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Performance evaluation of some steels as extrusion die on AA6063-type Al-Mg-Si alloy

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This study deals with the performance evaluation of mild and tool steels, their microstructure and extrusion property associated with changes in induced dies of entry angles 15°, 45° and 75° on AA 6063-type Al-Mg-Si alloy. Based on the service requirement in extrusion operations, microhardness and wear properties are used as criteria. The extrusion operation reveals the formation of clusters, surface modification occurring as a result of various ranges of die angles. The effect of extrusion pressure, sample elongation, hardness and die speed angle are systematically studied using microhardness tester, optical microscope (OPM), scanning electron microscope with energy dispersive spectroscopy (SEM-EDS). The mild steel die enables slips and dislocation movement of the sample to take place with ease than the tool steel dies at 45° elongation. Formation of Mg_2Si and AlFeSi on mild steel extrusion has significantly influenced its mechanical properties as a result of response to increasing grain boundary which serves as nucleation site for the precipitates. The microhardness and wear resistance of extruded mild steel increased by 90%. Extrusion of the aluminum by the tool steel led to the formation of clusters and stretched along the slip directions.

Keywords: Microstructure, AA6063-type Al-Mg-Si alloy, Extrusion, Die entry angles, Dislocation

Aluminum extrusion technology continues to be a subject of evaluation concerning its application to the working environment[1-4]. The demand for and application of aluminum extrusion in architecture and in the manufacture industries have increased extremely. AA 6063-type Al-Mg-Si alloy are widely used in automobile, architectural and structural applications[5-6]. The reasons for its application in extruded form can be attributed to its good mechanical properties and physical characteristics. AA 6063 is an aluminium alloy which contains Si and Mg as the main alloying elements and it is heat treatable and weldable[4,7-11]. The essential intermetallic composites of this alloy provides better operating performance and resistance to wear and corrosion depending on the extrusion steel dies. 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 by the use of a ram[10-15]. A variety of shaped aluminum components are extruded at room temperatures to obtain good surface finishes, better dimensional consistency and improved strengths. Studies on the 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[16-18]. The type of the die used influences the mechanical properties, surface quality of the extruded profiles and the final microstructure which has been developed during the extrusion process[17-19]. However, tool steels are majorly used as die materials because of the high strength and good wear resistance they possess but these alloys are expensive when compared to the cost of manufacturing mild steel; which is readily available and cheap to form. In this study, we investigated extrusion of aluminum when mild steel is used as a die material and foresee its possibility of replacement for tool steel die at various extrusion angles for extrusion applications.

Materials and Method

Material preparation

The AA 6063 aluminum alloy used for the study was obtained from Nigeria Aluminum Extrusion

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Table 1 – Chemical composition of as-received AA6063-type Al-Mg-Si alloy

Elements	Al	Si	Mg	Fe	Cu	Mn	Ti	Cr
Composition (wt%)	95.00	0.45	0.50	0.22	0.03	0.03	0.02	0.03

Company (NIGALEX), Oshodi, Lagos, Nigeria with the chemical composition given in Table 1.

The alloy was sectioned and heated above its melting temperature of 660^{o}C before casting in a sand mould with cylindrical shape of 30 mm × 300 mm. The melt were allowed to solidify and ejected by breaking the mould. The cast samples were cleaned and machined to the shapes and sizes as shown in Fig. 1 for the extrusion process.

Die materials used for extrusion

The mild and tool steels of chemical compositions shown in Table 2, were used as the die material of which each steel was machined to form a circular end section and entry angles of 15°, 45° and 75° were made for each die material, making a total of six dies. The mild steel dies were annealed by first heating them to 850°C for 3 h. The tool steel dies were normalized by heating them to 750^{o}C where they were held for three hours before they were brought for cooling in air. The form tool and the ram, which were made of mild steel were heated at 850°C and quenched in water after been held for three hours in the furnace. This was done to increase the strength and hardness of the set up in order to prevent wear and deformation during extrusion as shown in Fig. 2.

Extrusion process

Extrusion was done at ambient temperature with 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 applied load (kN) on the ram was read on machine as a strain gauge was attached to the ram of the Avery Denison machine which measures the strain rate. Here, the time (s), taken for the indicator on the strain gauge to complete a revolution was recorded. In each revolution completed, 1 mm elongation was represented.

Microhardness test

Hardness test was carried out with Vickers micro hardness (Lecco Digital) with an applied load of 100 gf on each sample for 10 seconds dwell time. A microscope was attached to the hardness tester to

Table 2 – The chemical composition of the mild and tool steels used for the extrusion process

Elements	Mild steel composition (wt%)	Tool steel composition (wt%)
C	0.1195	0.1984
Si	0.2887	0.4398
S	0.0097	0.0101
P	0.0099	0.009
Mn	0.503	1.3888
Ni	0.0207	0.0173
Cr	0.043	0.0055
Mo	0.0052	0.0046
V	0.0065	0.041
Cu	0.0312	0.012

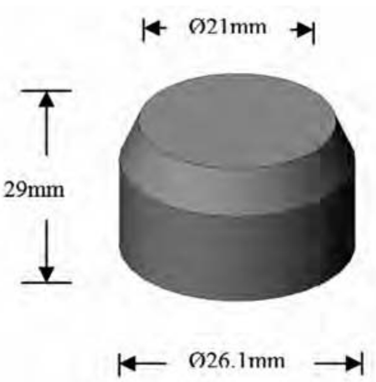

Fig. 1 – Schematic diagram of the specimen used for the extrusion operation

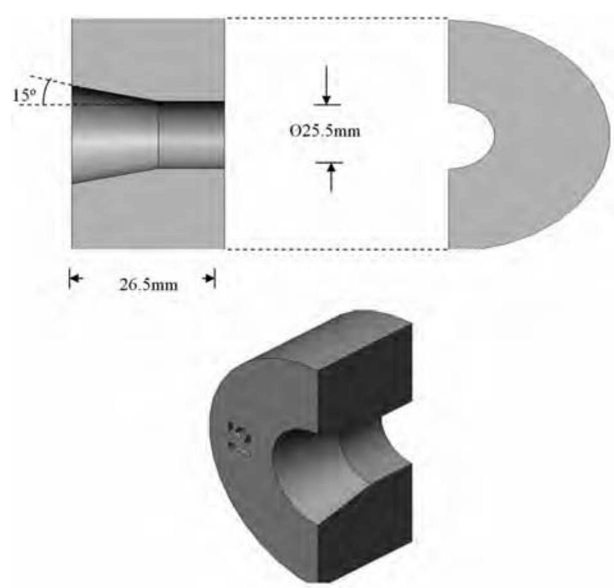

Fig. 2 – Schematic representation of the front, end and isometric view of the die with 15° entry angle

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.

Wear test

Three body abrasive wear tests were performed with ASTM-G65 dry sand rubber wheel apparatus on extruded aluminum sample for tribological study. All the samples were prepared by grinding the surfaces with 1200 µm grit SiC abrasive papers to ensure a common roughness and finishes. Silica sand with a particle size distribution between 300-600 microns was used as the abrasive material which was set to a flow rate of 7.89 g/s. An applied load of 20 N and rotational wheel speed of 120 rev/min was used. All samples were abraded for 30 min to evaluate the wear rates.

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 µm emery papers. The smoothened surfaces of these samples were polished and etched with waterman solution of 5 g of sodium hydroxide (NaOH) dissolved in 100 mL of water. The etched samples were finally examined under a metallurgical microscope at a magnification of ×10.

Results and Discussion

Characterization of the substrate material

The chemical composition of the extruded mild and tool die using spectrometer is shown in Table 2. The SEM micrograph of AA6063 aluminium alloy as-received sample is shown in Fig. 3.

Effects of die material on extrusion pressure and elongation

The sample extruded with mild steel die at entry angle (α) of 15^o (CM 15), exhibited a higher extrusion pressure over that with tool steel die at entry angle (α) of 15° (CT15) within an elongation of 0 and 0.38, which yielded at a lower pressure as shown in Fig. 4. The 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. The maximum pressure needed to deform CT15 is higher at 660 MPa, compared to 600 MPa for CM15. In Fig. 5 Hooke's law is obeyed until an extrusion pressure of about 86 MPa was attained at a small elongation of 0.05 for sample extruded with mild steel die at entry angle (α) of 45° (CM45) while sample extruded with tool steel die at entry angle (α) of 45° (CT45) obeyed this law up to a pressure of 375 MPa with similar sample elongation as shown in Fig. 4. 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. Sample extruded with mild steel die at entry angle (α) of 75° (CM75) had a better response to elongation than sample extruded with tool steel die at entry angle (α) of 75° (CT75) as shown in Fig. 6. The maximum pressure to deform CM75 is 912 MPa and this is greater than that which deformed CT75 (890 MPa).

Effect of die material on microstructure

Sample CT15 shows existing fine Mg_2Si crystals at the grain boundaries which are along the slip directions 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 intermetallic compounds as shown in Fig. 7.

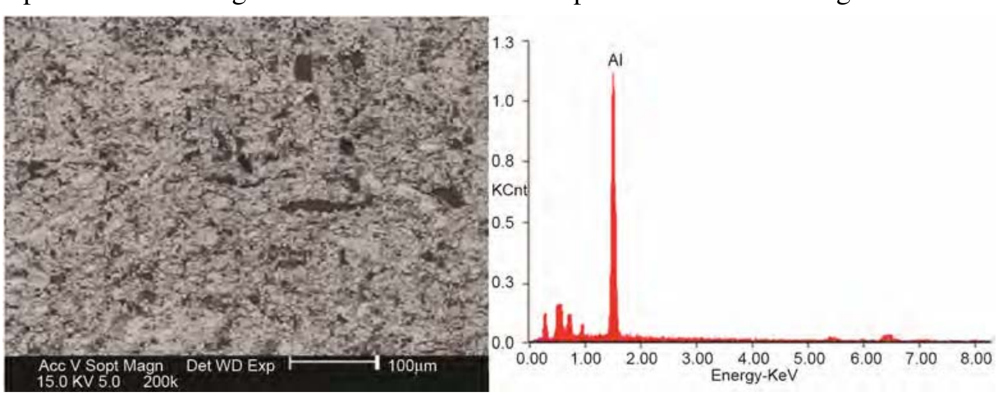

Fig. 3 – SEM micrograph of AA6063 aluminium alloy as-received sample

The structures show fine crystals of α-aluminum, AlFeSi and other phases. There is an increase in Mg_2Si precipitates in clustered form in the matrix with some of them being formed along the slip direction. In Fig. 8, an increase in the proportion of Mg_2Si at grain boundaries with increase in AlFeSi was noted in sample CT45° which also influenced the flow of the die. The slip lines are not as pronounced as the sample extruded in CM45.

The Mg_2Si crystals in Fig. 8 are at the grain boundaries in clustered form and stretched along the slip directions. The crystals of α-aluminum, AlFeSi and other phases have similar volume fractions. This is similar to the result obtained elsewhere[17]. In Fig. 9, CT75 shows that there is reduction in the clustering of Mg_2Si when compared to CM75 with its precipitates being much finer and well distributed in varying shapes ranging from needle-like to spherical. The

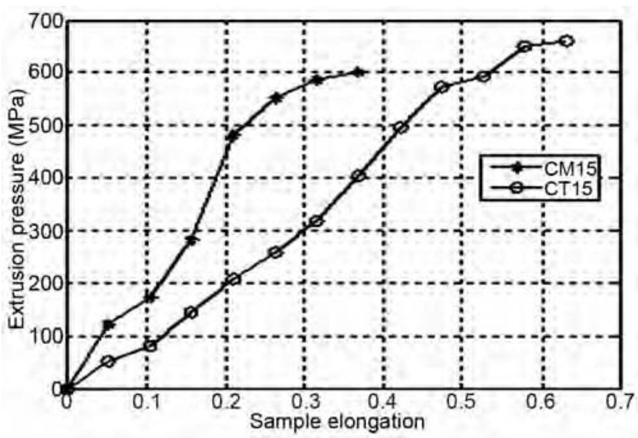

Fig. 4 – Variation of extrusion pressure with sample elongation using mild and tool steel dies at 15° entry angle

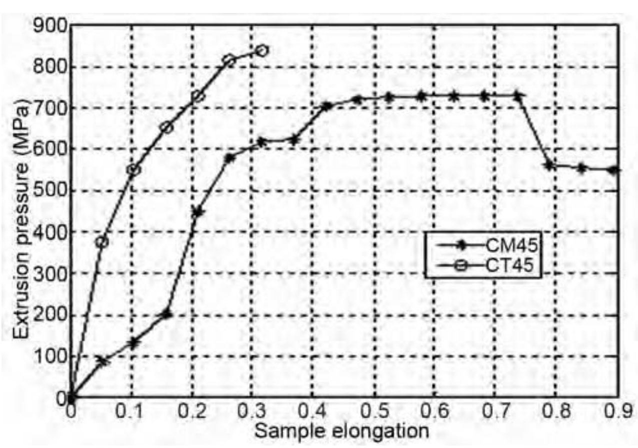

Fig. 5 – Variation of extrusion pressure with sample elongation using mild and tool steel dies at 45° entry angle

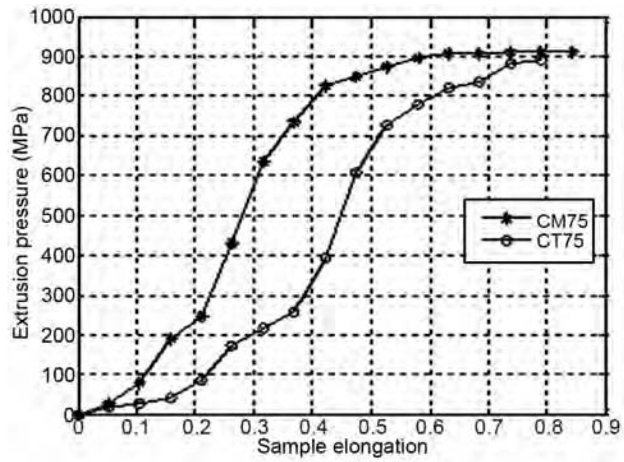

Fig. 6 – Variation of extrusion pressure with sample elongation using mild and tool steel dies at 75° entry angle

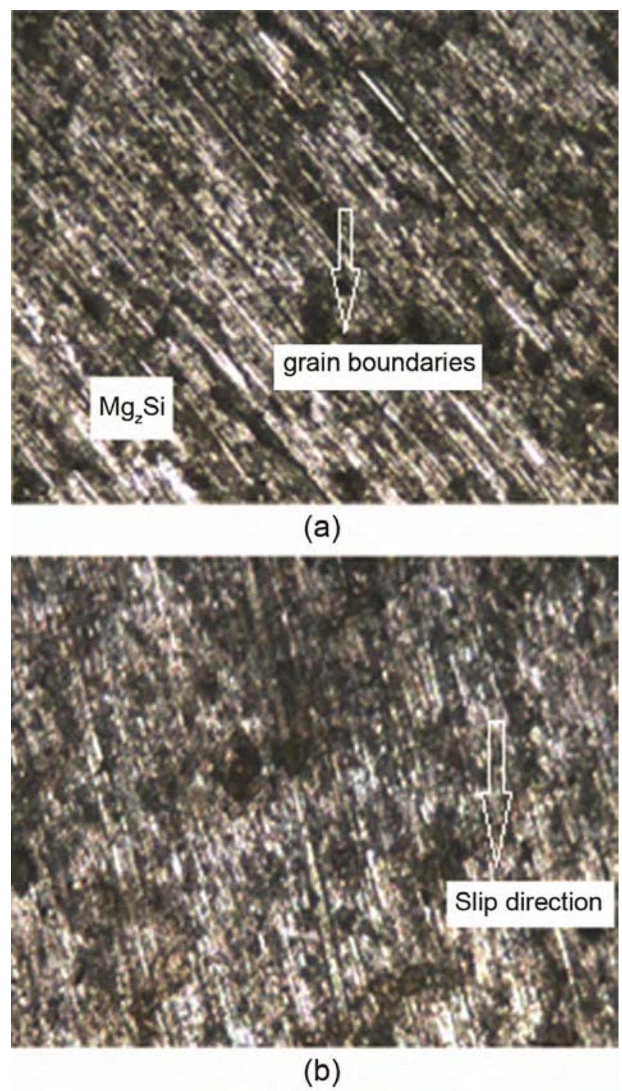

Fig. 7 – Micrograph of extruded samples for die of 15° entry angle using (a) mild steel and (b) tool steel

fineness of aluminum, AlFeSi and fourth phases are maintained. Figure 9 reveals that the Mg_2Si precipitates are at the grain boundaries in clustered form with increase in its volume fraction in comparison with the previous ones. Crystals of α-aluminum AlFeSi and the fourth phases are fine in the matrix. The volume fraction of AlFeSi and phases remained the same.

Effect of die material on hardness

From Fig. 10, it can be seen that the hardness of each extruded sample increases as the entry angle increases. Samples extruded on tool steel dies had slightly greater hardness values than those extruded on mild steel dies. The hardness values for the die materials at 75° are almost the same.

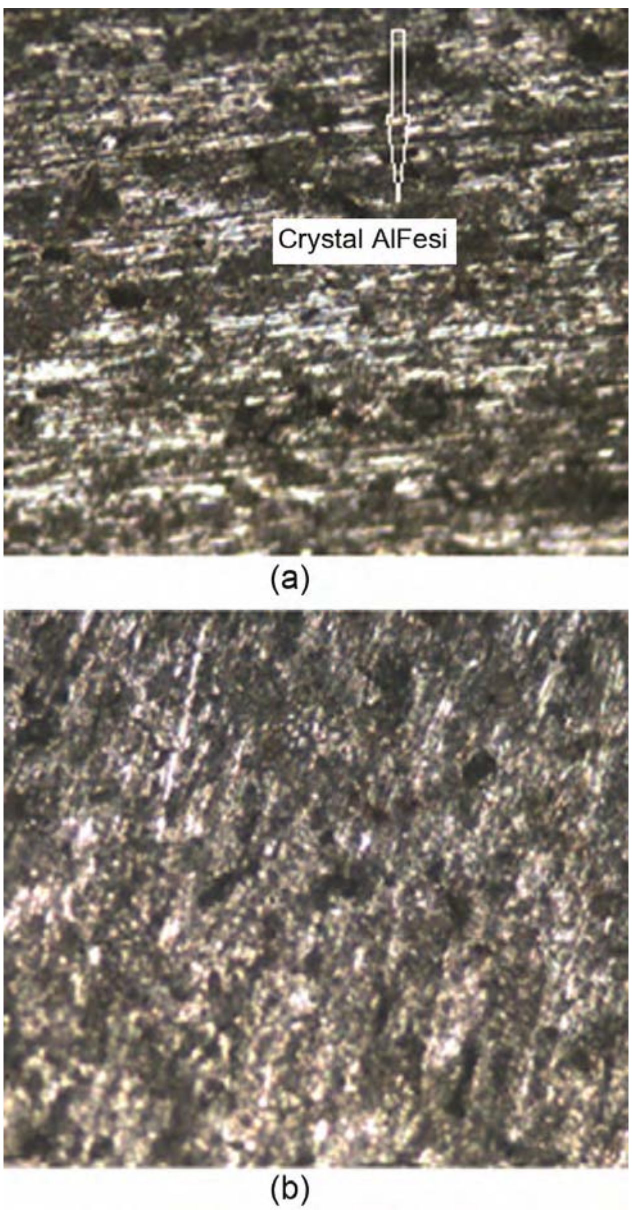

Fig. 8 – Micrograph of extruded samples for die of 45° entry angle using (a) mild steel and (b) tool steel

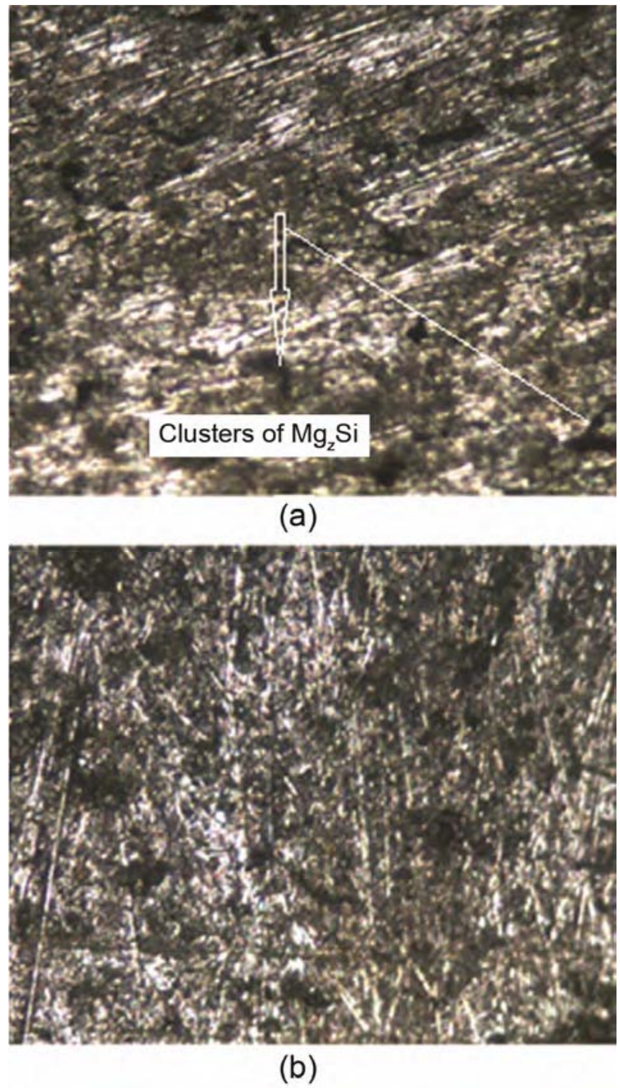

Fig. 9 – Micrograph of extruded samples for die of 75° entry angle using (a) mild steel and (b) tool steel

Fig. 10 – Variation of hardness with die entry angle at 75°

Effect of die material 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°. The percentage elongation using tool steel die remains 79% at entry angles of 75°. Figure 11 also shows that the best percentage elongation is obtained at entry angles of 45° on mild steel die which was due to the easy movement obtained from the mild steel die.

Effect of die material on ram velocity

Ram velocity reduces gradually as the extrusion pressure increases except in some instances where the reverse happened as extrusion pressure increases. This is in agreement with the observation reported elsewhere[2]. This could be as a result of deformation not taking place at the same rate in the samples. Figure 12 shows that the ram velocity for sample extruded with 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 that the ram traveled with ease when CT15 is used compared to CM15. The maximum ram velocity for CM45 is 0.011 mm/s as shown in Fig. 13 which indicated a better deformation response than CM45. Figure 14 shows the gradual increase in ram velocity for CM75 up to 0.208 mm/s when a pressure of 450 MPa was reached. The ram velocity decreases gradually from this value (0.208 mm/s) to 0.064 mm/s, when the maximum extrusion pressure of 912 MPa was reached. The ease of deforming sample with mild steel of 75° entry angle is better than that of tool steel of similar entry angle.

Effects of die material on extrusion ratio

Figure 15 shows the influence of extrusion ratio against die entry angle. It is evident that the extrusion ratio has the lowest value of approximately 1.9 when the sample was extruded in a tool steel die of

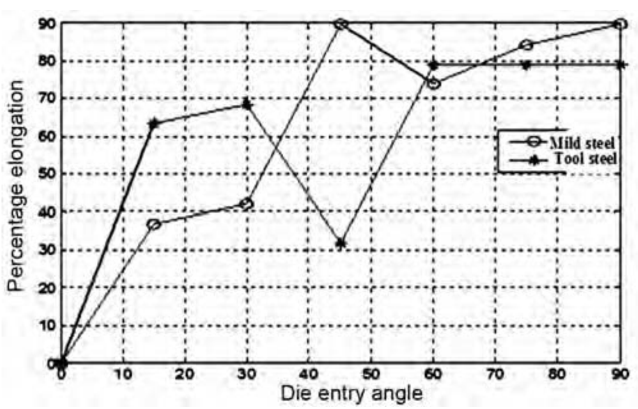

Fig. 11 – Variation of percentage elongation with die entry angles

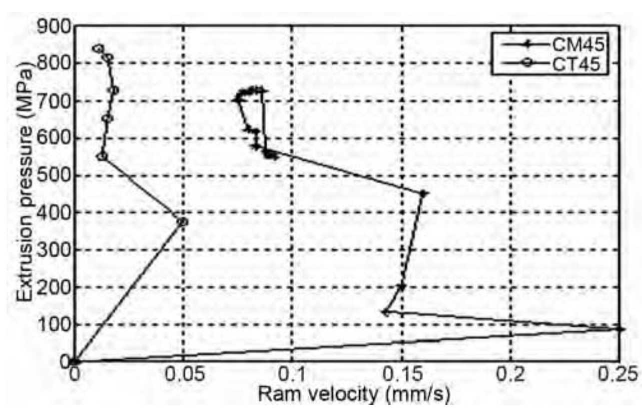

Fig. 13 – Variation of extrusion pressure with ram velocity of samples using mild and tool steel dies at 45° entry angle

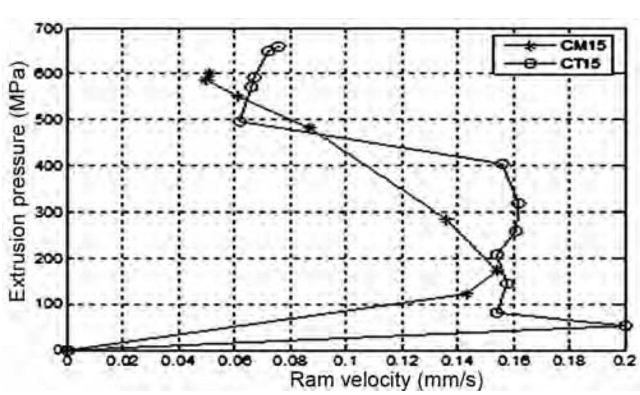

Fig. 12 – Variation of extrusion pressure with ram velocity of samples using mild and tool steel dies at 15° entry angle

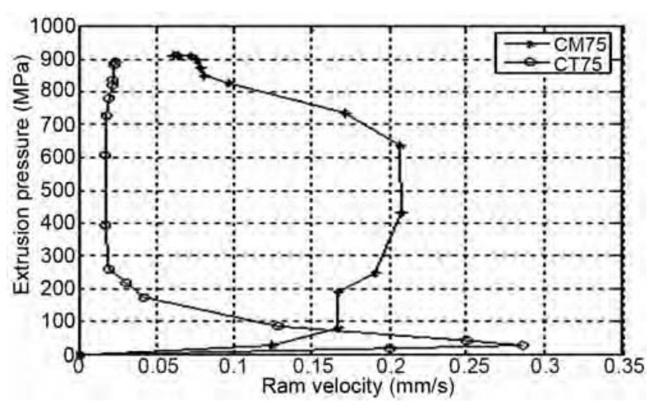

Fig. 14 – Variation of extrusion pressure against ram velocity of samples using mild and tool steel dies at 75° entry angle

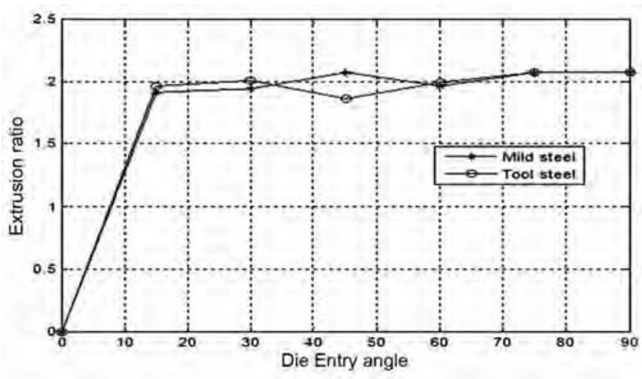

Fig. 15 – Variation of extrusion ratio with die entry angle

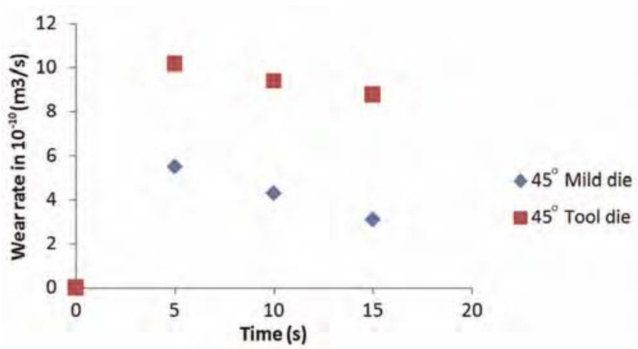

Fig. 16 – Variation of wear rate with abrasion time for mild and tool dies at 45° entry angle

45° entry angle. The maximum value of 2.07 was recorded when the sample was extruded in mild steel of die entry angles 45° and 75° respectively. The same result was recorded with tool steel die of 75° die entry angles.

Effect of wear along extrusion direction

Figure 16 shows the variation of wear rate as a function of time for AA 6063 sample extruded with mild and tool steel dies at entry angle 45°. The rate of wear significantly increased to a large extent initially for tool steel die before a gradual decline. This occurrence may be attributed to the degree of die penetration. However, for mild steel die, the rate of wear is significantly lower than that of tool steel die.

Subsequent to the wear rate evaluation, morphological behavior (Fig. 17) attests to better performance with lesser degree of deformation observed on the worn surface of the AA6063 alloy of mild steel die compared to tool steel die with massive grooves and debris. This shows that the wear mechanism and resistance exhibited by the extruded aluminum alloy at die entry angle of 45° in mild steel was attained because of the increase in the proportion of Mg_2Si at the grain boundaries.

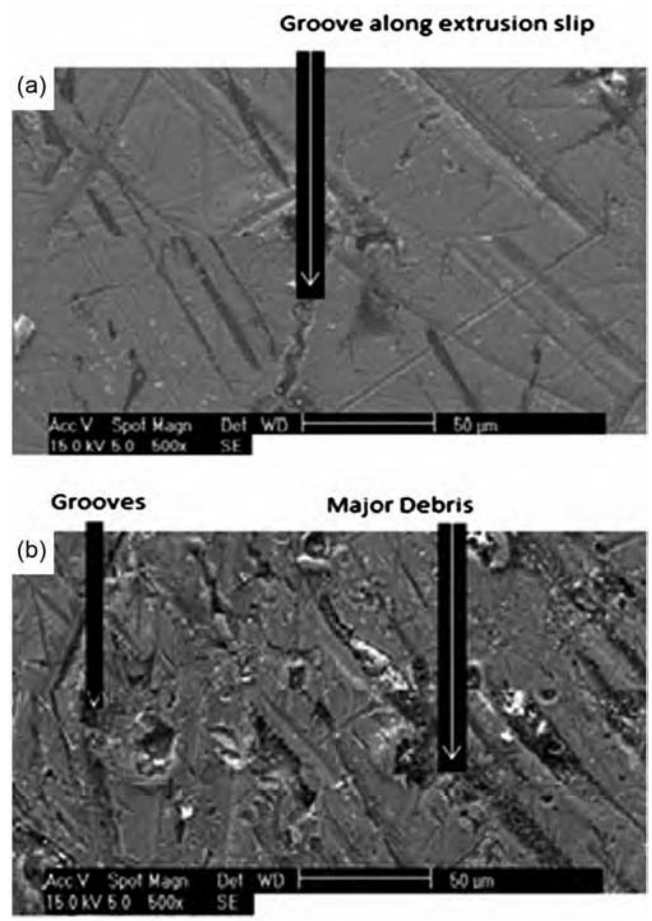

Fig. 17 – SEM micrographs of wear scars morphology at 45° entry angle (a) mild steel and (b) tool steel dies

Conclusions

Effective cold extrusion of 6063 aluminum alloy with mild steel entry die angle is achieved. The experimental results show that aluminum alloy deforms better when the die material is made of mild steel with die entry angles of 45° and 75° than tool steel. The percentage elongation of extruded samples at these entry angles is also superior, reason being 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 of 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 comparatively less 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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