudhari et al. [9] used tool steel as dies and punch at semi angles of 30^o, 45^o and 60^o in the cold forward extrusion of AA6351 and AA100 in order to explore their effects on hardness and surface finish. It was observed that higher amount of load was needed for the extrusion of both billets at 30^{o}and 60^o die angle as compared to 45^o coupled with low hardness
In term of die material, it must be noted that all the works reviewed were carried out using tool steel dies and the processes limited to angle variations. However, the use of inexpensive and readily available plain carbon steel dies has not been considered. This paper investigates the extrusion responses of 6063 aluminum alloy at varied die entry angles. Two extrusion process parameters namely: extrusion pressure and extrusion ratio using tool steel (TS) and plain carbon steel (PCS) as die materials.

II. EXPERIMENTAL PROCEDURE

Materials and Die fabrication

Billets of 25.1mm initial diameter and 19mm long were cut from samples of 6063 aluminum ingot whose composition is presented in Table1.

Table 1: Chemical composition of the billet 6063 AA used

Element	Si	Mg	Fe	Cu	Mn	Ti	Cr	Al
Composition (wt. %)	0.45	0.50	0.22	0.03	0.03	0.02	0.03	98.72

Table 2: Chemical composition of die materials

Element (wt%)	Fe	C	Si	S	P	Mn	Ni	Cr	Mo	V	Cu
PCS	98.96	0.119	0.288	0.012	0.014	0.502	0.021	0.043	0.005	0.006	0.031
TS	97.87	0.198	0.442	0.013	0.012	1.392	0.022	0.005	0.006	0.041	0.012

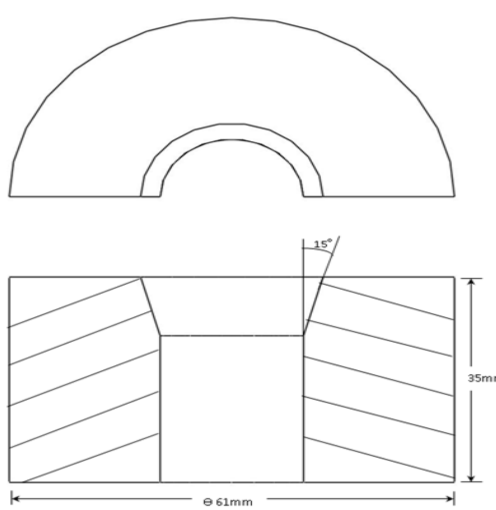


Figure 1 Schematic drawing of die with 15^o entry angle

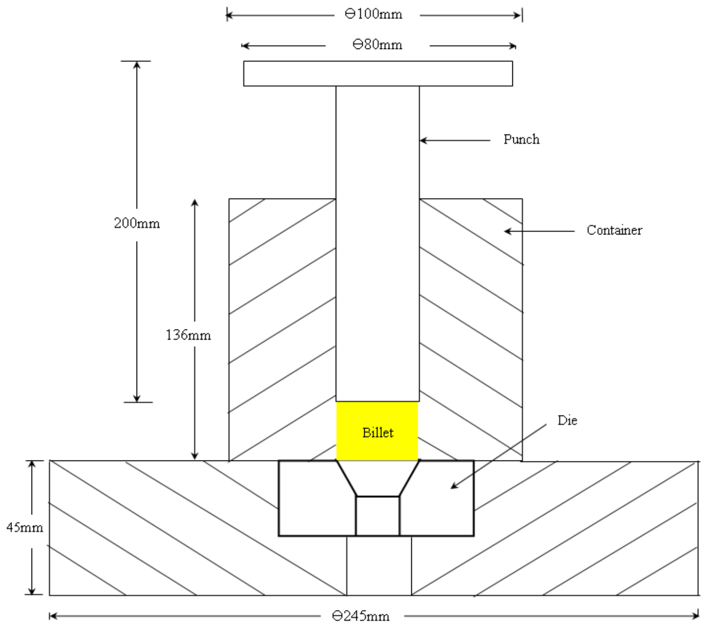


Figure 2 A cross- sectional view of extrusion set up

The die materials and their chemical compositions are shown in Table 2. Six extrusion dies with circular end section of 15°, 30°, 45°, 60°, 75° and 90°entry angles were made (see Figure 1). The forming tools, namely: the container, die holder and punch, were fabricated from plain carbon steel (see Figure 2). After fabrication, the plain carbon steel (PCS) and tool steel (TS) dies were stress – relieved at 750°C. The form tool and the ram were also heated to 850°C, soaked for three hours and then quenched in still water to increase their wear and distortion resistance during extrusion.

Extrusion Campaign

Extrusion of the billet was carried out at ambient temperature (37°C) using an Avery Denison machine. The machine was adapted to provide compressive load on the ram as the dies were placed in succession into the form tool. Test samples that were machined to a diameter of 25.1mm and 19mm long, were inserted through the upper cylindrical part of the form tool while the loads (kN) applied on the ram was read and recorded. The strain gauge attached to the ram of the machine provided of means of measuring the strain rate with each revolution completed representing 1mm elongation of the test sample.

Hardness test

Micro-hardness test (HV) was carried out on the extrudates in order to evaluate the extent of structural distortion suffered during extrusion. This was done using a on the samples were carried out using a Leco Micro Hardness Tester (digital) with 100gf load applied for 10 seconds dwell time. The hardness tester has an attached microscope to view the accuracy in the alignment between the indenter and the specimen geometry. Three readings were taken on each sample and the average value recorded.

Micro Structural Examination

The extruded samples, having cylindrical shape were ground using 220 and 600 microns emery papers in succession to obtain smooth surfaces. These ground samples were polished using aluminum powder to produce mirror like surfaces. The polished surfaces were etched for 20 seconds in a solution containing 5grammes of sodium hydroxide (NaOH) dissolved in 100ml of water. The samples microstructured features were examined using an optical microscope at x400 magnification and the micrographs are shown in Plates 1-2.

III. RESULTS AND DISCUSSION

Extrusion Pressure

The effects of die material and die entry angle on extrusion pressure of extruded samples are illustrated in Figures 3. Figures 3(a) – (f) show increase in maximum extrusion pressures with increasing entry angles irrespective of die material. However, the extrusion pressure is lower on a tool steel (TS) die though with a difference less than 15%. Preceding this value, the magnitudes of applied pressures appear disorderly for every punch travel. Non homogeneity in work hardening of extrudates as a result of complexities of dislocation coupled with the presence of multiphase microstructure of the 6063 aluminum alloy may have been responsible for this observation .This agrees well with [10]. Within the strain of 0 → 0.38, PCS 15, i.e. the sample extruded in PCS die at 15° entry angle demonstrated a higher extrusion pressure over that of TS15 (Figure 3(a)). The body wedge exhibited action of TS die appear to have produced cluster of incoherent crystals of Mg_2Si at the grain boundaries which permit easy flow over that of PCS die (see Plates 1a and 2a). Furthermore, the precipitation of Mg_2Si at grain boundaries along with AlFeSi intermetallics, being more in the TS 30 die extrudate, could be responsible for its higher yield point (100MPa) compared to that of PCS (20MPa) (see Plates 1b and 2b). Sample yielded at a lower pressure (86MPa) in the PCS 45 as compared to 375MPa, which was the magnitude of the pressure where the sample in TS 45 die yielded (Figure 3(c)). The PCS 45 die has enabled easy motion of dislocation through the sample as it was strained to 0.89. Both dies exhibited similar trend of extrusion pressure for 45º, 60º, 75º, and 90º angles (Figures 3(d)-(f)) though the tool steel die still demonstrated lower extrusion pressures.

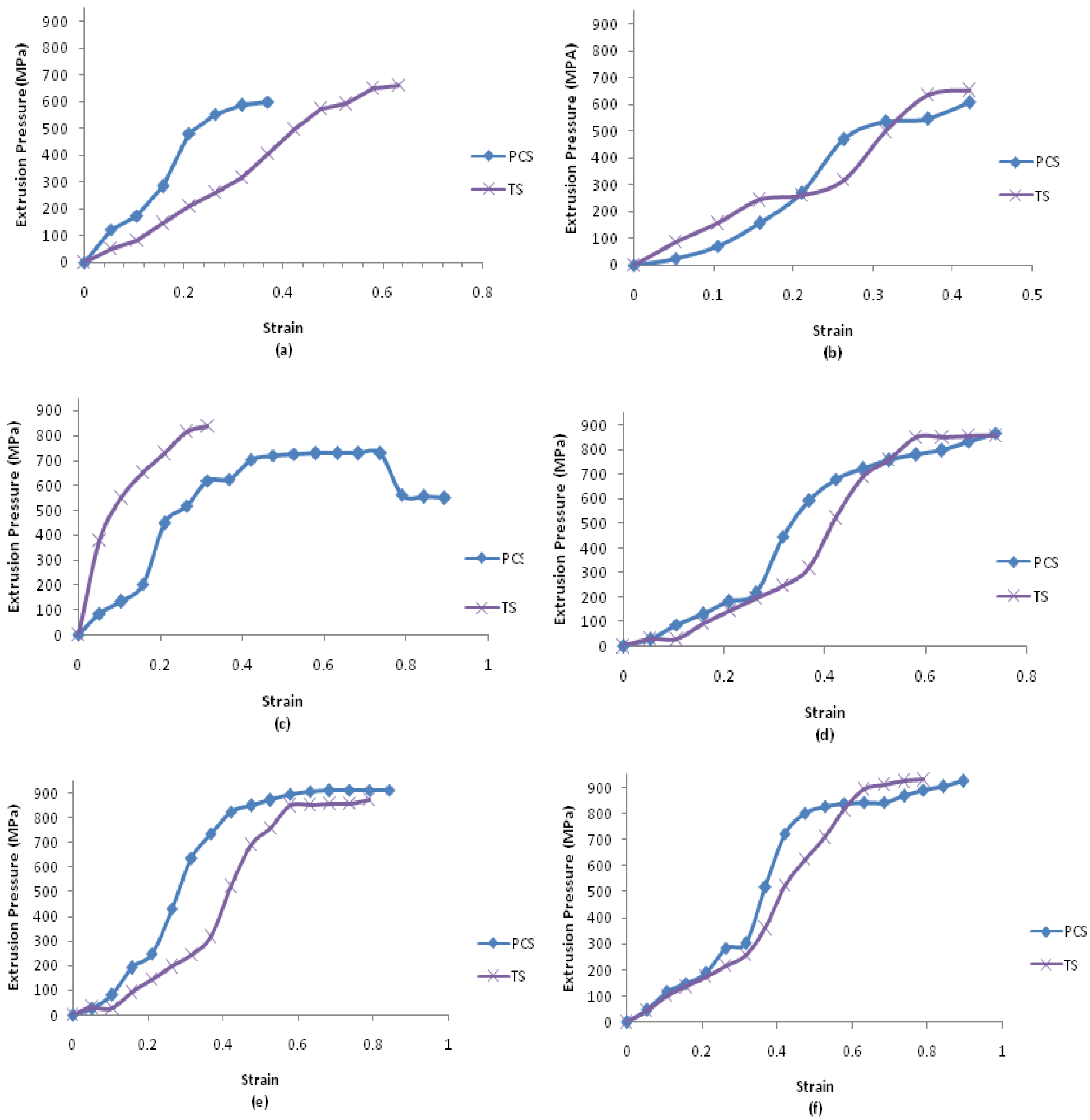


Figure 3 Effects of die entry angle material on flow pressure at (a) 15º (b) 30º (c) 45º (d) 60º (e) 75º and (f) 90º

Ductility of Extrudates

At lower die entry angles (15º, 30º), TS extrudates exhibited significant improvement in percent elongation between 64% and 68% over extrudates in PCS die which varied from 38% to 42% (Figure 4). At 45º entry angle, samples extruded in TS die have poor elongation of 32% compared to that from PCS die (90%). The peak elongations (90%) for the samples extruded in PCS die occurred at 45º and 90º entry angles while that of TS die (80%) occurred at 60º, 75º and 90º. Better surface finish in TS than PCS dies imparts on material flow during extrusion which is responsible for higher elongation of extrudates in TS die. This study has shown that materials optimization is better when PCS die is used.

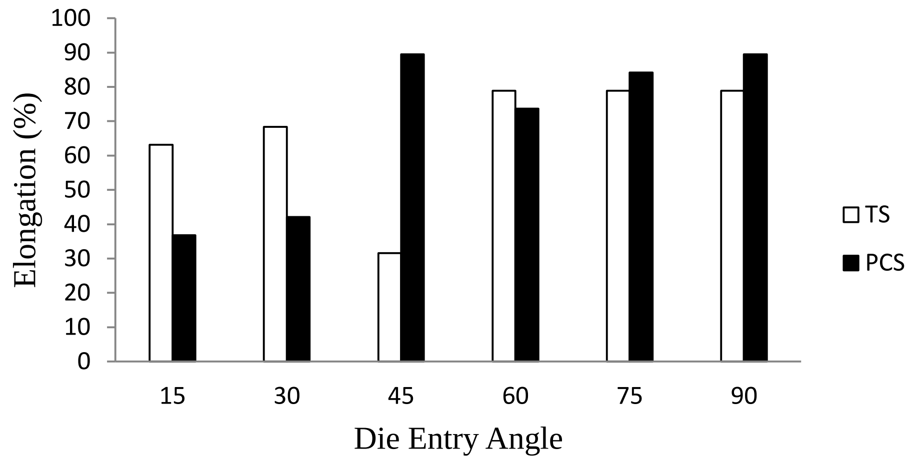


Figure 4 Percentage Comparative percent elongation in TS and PCS dies.

Micro- hardness of Extrudates

As shown in Figure 5, the hardness of extrudates increases as the die entry angle increases. At 15º, 75º and 90º die entry angles, extrudates exhibited similar trend of micro-hardness independent of the die material. However, samples extruded in TS die show substantial higher hardness at 30º and 60ºentry angles; though the values are not significantly different from samples extruded in PCS die.

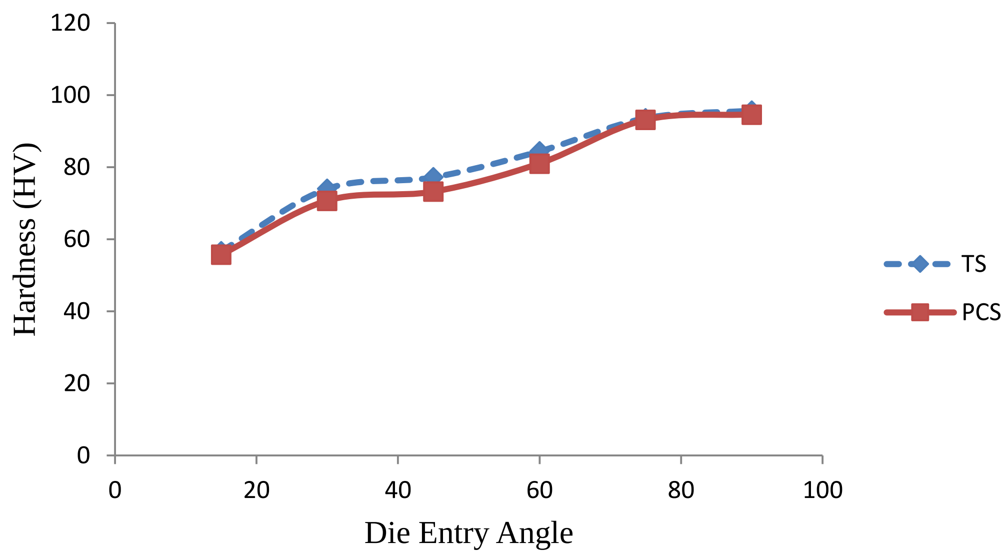


Figure 5 Effect of die entry angle on extrudates micro-hardness

Lateral deformation of Extrudates

The lateral deformation property measures the relative linear strain of the material undergoing extrusion. Lateral deformation index of extrudates was obtained by dividing the initial cross sectional area by the deformed area. The results at varied entry angles are illustrated in Figure 6. At 15º, 30º, 45º and 60º die entry angles, extrudates from TS dies exhibited higher deformation index compared to that of PCS die, although the differences are minimal. The strain ratios at 75^o and 90^o angles are the same independent of die material. The results generally suggest that a PCS die can effectively replace TS die in extrusion especially for components of less intricate geometry.

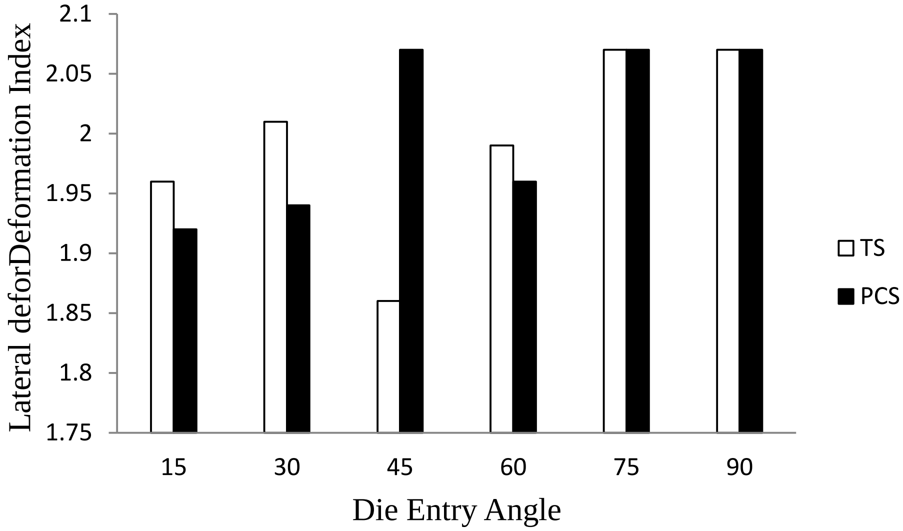
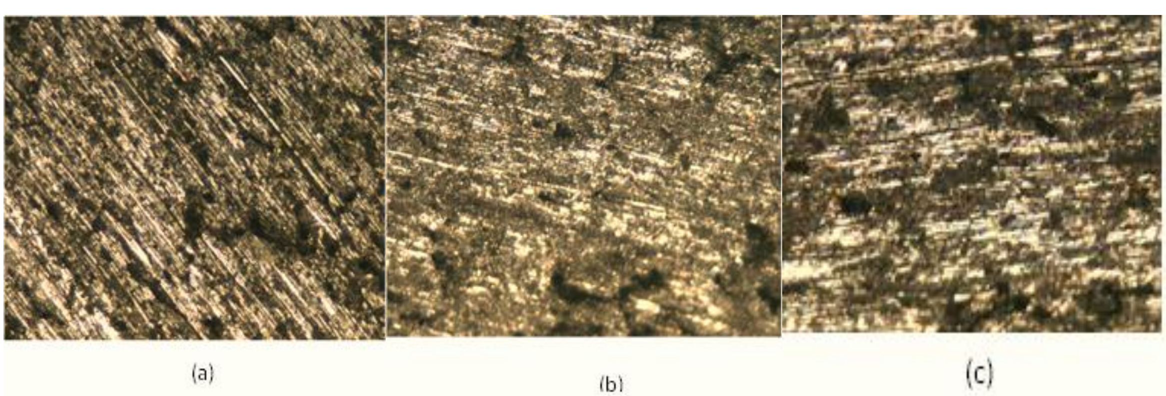


Figure 6 Comparative lateral deformation index of extrudates in TS and PCS dies

Microstructural Examination

The presence of AlFeSi and Mg_2Si phases in 6063 alloy microstructure have been proven to influence the qualities and characteristics of its extruded products [11]. However, the relatively higher hardness exhibited by extrudates can be attributed to the hardening effect of AlFeSi intermerallic such that the ease in dislocation motion reduces gradually as the die entry angle increases. Higher carbon content in die material, coupled with increasing die entry angle may have also influenced the flow of material which in turn, affected the geometry and distribution of evident phases. Further, extrudates may have exhibited anisotropic behavior as crystals tend to flow along visible deformation direction (Plates 1 and 2 (a) – (f)). Plate 1a is the micrograph of the extruded sample in PCS die at 15^o entry angle. The microstructure shows clustered Mg_2Si precipitates within the aluminum matrix. In Plate 2a, low fraction of plate-like Mg_2Si precipitates indicate deformation texture while the structure of extrudate in TS die at 30^o (Plate 2(b)) reveals few Mg_2Si evenly distributed within the matrix compared with the same product extruded (Plate 2(a)). However, extrusion with PCS die at 45^o resulted in needle – like Mg_2Si, AlFeSi grains at 180^o (Plate 2(c)).This suggests that die entry angle affected the orientation of grains which appear to align parallel to dislocation motion direction thereby relieving the impediment potency along that direction. This type of structure is capable of conferring improved ductility on the extrudate. At entry angles above 30^o, fine grains of Mg_2Si were developed in extrudates from both TS and PCS dies. The increase in dislocation motion impediment resulting in further work hardening during extrusion process has been responsible for this observation. For this reason, the die materials have no significant effect on the etrudates' microstructure.



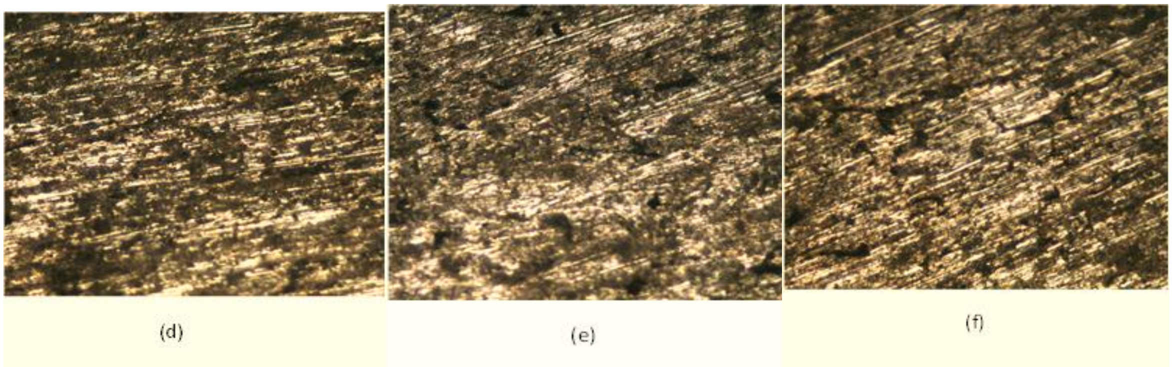


Plate 1 Micrographs of samples extruded in PCS die at varied entry angle showing varying morphologies within α -Al matrix (a) 15^{O} (b) 30^{O} (c) 45^{O} (d) 60^{O} (e) 75^{O} (f) 90^{O}

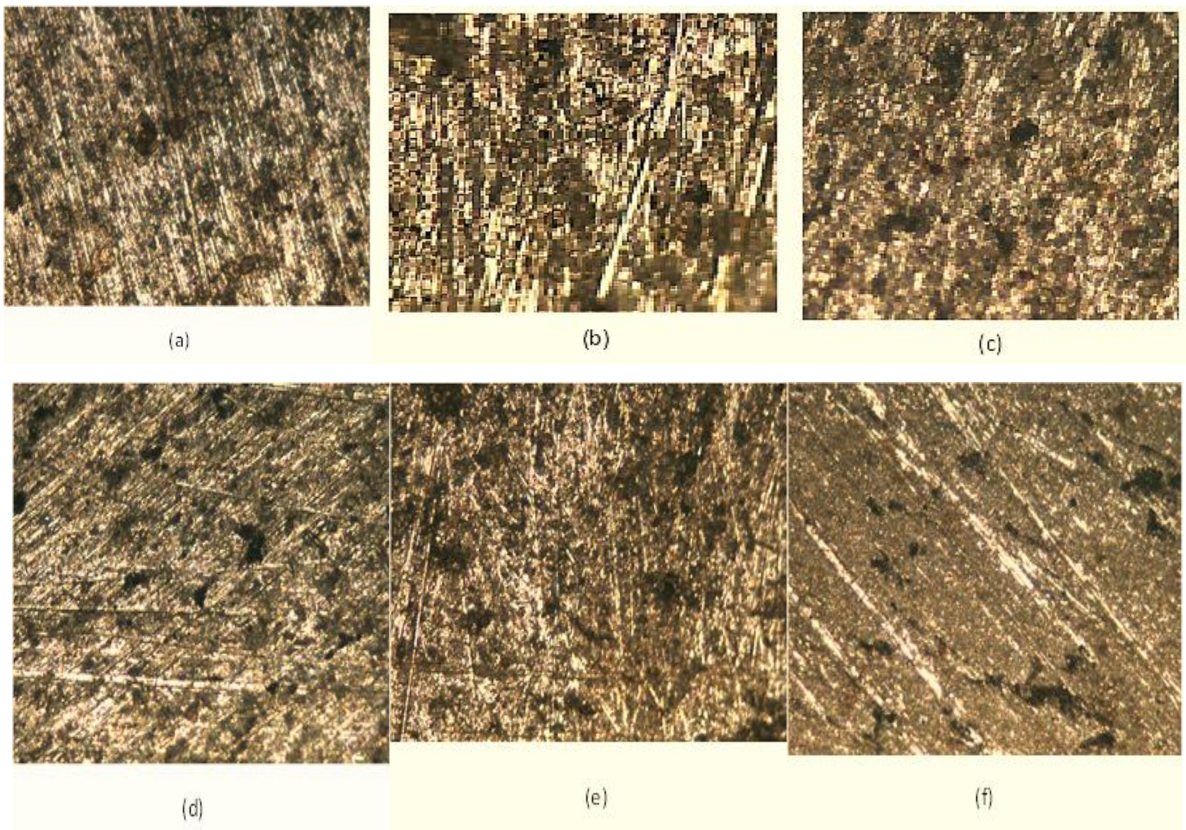


Plate 2 Micrographs of samples extruded in TS die at varied entry angle showing varying morphologies within α -Al matrix (a) 15^{O} (b) 30^{O} (c) 45^{O} (d) 60^{O} (e) 75^{O} (f) 90^{O}

IV. CONCLUSION

In this study, a maximum cold extrusion pressure of 930MPa is obtained for the 6063 aluminum alloy at 90^{o} die entry angle. The results from this study have shown that materials optimization is enhanced when plain carbon steel die of 45^{o}, 75^{o} and 90^{o} entry angle designs are used as extrudates from these entry angles demonstrated superior lateral deformation index. However, given the small difference of 3MPa in maximum extrusion pressure between tool steel and plain carbon steel dies and in consideration of manufacturing cost, plain carbon steel can effectively replace tool steel as die material without compromising extrudates desirable quality.

REFERENCES

[1] Flitta, I. and Sheppard, T. (2003) Nature of friction in extrusion process and its effect on material flow. Materials science and Technology 19, pp 837-846.

[2] Piwnik, J. and Mogielnicki, K. (2010) The friction influence of stress in micro extrusion. Archives of Foundry Engineering 10(1) pp 451-454.

[3] Qamar, S.Z (2009). FEM study of extrusion complexity and dead metal zone. Archives of Materials Science and Engineering 36(2) pp 110-119.

[4] Tiernan, P., Hillery, M.T., Draganescu, B and Gheorghe, M. (2005) Modeling of cold extrusion with experimental verification, Journal of Materials Processing Technology 16 pp 360-366.

[5] Yuan, S.I, Li, F. and He, Z. (2008) Effects of guiding angle on plastic metal flow and defects in extrusion of aluminum alloy. Journal of Materials Science and Technology 24(2) pp 256-260.

[6] Ajiboye, J.S and, Adeyemi, M.B. (2006) Effects of die land on the cold extrusion of lead alloy. Journal of Materials Processing Technology 171 pp 428-436.

[7] Wichlanrak, R., Morakotjinda, M., Yodkaew, T., Torsangtum, N., Kratathong, R., Daraphan,A., Coovattanachai, O.,Vetayanugul, Thavarungkul, N., Poothong, N. and Tongsri (2008). Extrusion of Cu feed materials. Journal of Metals, Materials and Minerals 18(2) pp 45-48.

[8] Arifa, A.F.M., Sheikha, A.K., Qamara, S.Z and Al-Fuhaid, K.M. (2001) Variation of pressure with ram speed and die profile in hot extrusion of aluminum 6063. Materials and manufacturing processes 6(5) pp 701-716.

[9] Chaudhari, G.A, Andhale, S.R and Patil, N.G. (2012) Experimental evaluation of effect of die angle on hardness and surface finish of cold forward extrusion of aluminum. International Journal of Emerging Technology and Advanced Engineering 2(7) pp 334-338.

[10] Monteiro, W.A., Buso, S.J., Ferrari, R.B, Esposito, I.M., Cetlin, P.R., Aguillar, M.T.P. and Corrêa, C.S. (2010) Mechanical and microstructural aspects observed in 6063 aluminum alloy after thermomechanical treatment. International Materials Congress pp 4243-4250.

[11] Rivas, A.L., Munoz, P., Camero, S. and Sayago, O.Q. (1999) Effects of microstructure on the mechanical properties and surface finish of extruded AA-6063 aluminum alloy. Advanced Materials Science and Technology 2(1) pp 15-23.

