The influence of steel die parameter and micro-structural investigation on AA6063 aluminum alloy

Gbenebor, O.P. , Adeosun, S.O. , Fayomi,O.S. , Joseph,O.O.

Abstract— The study investigated the influence of steel die parameter and the microstructural evaluation of AA 6063 aluminum alloy extruded at room temperature using different die entry angles. Mild and tool steel dies of entry angles of 15°, 30°, 45°, 60°, 75° and 90° were used to extrude the work sample. Microstructural analysis, coupled with ram velocity, elongation, hardness, and maximum extrusion pressure of the extruded samples, were determined. It was observed that theaximum extrusion pressure required for extrusion and hardness of extruded samples increased with increasing die entry angle .Experimental results show that aluminum alloy deforms better when the die material is made of mild steel with die entry angles of 45°, 75° and 90° as compared to tool steel.

Index Terms— AA6063 aluminum alloy, die entry angle, extrusion, extrusion pressure, extrusion ratio, microstructure, ram velocity

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1 INTRODUCTION

AA 6063 is a heat treatable and wieldable aluminum alloy with magnesium and silicon as the alloying elements. Owing to its good mechanical properties, this alloy is mostly used in extruded shapes for architecture - window frames, door frames and roofs [1-8].The process of metal extrusion entails the forcing of a stock of material in the form of a billet, which is placed in a chamber, through a die opening (which could be of any shape) by the use of a ram [2-5].

A variety of shaped aluminum components are extruded at room temperatures to obtain good surface finishes, better dimensional consistency and improved strengths [3-6]. Investigations on effects of die profile associated with some other extrusion parameters like extrusion/ram pressure, ram speed, metal flow, nature of friction and product defects have been areas of interests for extrusion researches [7-8].

Tool steels are majorly used as die materials because of the high strength and good wear resistance they possess, however, these alloys are expensive (cost of manufacturing or procurement) compared to mild steel, which is readily available and cheap to form [7-10]. It is therefore necessary to investigate the products of aluminum extrudates when a mild steel is used as a die material and see if it could reasonably substitute tool steel die (to some extent) in extrusion applications.

2 MATERIALS AND METHODS

2.1 Material preparation

AA 6063 aluminum alloy used for this study was obtained from Nigeria Aluminum Extrusion Company (NIGALEX), Oshodi Lagos, Nigeria. The chemical analysis of this alloy is shown in Table 1.

Table1 Aluminum alloy AA 6063 spectrometer analysis

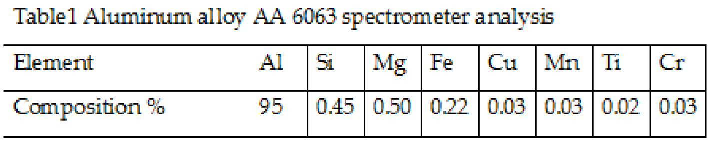


Table1 Aluminum alloy AA 6063 spectrometer analysis

Element	Al	Si	Mg	Fe	Cu	Mn	Ti	Cr
Composition %	95	0.45	0.50	0.22	0.03	0.03	0.02	0.03

The alloy was heated above its melting temperature (660°C) and was cast in a sand mould with cylindrical sample of 30mm x 300mm. The metals were allowed to solidify and ejected by breaking the mould. The cast samples were cleaned and machined to the shape and size as shown in Figure1 for the extrusion process.

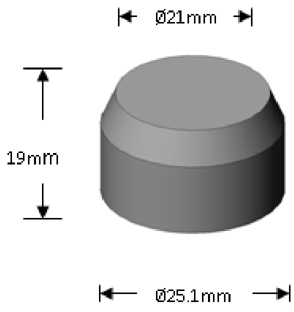


Fig1. Schematic diagram of the specimen to be extruded

2.2 Die and form tool materials

Mild and tool steels of chemical compositions shown in tables 2 and 3, were used as the die material of which each steel .was machined to form a circular end section and entry angles of 15, 30,45,60,75 and 90 degrees were made for each die material, making twelve dies in all. The mild steel dies were annealed by first heating them to a temperature of 850°C and held for three hours at this temperature. The tool steel dies were normalized by heating them to a temperature of 750°C where they were held for three hours before they were brought out to cool in air. The form tool and the ram, which were made of mild steel were heated to a temperature of 850°C and quenched in water after holding for three hours in the furnace. This was done to increase the strength and hardness of the set up to prevent wear and deformation during extrusion.

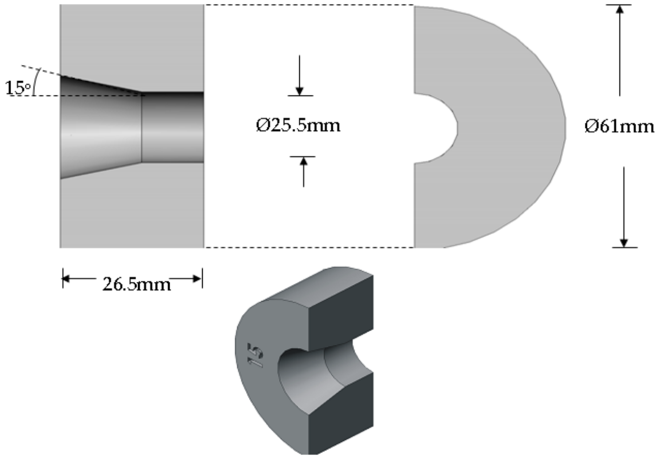
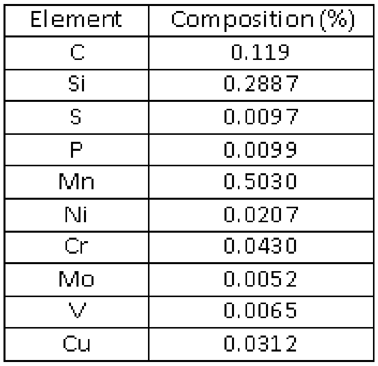


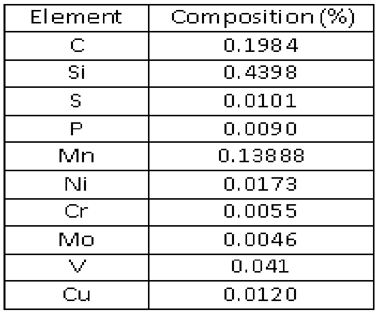
Fig.2 Front, end and isometric view of the die with 15° entry angle.

Table 2 Mild steel spectrometer analysis



Element	Composition (%)
C	0.119
Si	0.2887
S	0.0097
P	0.0099
Mn	0.5030
Ni	0.0207
Cr	0.0430
Mo	0.0052
V	0.0065
Cu	0.0312

Table 3 Tool steel spectrometer analysis



Element	Composition (%)
C	0.1984
Si	0.4398
S	0.0101
P	0.0090
Mn	0.13888
Ni	0.0173
Cr	0.0055
Mo	0.0046
V	0.041
Cu	0.0120

2.3 Extrusion

Extrusion was done at ambient temperature with the AVERY DENISON machine which was adapted to supply a compressive load on the ram. The die to be used was fitted into the form tool and the sample to be extruded was inserted through the upper cylindrical part of the form tool. The load (in KN) applied on the ram was read on this machine as a strain gauge was attached to the ram of the AVERY DENISON machine to measure the strain rate. Here, the time (in seconds), taken for the indicator on the strain gauge to complete a revolution was recorded. Each revolution completed represented 1mm elongation.

2.4 Micro – hardness test

Hardness test was carried out with vickerLeco Digital micro hardness with an applied load of 100gf on each sample for10 seconds. A microscope was attached to the hardness tester to view the accuracy in the alignment between the indenter and the specimen geometry. Three readings were taken for each sample and the average values were calculated.

2.5 Microstructural examination

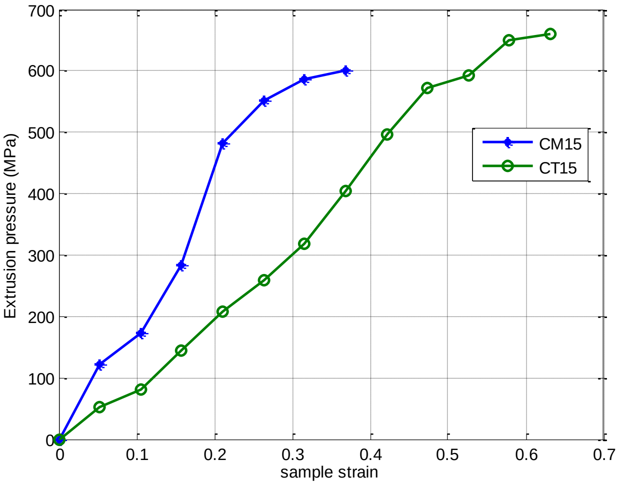
The extruded samples were first rough ground on a bench vice by filing them to an appreciable smoothness. The samples were later taken for smooth grinding by making use of 220 and 600 microns emery papers .The smoothened surfaces of these samples were polished in other to remove scratches obtained during the grinding process. Samples were held on the surface of a polishing machine containing aluminum powder kept moist by continuous application of waterman etchant solution of 5 grammes of sodium hydroxide(NaOH) dissolved in 100ml of water, was used. The etched samples were finally examined under a metallurgical microscope at a magnification of x10.

3 RESULTS AND DISCUSSION

3.1 Effects of material on extrusion pressure and elongation

The sample cold extruded with mild steel die at entry angle (α) of 15º (CM 15), exhibited a higher extrusion pressure over that of CT15 within a strain of 0 and 0.38, which yielded at a lower pressure as shown in Figure 3(a). From study, sample CT15 had better elongation compared to the sample extruded with a mild steel die (CM15) and hence, the percentage elongation for CT15 is greater than that for CM15 as shown in Figure 3(a) below. The maximum pressure needed to deform CT15 is higher since its maximum pressure is 660Mpa, which is higher than 600Mpa at CM15. Sample CM30 yielded readily at a pressure of 10MPa than CT30, which yielded at 90MPa (Figure 3(b)).The elongation of CT30 is superior to that of CM30. Hooke's law is obeyed until an extrusion pressure of about 86MPa was attained at a small strainn of 0.05 for CM45 while CT45 obeyed this law up to a pressure of 375MPa with similar sample strain as shown in Figure 3(c). The mild steel die enables slips and dislocation movement of the sample to take place with ease than the tool steel dies, hence, having a better elongation. Samples CM60 and CT60 (Figure 3(d)) show similar response to extrusion pressure. Although, the difference in their maximum pressure is small, the maximum pressure for CM60 is less than the maximum pressure to deform CT60.

Sample CM75 had a better response to elongation than sample CT75 as shown in Figure 3(e). The maximum pressure to deform in CM75 is 912MPa and this is greater than that which deforms in CT75 (890MPa) while samples extruded in mild and tool steel dies of 90º entry angle (CM90 and CT90), have comparable responses at similar extrusion pressure up to 200MPa (Figure 3(f)). The maximum pressures are comparable with CM90 at 923MPa while for CT90, at 930MPa respectively.



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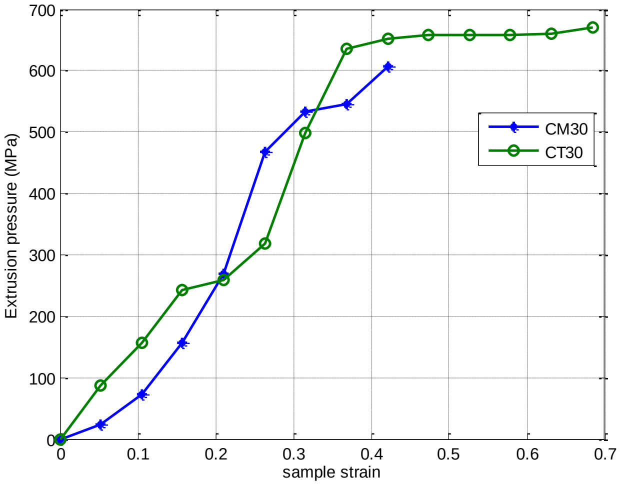

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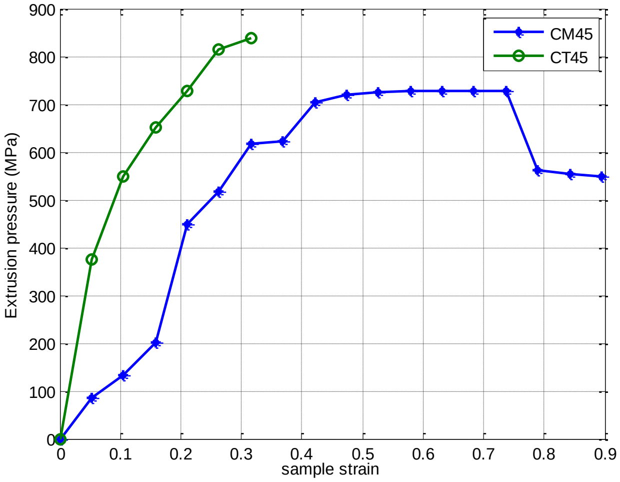

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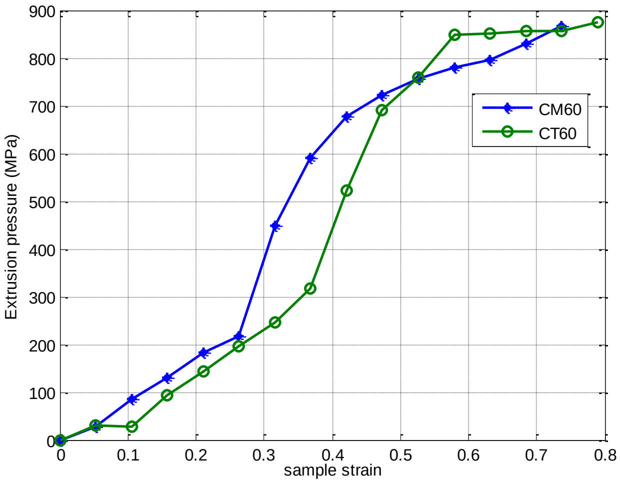

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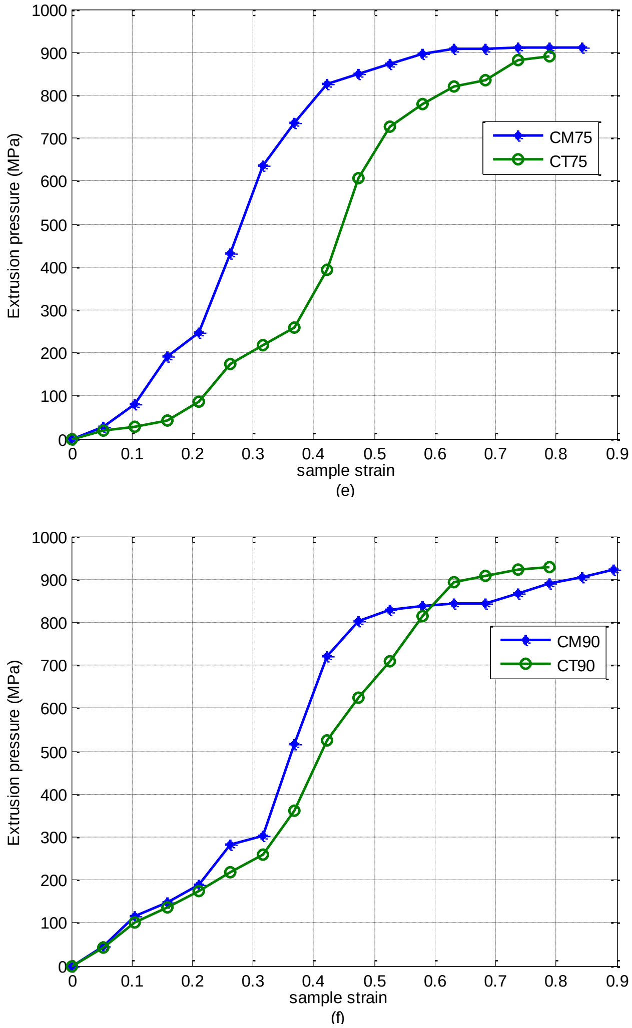
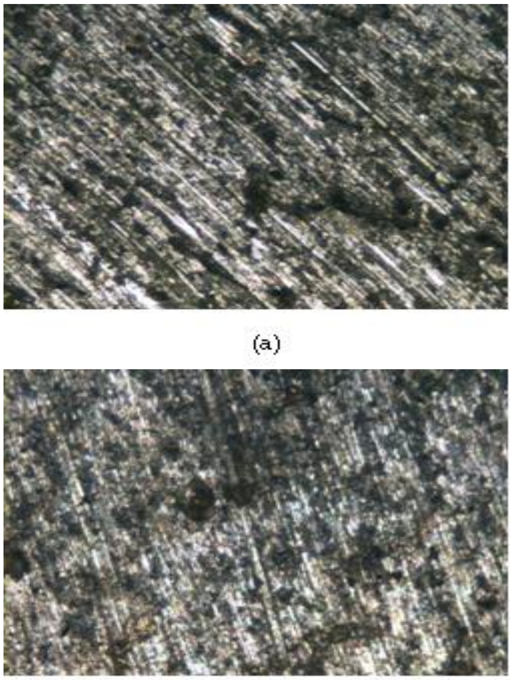


Fig.3 Extrusion pressure against sample elongation using mild and tool steel dies at varying entry angles (a) 15° (b) 30° (c) 45° (d) 60° (e) 75° (f) 90°.

3.2 Effects on microstructure

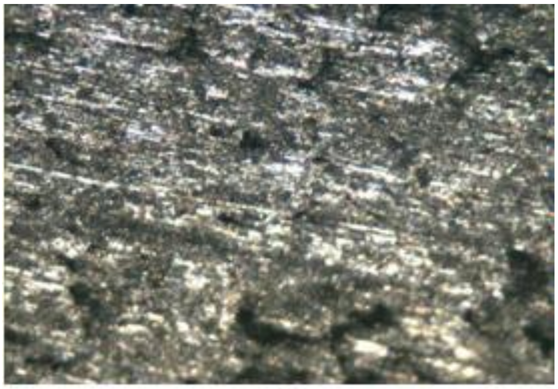
Sample CT15 shows existing fine Mg_2Si crystals at the grain boundaries which are along the slip direction compared to the structure of the sample extruded in mild steel die, CM15, which contains clusters of Mg_2Si precipitates along the grain boundaries in a matrix containing fine crystals of α-aluminum, AlFeSi and other inter metallics as shown in Figures 4(a) and (b).


(a)

(b)

Fig.4 Micrographs of extruded samples using (a) mild steel die of 15° entry angle (b) tool steel die of 15° entry angle.

Sample CT30 (Figure 5(b)) shows a precipitation of Mg_2Si phase at grain boundaries with precipitated AlFeSi, which has stronger intensity than the fourth phases in its structure compared to CM30, which has precipitates of Mg_2Si in its structure clustering fairly along the grain boundaries as shown in Figure 5(a).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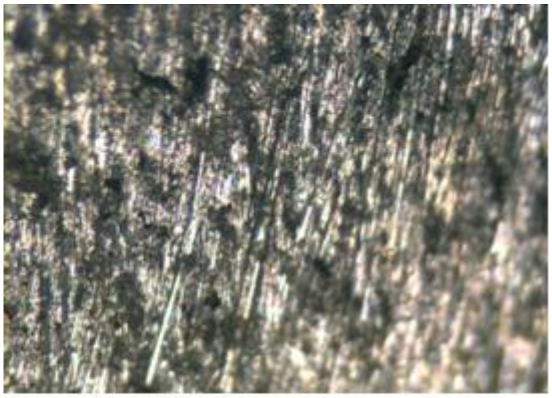
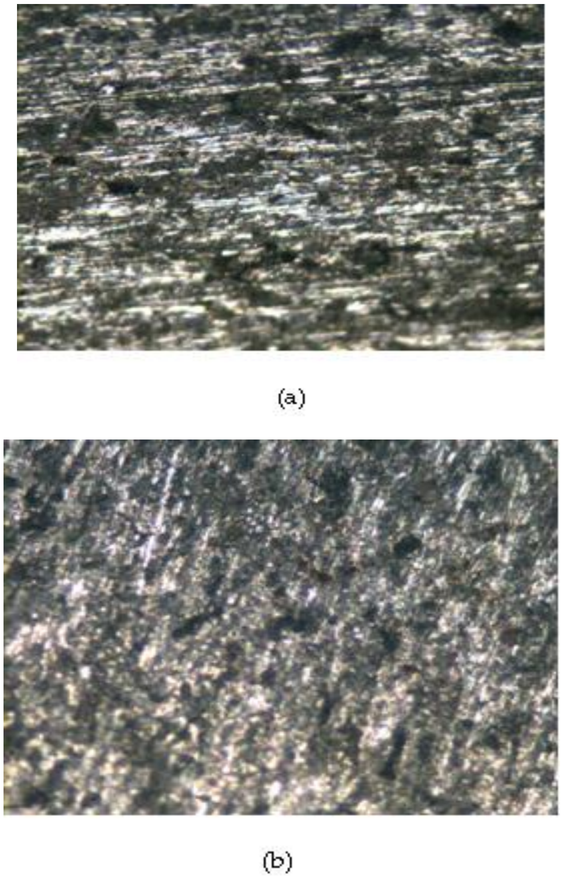


(b)

Fig.5 Micrographs of extruded samples using (a) mild steel die of 30° entry angle (b) tool steel die of 30° entry angle.

Figure 6(a) shows that there is an increase in Mg_2Si precipitates in clustered form in the matrix with some of them been formed along the slip lines. Alpha- aluminum and AlFeSi crystals are displayed in the slip direction. In Figure 6 (b), there is an increase in the proportion of Mg_2Si at grain boundaries with increase in AlFeSi and fourth phases which are roughly equal. The slip lines are not as pronounced as the sample extruded in CM 45.



(a)

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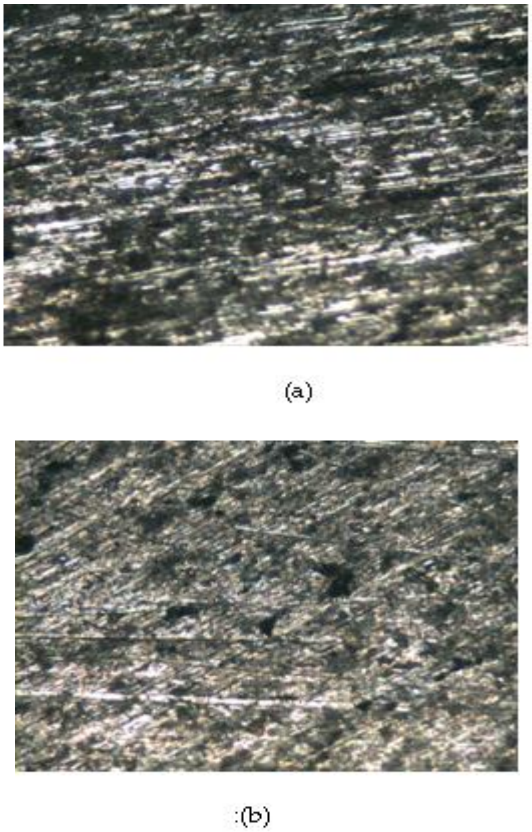
Fig.6 Micrographs of extruded samples using (a) mild steel die of 30° entry angle (b) tool steel die of 45° entry angle.

The deformation texture prevails in the matrix with increase in Mg_2Si precipitates which are well distributed in the matrix (Figure 7(a)). The volume fraction of AlFeSi and the fourth phases remain the same. The slip directions re visible. Some Mg_2Si precipitates are formed along slip directions as well as distorted grain boundaries. The structure of sample CT60 (Figure 7(b)) reveals a decrease in volume of Mg_2Si precipitates with crystal shapes ranging from needle-like to spherical. This phase is fairly distributed in the matrix.. There is however, increase in volume fraction of AlFeSi and fourth phases, which are inseparable but higher than that in CM 60. Slip lines are as pronounced as they were previously.



(a)

:(b)

Fig.7 Micrographs of extruded samples using (a) mild steel die of 30° entry angle (b) tool steel die of 60° entry angle.

The Mg_2Si crystals in Figure 8(a) are at the grain boundaries in clustered form and stretched along the slip directions. The crystals of α –aluminum ,AlFeSi and the fourth phases havie similar volume fractions. Figure 8(b) shows that there is reduction in the clustering of Mg_2Si when compared to CM75 with its precipitates been much finer and well distributed in varying shapes ranging from needle-like to spherical. The finess of aluminum, AlFeSsi and fourth phases are maintained.

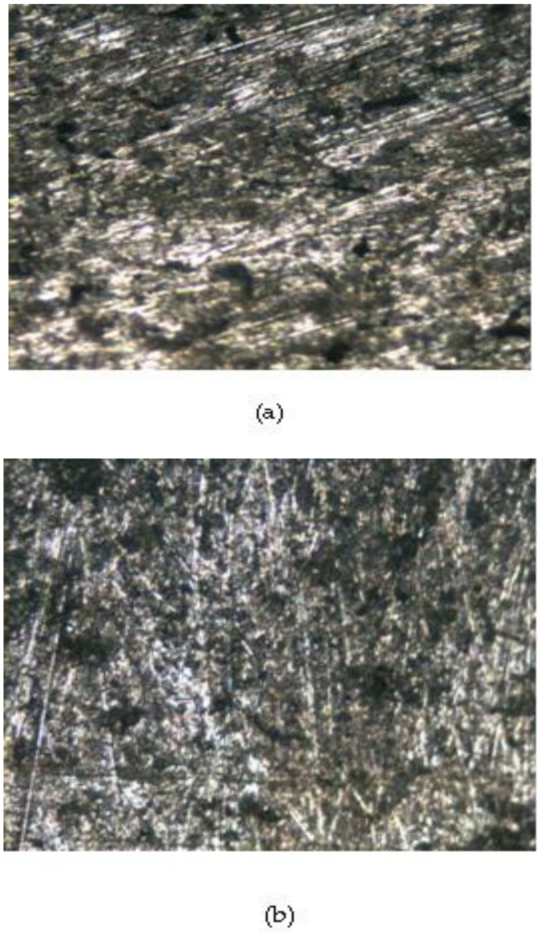


Fig.8 Micrographs of extruded samples using (a) mild steel die of 30° entry angle (b) tool steel die of 75° entry angle.

Figure 9 (a) reveals that the Mg_2Si precipitates are at the grain boundary in clustered form with increase in its volume fraction in comparison to the previous ones. Crystals of α-aluminum AlFeSi and the fourth phases are fine in the matrix. The volume fraction of AlFeSi and the fourth phases remained the same. The crystals in the matrix of the structure for CT90, (Figure 9(b)) are very fine with considerable distortion in the Mg_2Si precipitates in the matrix. There is significant increase in volume of AlFeSi and fourth phases. There is considerable reduction in the volume of Mg_2Si crystals precipitated.

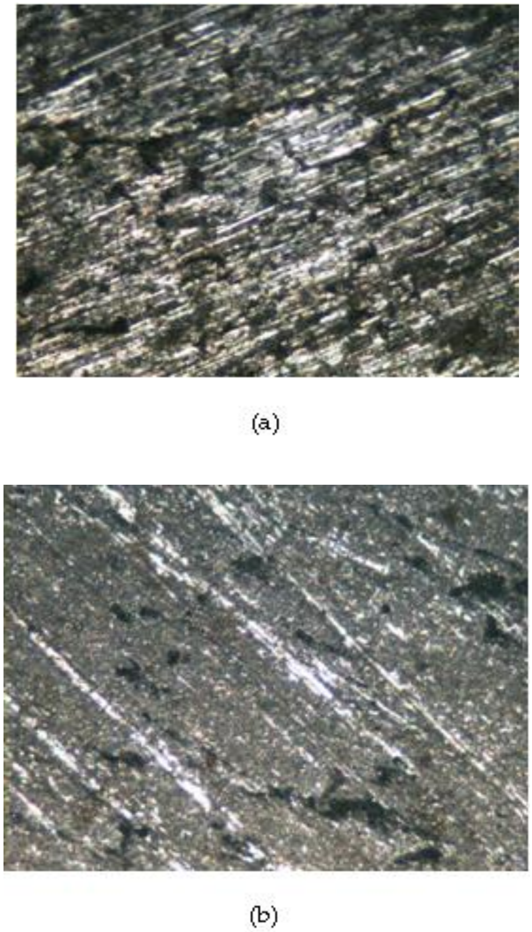


Fig.9 Micrographs of extruded samples using (a) mild steel die of 30° entry angle (b) tool steel die of 90° entry angle

3.3 Effects on hardness

The hardness of each extruded sample (Figure 10) increases as the entry angle increases. Samples extruded on tool steel dies had greater hardness values than those extruded on mild steel dies though, with a slight difference. The hardness values for the two die materials at 75°and 90° are almost the same.

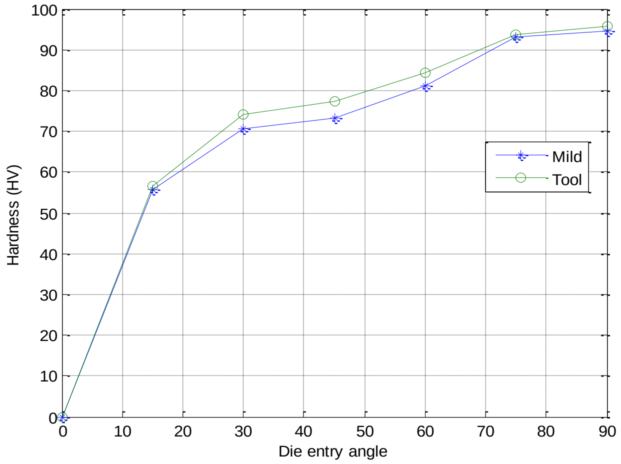


Fig.10 Hardness against die entry angle for mild and tool steel dies.

3.4 Effect on percentage elongation

Figure 11 shows that the samples extruded using tool steel die have better percentage elongation than those extruded with mild steel dies at die entry angles of 15°,30° and 60° respectively. The percentage elongation using tool steel die remains 79% at entry angles of 60°, 75° and 90°. The Figure also shows that the best percentage elongation is obtained at entry angles of 45° and 90° on mild steel die.

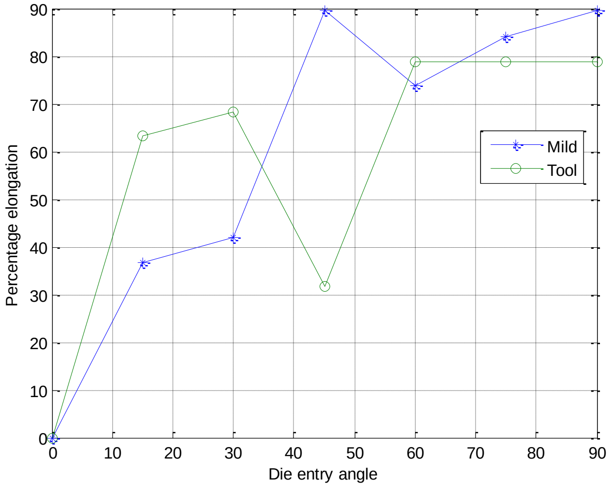
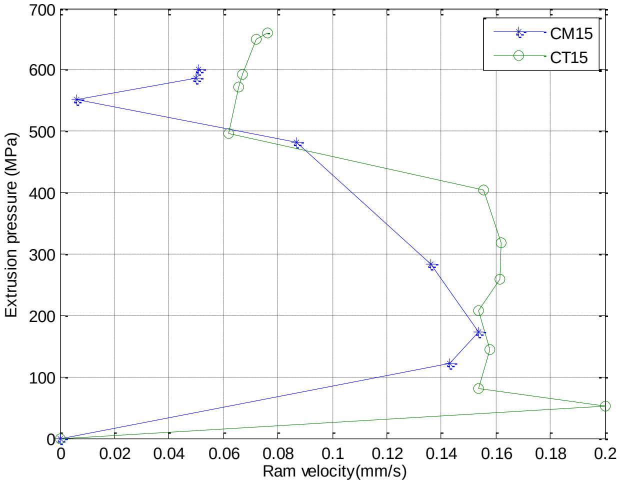


Fig.11 Percentage elongation against die entry angle for mild and tool steel dies.

3.5 Effects on ram velocity

Ram velocity reduces gradually as the extrusion pressure increases except in some instances where the reverse happens as extrusion pressure increases. This could be as a result of deformation not taking place at the same rate in the sample. Figure 12(a) shows that the ram velocity for sample extruded in tool steel of die entry angle of 15° (CT15) declined slowly compared to that extruded in mild steel of the same entry angle (CM15). This means the ram traveled with ease when CT15 is used compared to CM15. The ram velocity for CT30 reduces gradually with an increasing extrusion pressure till it becomes constant at 0.022mm/s between extrusion pressures of 300MPa and 700MPa (Figure 12(b)). There are fluctuations in ram velocity as extrusion pressure for CM30 increases. The Figure shows that the sample deforms with ease when extruded in a mild steel die of 30° entry angle than in tool steel die of the same entry angle. Samples in Figure 12(c) show a comparable response to deformation but at different extrusion pressures and ram velocities. The maximum ram velocity for CM45 is 0.011mm/s. This means for a better deformation response, CM45 is preferable. There is a gradual decrease in ram velocity for the sample extruded in mild steel die of 60° entry angle (CM60) as shown in Figure 12(d). This gradual reduction in ram velocity is also similar for CT60 until a velocity of 0.027mm/s is reached at an extrusion pressure of 317MPa.The ram velocity remains nearly constant until the maximum extrusion pressure is attained (847MPa). The ram travelled with ease on CM60° compared to CT60. Figure 12(e) shows the gradual increase in ram velocity for CM75 up to 0.208 mm/s when a pressure of 450MPa was reached. The ram velocity decreases gradually from this value (0.208mm/s) to 0.064mm/s, when the maximum extrusion pressure, 912MPa is reached. The pattern of extrusion pressure - ram velocity relationship for CT75 in Figure 12(e) is similar to that of CT60 in 12(d) (extrusion pressures and ram velocities are not similar) The ease of deforming sample with mild steel of 75° entry angle is better than that for tool steel of similar entry angle.
Ram velocity for samples extruded in mild and tool steel dies of 90° entry angle (CM90 and CT90), as revealed in Figure 12(e) decrease gradually at increasing extrusion pressure. The ram velocity for CM90 is greater than that for CT90, therefore, the ram travels with ease on mild steel die



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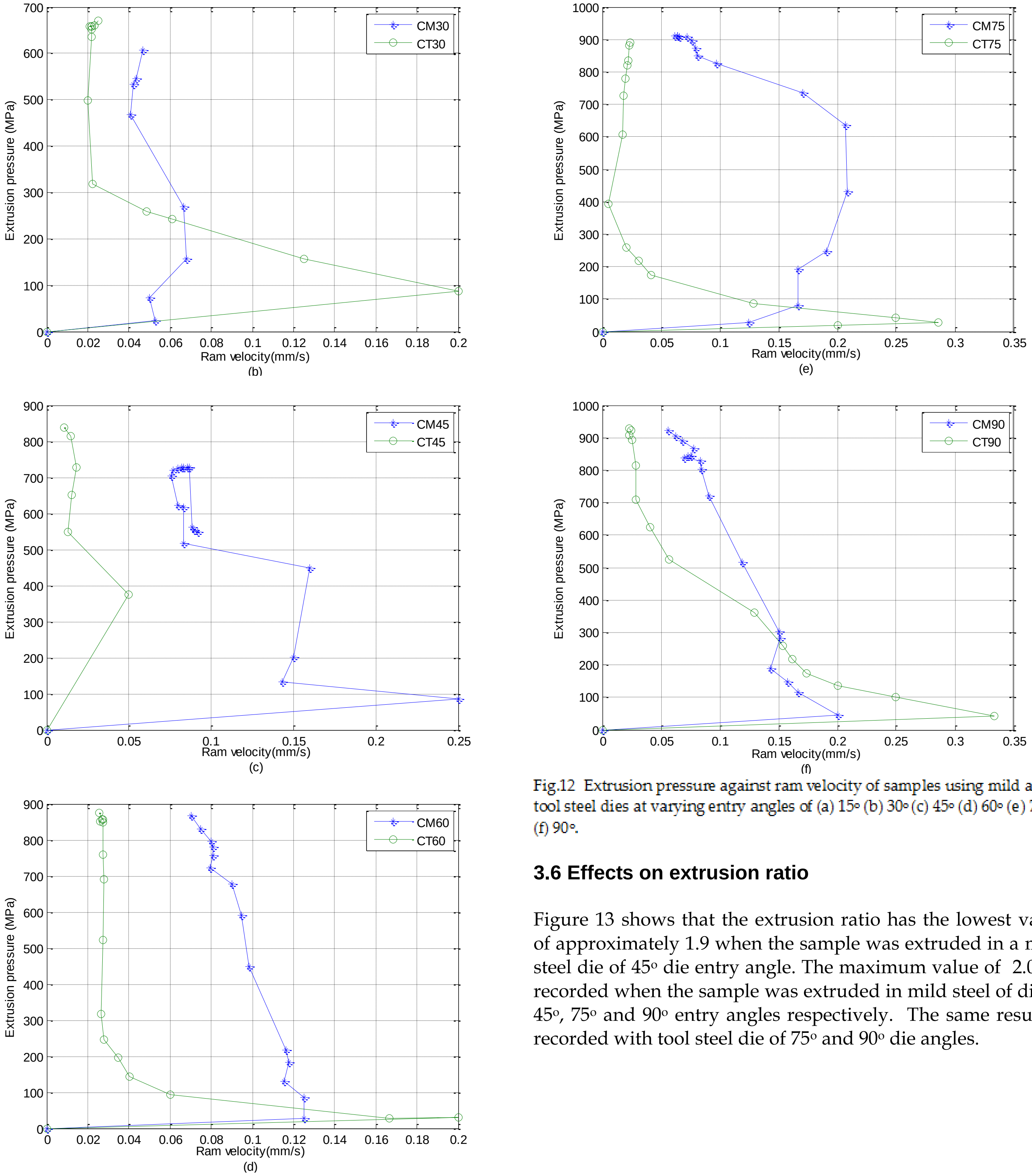

Fig.12 Extrusion pressure against ram velocity of samples using mild and tool steel dies at varying entry angles of (a) 15° (b) 30° (c) 45° (d) 60° (e) 75° (f) 90°.

3.6 Effects on extrusion ratio

Figure 13 shows that the extrusion ratio has the lowest value of approximately 1.9 when the sample was extruded in a mild steel die of 45° die entry angle. The maximum value of 2.07 is recorded when the sample was extruded in mild steel of die at 45°, 75° and 90° entry angles respectively. The same result is recorded with tool steel die of 75° and 90° die angles.

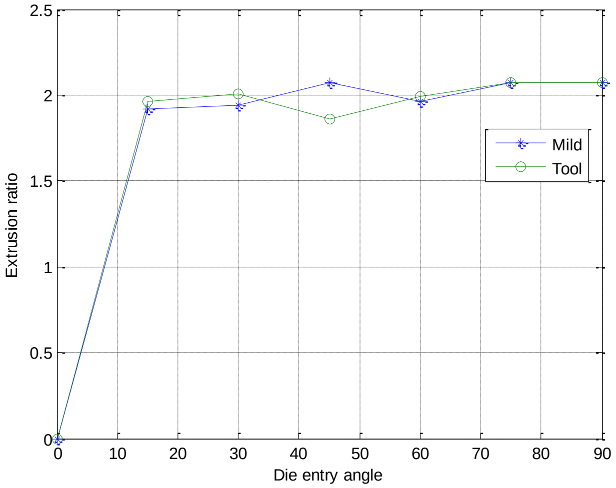

Fig.13 Extrusion ratio against die entry angles of samples using mild and tool steel dies at varying entry angles of (a) 15° (b) 30° (c) 45° (d) 60° (e) 75° (f) 90°.

4 CONCLUSION

Successful cold extrusion of 6063 aluminum alloy with mild and tool steel entry die angle was achieved. At 90°, the extruded samples have superior hardness independent of the die material. The experimental results show that aluminum alloy deforms better when the die material is made of mild steel with die entry angles of 45°, 75° and 90° than on tool steel. The percentage elongation of extruded samples at these entry angles is also superior, reason been that the ram velocity under applied pressure, is a function of the ease at which deformation takes place. Extrusion with a mild steel die at 45° entry angle (CM45) engenders ease in ram travel and this could be attributed to increase in Mg_2Si precipitates clustering in the matrix. The difference in the maximum extrusion pressure and hardness between tool steel and mild steel dies is small and considering the economy of the work, mild steel can still be used to get desirable results since it is cheaper than tool steel.

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- *Gbenebor, O.P is currently an accademic at the College of Science and Technology, Covenant University, P.M.B 1023, Ota, Ogun state, Nigeria. E-mail: gbeneborphilips@yahoo.co.uk*
- *Adeosun, S.O (Ph.D) is currently an accademic at the Faculty of Engineering, University of Lagos, Yaba, Lagos, Nigeria.*
- *Fayomi, O.S is currently a researcher at the Faculty of Engineering and Built Environment,Tshwane University of Technology, P.M.B X680, Pretoria, South Africa*
- *Joseph, O.O is currently an academic at the College of Science and Technology, Covenant University, P.M.B 1023, Ota, Ogun state, Nigeria.*