Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2018, 5(3): 170-175

Research Article ISSN: 2394 - 658X

Effect of Die Angle and Reduction Ratio on the Pressure and Hardness of Extruded Al-Mg-Zn Alloy

Oryina Mbaadega Injor, Alex Okibe Edeoja and David Terfa Gundu

Department of Mechanical Engineering, University of Agriculture, Makurdi, Nigeria
aoedeoja@gmail.com

ABSTRACT

In this paper, the effect of die angle and reduction ratio on the pressure and hardness of extruded Al-Mg-Zn alloy was investigated. Medium carbon steel dies with entry angles of 75°, 90°, 105°, 120°, 150° and reduction ratios of 0.21, 0.40, 0.48 and 0.62 were used to extrude the alloy at temperature of 500 ^{0}C. The extruded samples were subjected to hardness test using Vickers hardness testing method. The hardness numbers at 200 g load applied using 10 seconds dwell time indicated improvement in the hardness of the extruded alloy. The hardness increased with increase in the die angle and reduction ratio while the extrusion pressure reduced with increase in die angle to a minimum of 90° die angle and then gradually increased with further increase in die angle. A two-factor ANOVA of the extrusion load and pressure with the other variables of the alloys at 0.05 % significance all show significant differences. The results indicate good information for use in the design of dies for applications in extrusion.

Keywords: Al-Mg-Zn alloy, die entrant angle, Die reduction ratio, Extrusion, Extrusion load, Extrusion pressure, Hardness, Medium carbon steel dies

---

INTRODUCTION

There has been considerable interest in the investigation on the effects of die geometry and other extrusion parameters on the extrusion pressure, flow patterns and mechanical properties of shaped sections [1-4]. Mechanical working processes such as rolling, forging, extrusion, drawing, pressing, etc are the major processes for obtaining engineering component requirements as a result of the permanent changes in the shape of the material under the action of external forces. Geometrical characteristics of the extrusion die influence both the extrusion process and the mechanical properties of the extruded material. Experimental investigations have been made to achieve the effect of die reduction ratio, die angle and loading rate on the quality of extruded parts, extrusion pressures and flow patterns for both lead and aluminium [5].

Optimization of metal flow is very important as it directly affects mechanical properties, extrusion speed and surface finish of the extruded products [6]. Previous research has shown that extrusion die geometry, frictional conditions at the die billet interface and thermal gradients within the billet greatly influence metal flow in extrusion [7-8]. 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 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. New heat treatments of the Al-Mg-Zn-Cu alloys can improve the hardness, optimum mechanical properties which change the microstructure of the alloy in order to obtain the desired properties [9].

Microstructure improvement can be obtained by mechanical forming processes. Investigations have shown that environmentally friendly process of powder compacting followed by hot extrusion, destroyed dendrites and formed deformation structures with grain size of 1–1.5l m [10]. Several other studies have shown that extrusion flow conditions, owing to varying die bearing parameters, are affected by the die geometry, and this also affects the resulting microstructure and hardness of the extruded metal [11].

In this paper, effects of extrusion die angle on Al-Mg-Zn alloy were evaluated. The extrusion loads were measured using compressive testing machine and dividing it with the area of the billet gives the extrusion pressure. The hardness values were determined using Vickers hardness testing technique. Measurements were carried out using a rotated measuring screen and two readings were taken at right angles and the average was used to determine the hardness number (H_D).

DESIGN, MATERIAL, PROCEDURE, TECHNIQUE OR METHODS

Square billets of 25.4 mm diameter and 25.4 mm length were cut from cast and machined samples of Al-Mg-Zn alloy whose composition as obtained by Atomic Absorption Spectrometry (AAS) elemental composition of the alloy are given in Table 1. Extrusion dies with entry angles of 75°, 90°, 105°, 120°, 150° and reduction ratios of 0.21, 0.40, 0.48 and 0.62 were used.

The aluminium alloy was melted and cast in sand moulds to ϕ26 mm. Extrusion billets were machined to ϕ25.4 mm x 25.4 mm. The experimental extrusion rig was used for the extrusions, and extrusion billets were directly extruded on the manual ELE Compact-1500 hydraulic compression testing machine as shown on Figure 1.

Micro-hardness test (Hv) was carried out on both the as-cast and the extruded samples in order to evaluate the extent of structural distortion suffered during extrusion. This was done using a LECO 320 Vickers hardness tester with 200 g load applied for 10 seconds dwell time, with hardness tester having an attached microscope to view the accuracy in the alignment between the indenter and the specimen geometry and three readings were taken on each sample, and the average value recorded.

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 aluminium 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 micro-structured features were examined using an AX 10 model optical microscope at x100 magnification.

Table 1 - AAS Elemental Composition of Al-Zn-Mg Alloy

Element	Si	Cu	Mg	Zn	Al	Others
Chemical Composition (%)	0.64761	0.00791	6.07461	11.01782	80.01173	2.24032

Fig. 1 Extrusion setup

RESULTS AND DISCUSSION

The extrusion load versus ram displacement curves for Al-Mg-Zn alloy is shown in Figure 2 at various die reduction ratios. From the curves, only two stages are indicated namely; coring and steady stages. This is because the extrusions were controlled to avoid getting to the unsteady stage. The unsteady stage is characterized by a rapid increase in extrusion loads as the ram or dummy approaches the die surface. The highest extrusion load was 340 MPa while the least was 153 MPa. This could be attributed to higher resistance to deformation offered by the dry samples of the alloy as a result of friction [5].

Figure 3 shows the variation of extrusion pressure with die angle. The result indicates that increasing die angle reduced extrusion pressure to a minimum value of 90° die angle, and then increased gradually with further increase in die angle. The reduced extrusion pressure at 90° die angle is due to the least redundancy energy at the shear angle of 45° for most metals by which extrusion flow is mostly by slip [14]. It is also observed that extrusion pressure is higher for entrant angles below 90° as shown in figure 3.

Figure 4 shows the variation of hardness with die angle and figure 5 shows micro-hardness and die reduction ratios. The hardness of extrudates increased with increase in the die angle. The highest hardness was obtained in die angle

90° while the least was seen in die angle 60° as shown in figure 4. However, the relatively higher hardness exhibited by extrudates can be attributed to the hardening effect of $Al_2Mg_3Zn_3$ intermetallic such that the ease in dislocation motion reduces gradually as the die entry angle increases [15] while in the case of reduction ratio, R the hardness also increases as the reduction ratio increases as shown in figure 5.

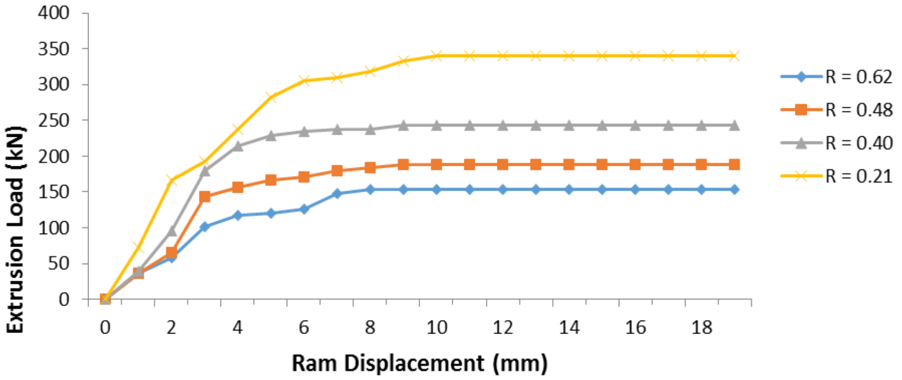


Fig. 2 Plot of Extrusion Load versus Ram Displacement for Lubricated Samples

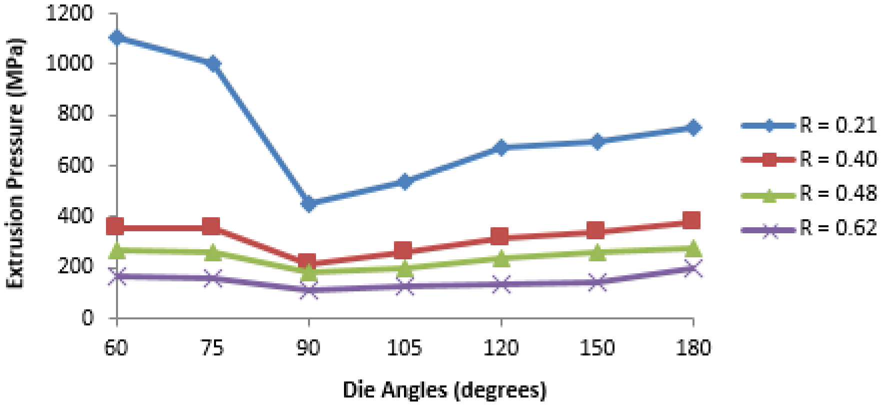


Fig. 3 Plot of Extrusion Pressure against Die Angles

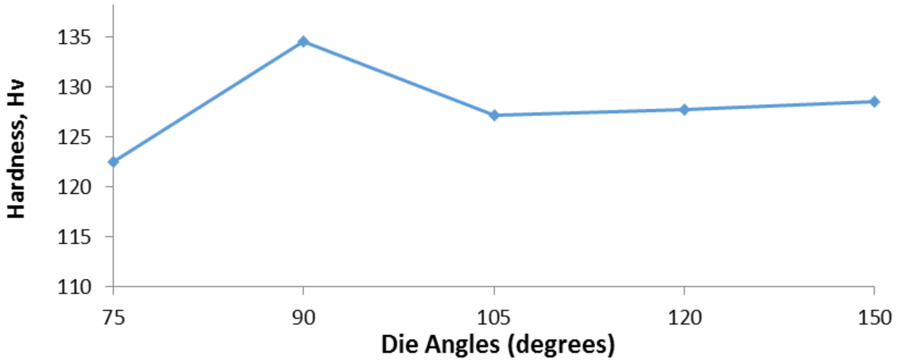


Fig. 4 Plot of Micro-Hardness against Extrudates of various Die Angles

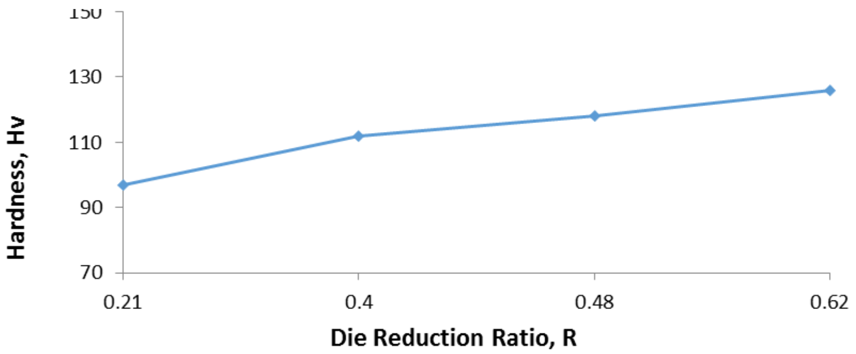


Fig. 5 Plot of Micro-Hardness against Extrudates of various Reduction Ratios

Figure 6 shows the variation of extrusion pressure with die reduction ratio for dry and lubricated samples. The result showed that die reduction ratios have significant influence on extrusion pressure. The results indicate that increasing die reductions reduced the extrusion pressure. Under dry condition, the extrusion pressure reduced from 506 Mpa for reduction ratio of 0.21 to 126 Mpa for reduction ratio of 0.62, while under lubricated condition, the extrusion pressure reduced from 450 Mpa to 112 Mpa. The results are similar to those obtained using homogenized and rapid quenched AA 6061 aluminium alloy [16], in hot extrusion process [17]. Figure 7 compares the values of maximum extrusion loads for various reduction ratios for both dry and lubricated samples. For the extrusion of lubricated samples using shear butter as lubricant, the average maximum extrusion load was 231.25 kN while for dry extrusion, it was found to be 260 kN which indicates an 11.06 % reduction in extrusion load. It is then obvious that shear butter has a great potential as a substitute lubricant in the extrusion of Al-Mg-Zn alloy [18].

Figures 8 and 9 show micro-graphs of samples extruded at various angles. The presence of Al_6CuMg_4, $Al_2Mg_3Zn_3$, AlCuMg, $MgZn_2$, Al_2Cu and $MgZn_2$ phases in the alloy micro-structure have been proven to influence the qualities and characteristics of its extruded products [12]. The micro-structures are constituted mainly by columnar dendrites of α-Al with small τ ($Al_2Mg_3Zn_3$) precipitates and eutectic (α + τ) in inter-dendritic regions, [13] as shown in Figures 7 and 8 respectively. The backscattered electron images reveal a relatively dark matrix within areas of intense precipitation of the Zn–Mg base phases compared with other areas. The structure of Figures 8(c) and 9(d) shows a pore-free matrix with many fine precipitates which are usually smaller indicating better properties.

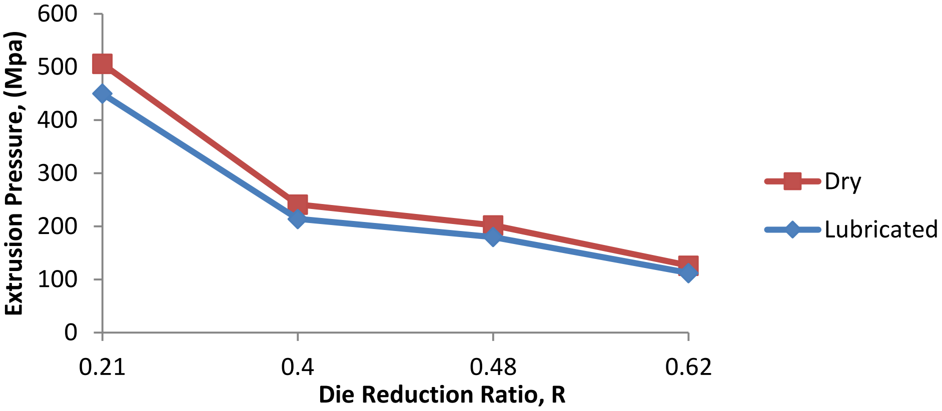


Fig. 6 Plot of Extrusion Pressure against Die Reduction Ratios for Dry and Lubricated Samples

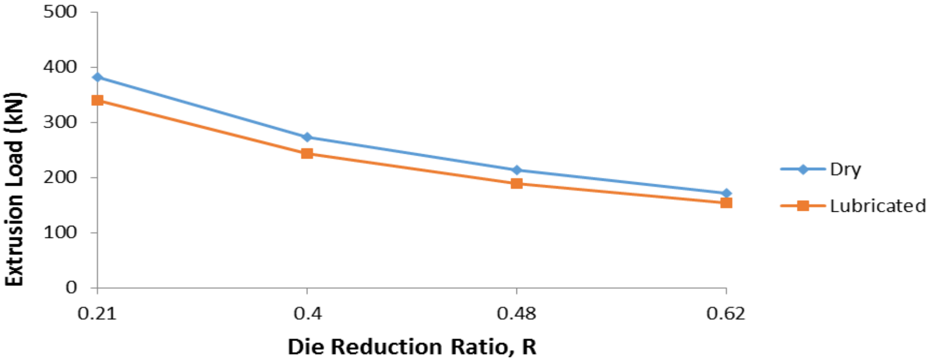
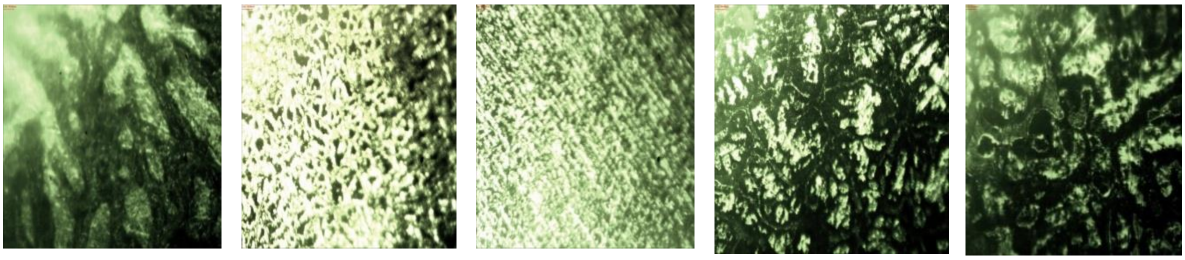


Fig. 7 Plot of Extrusion Load against Die Reduction for Dry and Lubricated samples



(a) (b) (c) (d) (e)

Fig. 8 Micrographs of samples extruded at various die angle showing varying morphologies with α-Al matrix (a) As cast (b) 75^0 (c) 90^0 (d) 105^0 (e) 120^0

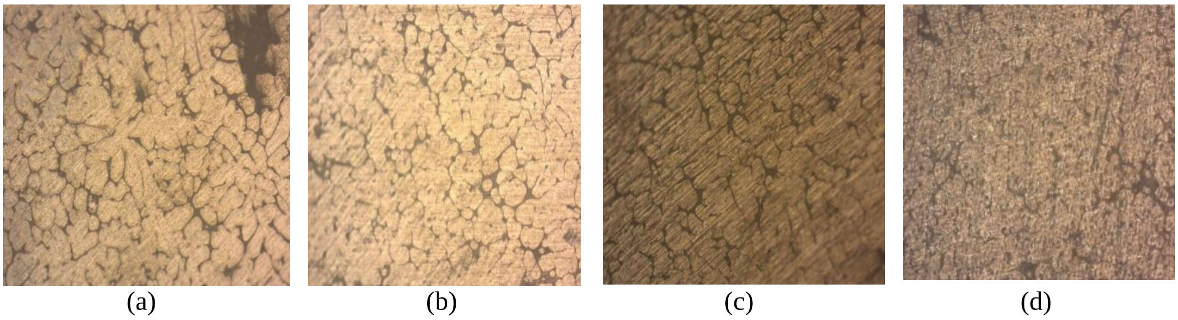


Fig. 9 Micrographs of samples extruded at various reduction ratio, R showing varying morphologies with α-Al matrix (a) R = 0.21 (b) R = 0.40 (c) R = 0.48 (d) R = 0.62

Table 2 - Two Factor ANOVA for Extrusion Load for Ram Displacement at Various Die Ratios

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	356223.3	20	17811.17	29.60849	7.51E-24	1.747984
Columns	287783.1	3	95927.71	159.466	1.52E-28	2.758078
Error	36093.36	60	601.556			
Total	680099.8	83				

Table 3 - Two Factor ANOVA for Extrusion Pressure at various Die Angles and Reductions for Samples of Al-Mg-Zn Alloy

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	1008324	3	336108	51.71343	3.83E-08	3.287382
Columns	115899.8	5	23179.97	3.56646	0.025247	2.901295
Error	97491.5	15	6499.433			
Total	1221715	23				

Table 2 shows the analysis of variance (ANOVA) at 0.05% significance for extrusion load for ram displacement at various die ratios for the samples of Al-Mg-Zn alloy while Table 3 shows the one for extrusion pressure at various die angles and reductions for the samples at the same level. The results for the extrusion load for ram displacement at various die ratios indicated statistically significant differences for the various parameters. The same results are indicated for extrusion pressure at various die angles and reductions. They indicate that the hardness of the alloys is affected by the die angle and reduction ratios.

CONCLUSION

The study has shown that the hardness of Al-Zn-Mg alloy is affected by both die entrant angle, die reduction ratio and the extrusion pressure. However, while there is improvement in the hardness of the extruded alloy, the hardness does not follow a particular pattern under extruded condition as it was higher with die angle 90° accompanied by relatively low extrusion pressure, and lower with die angle 60° yielding higher extrusion pressures. Conversely, the hardness increased with increase in reduction ratio.

Acknowledgements
The whole aspects of the research were funded by the authors. The contributions of the laboratory staff of Departments of Mechanical and Civil Engineering in University of Agriculture, Makurdi, Nigeria is highly appreciated by the authors.

REFERENCES

[1] RK Goswami, RC Anandani, R Sikand, IA Malik and AK Gupta, Effects of extrusion parameters on mechanical properties of 2124AI-SiCp stir cast MMCs, *Materials Transactions. Japanese Institute of Metals*, **1999**, 40(3), 254-257.
[2] Pacanowski and J Zasadzinski, The Effect of Selected Parameters of Aluminium Extrusion on Temperature Changes in the Die System, *Archives of Metallurgy*, **1998**, 43(4), 389-398.
[3] D Schmoeckel, GF Vonschlotheim and A Wansel, Evaluation of the Cold Extrusion Production Process, *1st International Symposium on Environmentally Conscious Design and Inverse Manufacturing*, **1999**, 186, 414-419.
[4] K Karhausen, AL Dons and T Aukrust, Microstructure Control during Extrusion with Respect to Surface Quality, *Materials Science Forum*, **1996**, 217-222, 403-408.

[5] SO Onuh, M Ekoja and AB Adeyemi, Effects of Die Geometry and Extrusion Speed on Cold Extrusion of Aluminium and Lead Alloys, *Journal of Materials Processing Technology*, **2003**, 132, 274-285.
[6] I Flitta and T Sheppard, Nature of Friction in Extrusion Process and its Effect on Material Flow, *Materials Science and Technology*, **2003**, 19, 837-846.
[7] T Altan, SI Oh and H Gegel, *Metal Forming; Fundamentals and Applications*, American Society for Metals, Metals park, Ohio, **1983**.
[8] J Piwnik and K Mogielnicki, The Friction Influence of Stress in Micro Extrusion, *Archives of Foundry Engineering*, **2010**, 10(1), 451-454.
[9] HT Naeem, KS Mohammed, KR Ahmad and A Rahmat, Corrosion Behavior of the Al-Zn-Mg-Cu Alloys with Nickel Additions, *Digest Journal of Nanomaterials and Biostructures*, **2014**, 9(4), 1309 – 1315.
[10] AV Sameljuk, OD Neikov, AV Krajnikov, YV Milman and GE Thompson, Corrosion Behavior of Powder Metallurgical and Cast Al–Zn–Mg base alloys, *Corrosion Science*, **2004**, 46, 147–158.
[11] T Gundu, L Tuleun and O. Injor, Effect of Pocket Die Bearing Geometry on Direct Cold Extrusion Process Responses, *American Journal of Mechanical Engineering*, **2014**, 2(3), 65-69.
[12] H Ahmed, AR Eivani, J Zhou and J Duszczyk, Aluminum Alloys: Fabrication, Characterization and Application, *Symposium TMS Annual Meeting*, New Orleans, **2008**.
[13] JO Alvarez, C Gonzalez, G Aramburu, R Herrera and JA Juarez-Islas, The Effect of Adding Different Mg Contents to an Al-12wt% Zn Master Alloy, *Materials Science and Engineering A*, **2005**, 402, 320-324.
[14] J Chakrabarty, *Theory of Plasticity*, Int. Ed, McGraw-Hill Inc., **1987**, 791.
[15] SO Adeosun, OI Sekunowo and OP Gbenebor, Effect of Die Entry Angle on Extrusion Responses of Aluminum 6063 Alloy, *International Journal of Engineering and Technology*, **2014**, 4(2), 127-134.
[16] S Karabay, M Yilmaz and M Zeren, Investigation of Extrusion Ratio Effect on Mechanical Behaviour of Extruded Alloy AA 6061 from the Billets Homogenized-Rapid Quenched and as Cast Condition. *Journal of Materials Processing Technology,* **2005**, 160(2), 138-142.
[17] GA Lee, DY Kwak, SY Kim and YT Im, Analysis and Design of flat-die hot extrusion process. Three-dimensional finite element analysis. *Journal of Mechanical Sciences*, **2002**, 44, 915- 934.
[18] F Fereshteh-Saniee, M Karimi and M Sabzalipor, An investigation on the Effects of Process Variables on the required load in Axisymmetric Forward Rod Extrusion, *3rd International Conference on Integrity, Reliability and Failure*, Porto/Portugal, **2009**, Paper Ref: S2411_P0348.