THE IMPACT OF CIRCULAR DIE PROFILES ON PARAMETERS OF LABORATORY EXTRUSION

Shettima, I.I.[1*], Hammajam, A.A.[1,2], Onuh, S.O.[1] and Kolo, L.A.M.[3]

[1]Department of Mechanical Engineering, University of Maiduguri, Borno state, Nigeria

[2]Department of Mechanical Engineering, Nigerian Army University Biu Borno State, Nigeria

[3]Department of works, Physical Planning and Development, University of Maiduguri, Borno State, Nigeria

*Corresponding email: ibrahimisashettima2019@gmail.com

ABSTRACT

In order to improve the hardness property and quality of extrudates products under metal flow conditions, and investigate into extrusion pressures and defects (piping and deflection). The study aimed to investigate the impacts of die profiles and land, die shape, inner extrusion pressure ratio and ram pressure on die reduction in area using experimental means. An experimental test was conducted using designed, modified and constructed laboratory extrusion rig and scrap lead metal from automobile batteries. The scrap had a lead metal yield strength of 17 Mpa and was cast and machined to billets diameter of 24.5 mm by 24 mm lengths. The die diameters used to extrude the billet were 11 mm, 15 mm, 16 mm, 20 mm, and 22 mm. The impacts of inner extrusion pressure ratio, P_i/σ_f *on die reduction in area* $R^*=1/(1-r)$ *was observed. It showed that the inner extrusion pressure ratio increased from 0.85 to 2.68 for die reduction in area of (1.23 to 2.68). Hence the results for inner extrusion pressure ratio on die reduction in area increases significantly with increase in die profiles as well as die shape. The die land influences increase in inner extrusion pressure. The correlation coefficients of* P_i/σ_f *along its regression line was calculated and the plane-strain equation was used to evaluate the reliability of the results which showed* $a' = 0.56$ *and* $b' = 1.36$ *for inner extrusion pressure which are satisfactory. The study also examined the impact of ram pressure on die reduction in area for piping, radius of curvature, and hardness properties of extrudates. The results finding indicated that, an increase in ram pressure led to an increase in both piping and radius of curvature, and the hardness of the extrudates improved, with average hardness values of* $66.8R_C$ *for* $R^* = 0.21$ *compared to* $52.2R_C$ *for* $R^* = 1.56$*. Additionally, average hardness values for* $R^* = 0.84$ *and* $R^* = 0.40$ *were shown at* $36.5R_C$ *and* $32R_C$ *respectively. It was discovered that the extruded products increased along their circumferential solid positions with a rise in die reduction in area and increased with an increase in ram pressure.*

Keywords: Die angle; Die Profiles; Die reduction in area; Maximum and Inner extrusion pressure ratio; Ram pressure; Quality of extrudates

1 INTRODUCTION

The appropriate work metal is pushed through a female die opening in the extrusion process, which can be done either hot or cold to create the required shape. Long, uniformly cross-sectioned pieces are typically produced using extrusion. Cold extrusion can accomplish the necessary strength, including near tolerance, with minimal to no material loss, while hot extrusion can generate a variety of sections [1]. Additionally, cold extrusion can improve the grain structure. Concrete, ceramics, metals,

polymers, and food products are the materials that are extruded most commonly. Extrusion can be used to make alloys of copper, lead, tin, aluminum, and other metals. Extrusion is a commonly utilized method in the manufacturing of machine parts used in the fields of aeronautics, astronautics, and mechanical manufacturing in recent years [2]. The issues with dies and tooling are often the cause of extrusion product defects. While some of these happen during the dies service life, others are connected to die design, die material, and die production. These latter include temperature issues, erosion, pitting, poor quality billet material, friction, and inadequate support tooling. Moreover, the plastic deformation of the die or its components brought on by mechanical, thermal, or a combination of these pressures results in deflection defects [3]. In order to provide raw materials with a reasonable strength after extrusion and to increase the rate of mass production in a way that is both cost- and time-effective, the extrusion industry has spent the last few decades primarily focusing on the establishment of an experience-based method of controlling extrude deflection and final product quality. Particularly in situations where the product has bent, the accumulated experience-based "know-how" typically offers a workable fix to get around the failure problem brought on by the extrusion process, by modifying the previously mentioned set of process parameters and/or the bearing region's dimensions in the die [4]. [5] Looked at the impact of land length on extrusion pressure die. It was discovered that extrusion pressure increased with the complexity of the die geometry; for a given reduction and die length, the pressure was highest for rectangular parts and lowest for square portions. They found that, for a given area reduction, extrusion pressure increases when die land length increases and vice versa. [6] Opted for experiment and evaluated the impact of die land on extrusion pressure in a similar manner. For each given percentage extrudate reduction, the study demonstrated that the die land-related contributions to extrusion pressure increase with die land length. Additionally, for any given percentage sample reduction, the extrusion pressure rises with die land length [7]. [8] conducted a study on upper bound elements for extrusion pressure prediction in 3D forward extrusion is presented. With the power of deformation owing to ironing action at the die land taken into consideration, the study of the influence of die land length has been extended to evaluate extrusion pressures to extrude sections such as circular, square, and rectangular forms using square or rectangular billets. For a given die reduction at a given die land length, the die opening with a rectangular section yields the highest extrusion pressure, followed by a circular die opening with a square section, which yields the lowest. Die land length has an increasing effect on extrusion pressures as die opening geometry becomes more complex. The die land length needs to be carefully chosen if it is to prevent excessive pressure collection at the emerging portion and maintain the excellent quality and metallurgical structure of the extrudes. A literature search indicated that previous studies employed graded materials such as lead, magnesium alloys, and aluminum alloys (AA-6060 and AA-6063) for the extrusion processes; however, this study used lead from car batteries (Lead Acid Battery) as scrap material; split extrusion dies were used to facilitate the removal of extrudes with fewer surface defects. To the best of knowledge and from the literature assessment, limited or no findings utilizes lead from scrap battery for cold extrusion. Thus, these findings try to fill the space in the field of laboratory production. Therefore, the aim of this work is to evaluate the effect of circular variable die profiles on parameters of lead extrusion using laboratory extrusion rig during cold forward pressure with a view to obtain optimum metal flow conditions.

2 MATERIALS AND METHODS

2.1 Materials

The following are the study's materials: Shear-butter (Oil extracted locally from African tree-shear-butter), was purchased at Maiduguri, Monday Market from Borno State; Spirit for cleaning (sodium hydroxide solution) obtained at Simple Pharmaceuticals, Dandal Road Maiduguri. Cotton Waste obtained at Faculty of Engineering Teaching Workshop, University of Maiduguri; Washing brush and marker were obtained at University Book Shop, University of Maiduguri. Scrap from car lead acid battery of known properties were obtained from local foundry SMEs within Maiduguri Metropolitan Council environs, used for casting the billets. Table 1 provides the chemical compositions of the extruded lead and tool steel (mild steel), while Table 2 shows the equipment, machines and instruments used for the experimental study [9, 10].

Table 1. Chemical Compositions of the Extruded Lead and the Mild Steel

Element	Pn	Sn	Bi			
Chemical Composition of Lead (wt %)	66	27.5	6.5			
Element	C	Si	S	P	Mn	Ni
Chemical Composition of Mild Steel (wt %)	0.1195	0.2887	0.0097	0.0099	0.5030	0.0207

Table 2. The equipment, machines and instruments used for the experimental study

SN	Equipment/Machine/Instrument	Location/Used
1	Blacksmith forge machine (Locally made)	At Faculty of Engineering Teaching Workshop (FETW), Unimaid. Used as foundry equipment for supplying air in heating and melting the lead metal.
2	Crucible (Scrap refrigerator gas cylinder).	At (FETW) used for holding the lead material while heating.
3	Tongs, (Mitech Metrology Co., Ltd)	At (FETW) used for holding and picking the crucible.
4	Skimmer (Mitech Metrology Co., Ltd)	For removing impurities from the molten metal.
5	Venire caliper (Mitech Metrology Co., Ltd)	Used for checking and comparing extrudates dimension with die openings.
6	Extrusion rig (Locally made)	Produced at (FETW), used for the experimental extrusion.
7	Dial gauge indicator	At Ramat polytechnic, Maiduguri used in testing and measuring extrudates deflections.
8	Compression testing machine (Seidner 794 West Germany)	At Ramat Polytechnic, Maiduguri used for the compression force of extrusion during the experimental compression test.
9	Centre lathe machine (Colchester)	At Ramat Polytechnic, Maiduguri for holding extrudates on the machines three jaw chuck to rotate and test for deflection.
10	Rockwell hardness testing machine (H_{RC}) HR-150A, Macro hardness Testing Machine Rockwell, 1489, Zhejiang Tugong instrument Co., ltd (ISO9001 Certified!)	At Aminu Tatari State Polytechnic Bauchi used for hardness testing of the extrudates.

2.2 Methods

Scrap lead was then melt, cast according to (ASTM B102-00) and machined into billets with dimensions of 24.5 mm in diameter and 24 mm in length. Billets were then extruded through the variable die openings of 11mm, 15mm, 16mm, 20mm and 22mm under pressure of compression testing machine on the objectives of the study. The effects of extrusion pressures, piping and deflection were recorded. Finally, the hardness property test was performed on the extrudates to determine any changes in their hardness property according (ASTM, E18-22). The research findings were made visible by using models to assess and produce tabular data and an excel tool to draw graphs.

2.2.1 The Extrusion Die Design

Die-making materials of choice include zirconia (Si3N4) and high alloy tool steels. Additionally, cold extrusions have a longer tool life and require less lubricant because to their exceptional wear resistance. However, as shown in Plate 6 **(A)**, constructed split flat face extrusion dies with an outer diameter of 40.6 mm × 10 mm thickness of the aforementioned die hole sizes were made from mild steel that was readily accessible locally.

2.2.2 Heat-Treatment Hardening and Case-Hardening of the Extrusion Tooling

In order to extend the life of the extrusion tools and enable them to withstand high pressure during the extrusion process, the heat-treatment procedure for the extrusion dies, die holder, pressure plate, and

ram was performed using an electric furnace with a maximum range of 1200°C. More specifically, to modify the microstructure systemically in order to attain the best possible desired qualities and metallurgical features [9]. After being immersed for an hour at 870°C ± 5°C to harden them, they were quenched in SAE 40 engine oil (Plate 1). After that, the ram, dies, and dummy block were case-hardened and tempered at 300°C using a carburizing box that contained some ground charcoal. To lessen the produced residual stresses, the components were then allowed to cool in the furnace for three hours. The purpose of case hardening was to raise the tools' surface carbon content, which in turn increased wear resistance Plate 1.

Plate 1. Photograph showing the furnace used and case-harden extrusion tooling at Faculty of Engineering Teaching Workshop, University of Maiduguri

2.3 Production of Billets

The Lead was cast by melting it and then pouring it into metal pipes taken as metal mold, the pipes were set (pecked) in a molding sand where a runner was created to reroute the molten metal into the pipes. To begin with, the scrap lead was die cast into pipes larger than the billet diameter, a crucible furnace with a 25 kg capacity was used to chop and melt scrap of car acid lead batteries. The lead metal was heated to its molten stage at 327.5°C, below the melting point of aluminum, which is between 600°- 660°C. As in die casting, a number of cut circular metal pipes of an appropriate length and diameter were obtained to act as dies, into which molten lead was poured until each pipe was full, much like in sand mold casting. After that, the die-cast metal was allowed to cool and solidify according to (ASTM B102-00). Plate 2 (**A**, **B** and **C**). Using a center lathe, the billets were machined to the dimensions of 24.5 mm in diameter and 24 mm in length Plate 2 (**D** and **E**).

Plate 2. Photographs showing the casting processes of the billets at Faculty of Engineering Teaching Workshop, University of Maiduguri

2.4 Experimental Design and Design Considerations

In this research, the extrusion factor influencing metal flow according to [1], was taken into account for the experimental design. Friction within the container was also taken into account [11]. The factors on which the design for experimental analysis of the die profiles, necessary for extrusion was determined by the following: These are the extrusion types, either direct or indirect; frictional effects at the die or between the container and die; press capacity and container size and shape; the kind, arrangement, and layout of the die; the alloy kind and length; the container and billet temperatures; the extrusion ratio; Die and tool temperatures, as well as extrusion speed [1].

2.5 Experimental Validation Models for the Extrusion

The plane's strain equation was chosen as the experimental validation model for the study, to confirm the rigs and data obtained from the distortion of the lead metal. This paper focuses on the objectives of the study on the following extrusion validation models.

2.5.1 Plain Strain Equation

The plain strain is estimated using equation 1 [12].

$$\frac{P}{\sigma_f} = a + b \times ln(R) \quad (1)$$

2.5.2 Inner Extrusion Pressure Ratio

The plain strain equation $\frac{P}{\sigma_f} = a + b \times ln(R)$ can be rewritten as;

$$\frac{P_i}{\sigma_f} = a' + b' \times ln\frac{1}{(1-r)} \quad (2)$$

Where $\frac{P_i}{\sigma_f}$ is the ratio of inner pressure and flow stress absorb by the metal (billet) required for extrusion on die reduction in area. From literatures the values of *a* and *b* are constants which according to [9, 12] are values which rely on extrusion parameters like redundant work and die friction. These values obtained from the work are within the range that is avail-able in literatures.

2.5.3 Fractional Reduction in Area and Die Reduction in Area

Fractional Reduction in Area and Die Reduction in Area was estimated using equations 3 and 4.

$$r = \frac{A_o - A_f}{A_f} \quad (3)$$

$$R* = \frac{1}{(1-r)} = lnR* \quad (4)$$

From the Equations (3) and (4), *r* represents the area reduction in fractions, A_o area of billet and A_f area of die opening while *R** denotes the area reduction [13].

2.5.4 Ram Force

The ram force model was adopted to solve for maximum and inner extrusion pressure using equation 5.

$$F = PA_o \Rightarrow P \propto \frac{F}{A_o} \quad (5)$$

Where F is the force reading or ram force that is recorded during the extrusion of the billet. This can be expressed as follows: *P* is the extrusion pressure, and A_o is the billet area [11].

2.5.5 Flow Stress of the Metal

The flow stress of the lead metal extruded can be evaluated from the Von Mises formulae equation 6.

$$\sigma_f = \frac{\sigma_y}{\sqrt{3}} \quad (6)$$

where the value obtained from von Mises' yield criterion is regarded as σ_f, the material's flow stress and σ_y represents the extruded material's yield strength or strength coefficient [12].

2.5.6 Average Flow Stress

The average flow stress is represented as ($\bar{Y}_f$), where n is the end-constant or strain hardening exponent, lnr_x = *lnR* is the die reduction ratios (extrusion ratio and die reduction in area), and *K* is the strength coefficient of the Metal [11].

$$\bar{Y}_f = \frac{K(lnr_x)^n}{1.25} \quad (7)$$

2.5.7 Ram Pressure

Evaluating the friction inside the container. Equation following provides the real ram pressure needed for direct extrusion:

$$p = \bar{Y}_f \left(\varepsilon_x + \frac{2L}{D_o}\right) \quad (8)$$

Where p is the required ram pressure where $\bar{Y}_f$ is the average flow stress, extrusion strain $\varepsilon_x = \frac{P_{max}}{\sigma_f}$ *and* $\frac{P_i}{\sigma_f}$; $L = L_B$ is the length of billet remaining that needs to be extruded, D_o is the billet's diameter, and the highest extrusion pressure ratio and inner pressure ratio on die reduction in area are all expressed in [11].

2.5.8 Die Shape Factor

To learn more about how the shape or profile of the die influences the amount of pressure needed to complete an extrusion process, which in turn affects how much metal billet needs to be squeezed. The die shape factor, which is the ratio of the pressure needed to extrude a cross section of a specific shape to the extrusion pressure for a circular cross section of the same area, can be used to evaluate the impact of the die orifice shape. Consequently.

$$K_x = 0.98 + 0.02 \left(\frac{C_x}{C_c}\right)^{2.25} \quad (9)$$

The extruded cross section's perimeter is C_x, the extruded shape's die shape factor is K_x, and the perimeter of a circle with the same area as the extruded shape is C_c. The range of $\frac{C_x}{C_c}$ is 1 to 6 [12].

2.5.9 Radius of Curvature of Extrudate Product Quality

The schematic diagram and derived formula for radius of curvature according [9] is presented in Figure 1.

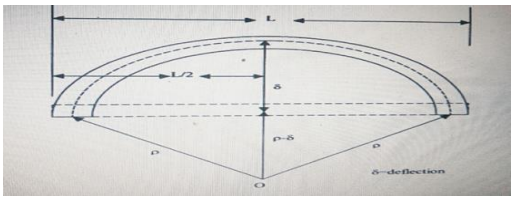


Figure 1. Schematic diagram for determining radius of curvature [9]

$$\rho = \frac{L^2}{8\delta} \quad (10)$$

By Pythagoras theorem, [9] expressed the formulae for product quality due to extrudate product deflection as δ, radius of curvature as (ρ) and L^2 as the square of increase in length of extrudates

2.5.10 Correlation Coefficient of the Graphical Inner Extrusion Pressure

The Pearson's correlation coefficient formula was used to calculate for the graphical correlation coefficient of the inner extrusion pressure ratio from the maximum extrusion pressure ratio as follows:

$$Correlation\ (r)\ r = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sqrt{\left[n\sum x^2 - \frac{(\sum x)^2}{n}\right]\left[\sum y^2 - \frac{(\sum y)^2}{n}\right]}} \quad (11)$$

Where, $r = correlation\ coefficient, n = number\ of\ observations, \sum xy = sum\ of\ the\ product\ of\ x\ an\ y$; $\sum x^2 = sum\ of\ squares\ of\ values\ of\ variable\ x$; $(\sum x)^2 = square\ of\ the\ sum\ of\ all\ the\ values\ of\ variable\ x$ [14].

2.5.11 Coefficient of Determination

The coefficient of determination for a simple regression line of *y* on *x* is the square of the correlation coefficient (*r)*, this is commonly represented by the symbol R^2. Consequently: coefficient of determination is the determined using equation 12.

$$\text{Correlation coefficient } (r) = R^2 = \frac{explained\ variation}{total\ variation} \quad (12)$$

For instance, the coefficient of determination $R^2 = (0.91)^2 = 0.828$ if the correlation coefficient, *r*, is equal to 0.91 [15]. The forecast is more accurate the stronger the correlation between *x* and *y*. According to this method, the best fitting regression line is the one where the sum of squared deviations between the estimated and actual values of the dependent variable for sample data is minimized. The least square regression line of *y* and *x* for a set of data is expressed using equation 13 [14, 15].

$$y = a + bx \quad (13)$$

2.5.12 Intercept Value (Constant) of the Graphical Inner Extrusion Pressure

The Graphical Inner Extrusion Pressure is determined using equation 14.

$$a = \frac{\sum y}{n} - b\left(\frac{\sum x}{n}\right) \quad (14)$$

From the graph, a' is the intercept value and b' is slope. $\frac{\sum y}{n}, \left(\frac{\sum x}{n}\right)$ are the ratio of the sum of product of y over number of observations [15].

2.5.13 Slope Value (Constant) of the Graphical Inner Extrusion Pressure

Alternatively, the value of b' which is the slope of graph of inner extrusion pressure can be obtained as expressed.

$$b' = \frac{P_i/\sigma_{f2} - P_i/\sigma_{f1}}{ln(R*)_2 - ln(R*)_1} \quad (15)$$

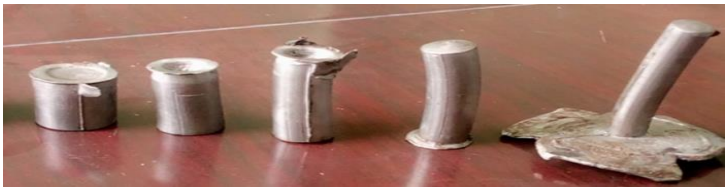
Where b' (slope) is the ratio of the difference of inner extrusion pressure ratio over the difference in die reduction in area.

2.6 Quality of Extruded Product and Measurement of Deflections

According to tribology, lubricant is primarily used in the metal forming process to reduce excessive wear and friction on contact surfaces [16]. This is significant because it functions as an agent to lessen extreme wear and friction on the contact surface. Because it affects surface polish, product quality, extrusion forces, and material flow during extrusion, lubrication has important properties [17]. A few product attributes, including dimensional accuracy, product curvature, and pipe flaws, were also looked into. Vernier caliper was used to verify the product's dimensional precision in order to compare it with the dies' dimensions [9]. The final dimensions of these products had a fairly good dimensional to within ± 0.06 mm of the dimensions.

2.6.1 Sample of Extruded Products Quality

The Photograph in Plates 3 and 4 shows the extrudates Product quality according to their reduction ratios.



R = 0.22	R = 0.41	R = 0.85	R = 0.98	R = 1.60
R^*= 0.21	R^*= 0.40	R^*= 0.84	R^*= 0.96	R^*= 1.56

Plate 3. Photograph of lead extrudates product quality showing some bent samples from R*=1.56 – R*=0.84

R^*=0.96 R^*=0.84 R^*=0.40 R^*=0.21

Plate 4. Photograph of lead extrudates product showing some piping defects from top view R*=0.21 – R*=0.96

2.6.2 Extrudates Products Deflection

Using a dial gauge indication mounted on a three-jaw lathe machine, the curvature of the product owing to product deflection was measured. These deflections were obtained by carefully clamping each extruded at a time on the three jaw chuck center lathe machine and by manually rotating the lathes chuck, maximum axial deflections were measured by using a dial Gauge indicator to read and measure the deflections at maximum of 5.08mm for the extruded product and an average of 2mm from the chucks face [6]. Measurement of extrudes deflection were carried out at the Mechanical Engineering Workshop of Ramat Polytechnic, Maiduguri, as shown in Plate 5. Equation (25) was used to determine the radius of curvature after the deflections.

Plate 5. Setup for measuring extrudes deflections at Mechanical Engineering Workshop, Ramat polytechnic Maiduguri

2.7 Mechanical Property (Hardness) Test

Hardness property test was conducted to reveal the change in hardness properties of the extrudates hardness due to effect of die profiles and extrusion ram pressure on die reduction in area. In this test, the scale 'C' hardness test with an indenter of Hardness Steel Ball of 1.588mm was used around three circumferential solid positions of the extrudates.

2.8 Experimental Techniques

[18] Points out that African indigenous inhabitants have utilized shear butter for a variety of purposes, including the creation of soap, lamps, heating oils, lubricants, and weatherproofing roofs. The lubrication oil used was shear butter. [9] Discovered that when lead alloy is extruded using an unlubricated Pb billet, the maximum extrusion and coring loads are reduced when shear butter is used as lubricant. Shear butter is therefore an excellent and efficient lubricant for the extrusion process, according to a study on the use of local lubricants in cold drawing processes.

2.8.1 Experimental Extrusion Procedure

The direct extrusion experiment was carried out at the Civil Engineering Laboratory of Ramat Polytechnic, Maiduguri on a compression testing machine, model Seidner 794 as presented in Plate 7. In order to facilitate the process, the compression machine was used to apply compressive load to the ram of the rig. To degrease, cotton waste soaked in sodium hydroxide solution was used to clean the container

wall, die, die holder, pressure plate, and ram each extrusion test. Before each test, the die, ram and the chamber were smeared with shear butter. Die holder assembly involves carefully placing the 22mm circular aperture into the die holder's recess, making sure the die is positioned symmetrically with respect to the recess, and tightening it to the bottom of the container Plate 6 **(A-D)**. Thereafter the billet and pressure plate were smeared with shear butter and were dropped into the extrusion chamber. The ram was freely placed into the extrusion hole until its end rests on the pressure plate. The entire extrusion rig assembly Plate 6 **(E)** was raised and positioned on the machine's vise or table such that the stabilizing plate rested on the ram head, ready for extrusion. Extrusion started by turning on the compression machine, which caused the extrusion ram to be compressed by its movable ram from the bottom. This process was repeated until extrusion started and ended. As the load was applied, the machine's gauge immediately provided the extrusion load, which was read and recorded in KN at the maximum extrusion pressure. Using dies with diameters of 20 mm, 16 mm, 15 mm, and 11 mm, this process was repeated for each extrusion process of the force values acquire.

2.8.2 Assembling the Direct Laboratory Extrusion Rig

The complete assembly of the laboratory extrusion rig presented in Plate 6.

Plate 6. Photograph showing the laboratory extrusion rig assembly

Different components machined to function as a unit showing the stages of assembling the extrusion rig viewing from **A-E:** Die (**A**); Die holder (**B**); Assembled die and die holder (**C**); Assembled die holder to the container (**D**); Complete assembly of the extrusion rig viewing from the front view vertically downward is a ram, the top and bottom plate, and the middle surface as the container which is seated on its stand.

2.8.3 Experimental Setup

Plate 7 shows the experimental extrusion set-up carried out at Department of Civil Engineering, Strength of Materials Laboratory, Ramat Polytechnic, Maiduguri. The different parts of the compression testing machine for extrusion **A-G:** Stabilizer (**A**); Complete set of the extrusion rig (**B**); Machines ram (**C**); Pressure lever (**D**); Analogue Pressure Gauges (**E**); Speed selector (**F**); Hand wheel **(G)**.

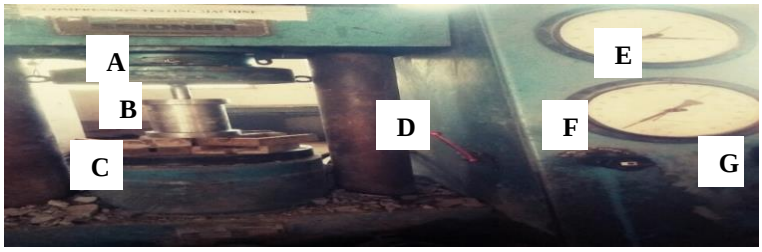


Plate 7. The experimental setup for the extrusion process on a compression testing machine (Model Seidner 794 West Germany) at Strength of Materials Laboratory Ramat Polytechnic, Maiduguri

3 RESULTS AND DISCUSION

Prior to metal flow on die reduction in area, the billet has to absorb ram pressure at its Maximum extrusion pressure $\left(\frac{P_{max}}{\sigma_f}\right)$. The pressure at its maximum decreases with decrease in die reduction in area at length of billet remaining (L_B) 24mm to 0mm with ram pressures of 70.01Mpa to 25.54Mpa, for die profiles 11mm, 15mm, 16mm, 20mm and 22mm. From Table 3; Figure 2 demonstrated that the die reduction in the

area of the extruded circular profiles influences the inner extrusion pressure ratio with a linear correlation coefficient of r = 0.99 and R^2 = 0.98 at 98%, respectively. This suggests that the whole variance of the inner extrusion pressure ratio on its percentages may likewise be explained by the regression lines using their independent variable x, (x = lnR*). For the smeared extrusion of the circularly shaped lead extruded, using the regression line approach for which the plain-strain equation relates, the die land length may have an impact on the empirical relations for the inner extrusion pressure on die reduction in area (lnR*), which are $2.68 \leq R \leq 2.71$, $1.87 \geq R \geq 1.86$, $1.70 \geq R \geq 1.69$, $1.10 \geq R \geq 1.09$, and $0.85 \geq R \geq 0.83$. These relationships are less or greater than the maximum extrusion pressure ratio. Additionally, the die reduction in area of the inner extrusion pressure ratio is less than the extrusion ratio (lnR) of the maximum extrusion pressure ratio by $1.56 \leq R \leq 1.60$, $0.96 \leq R \leq 0.98$, $0.84 \leq R \leq 0.85$, $0.40 \leq R \leq 0.41$, and $0.21 \leq R \leq 0.22$. This could be due to the disparity between the reduction's ratios (die reduction in area and extrusion ratio). Likewise, the inner extrusion pressure ratio's values for a' = 0.56 and b' = 1.36 were derived from the regression and correlation coefficients to determine the slope and intercept of Figure 2. The obtained values, which are documented in literature, fall within the range. [9] Have reported similar works.

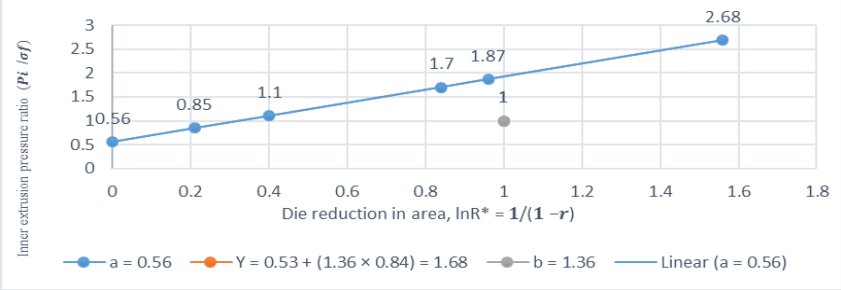
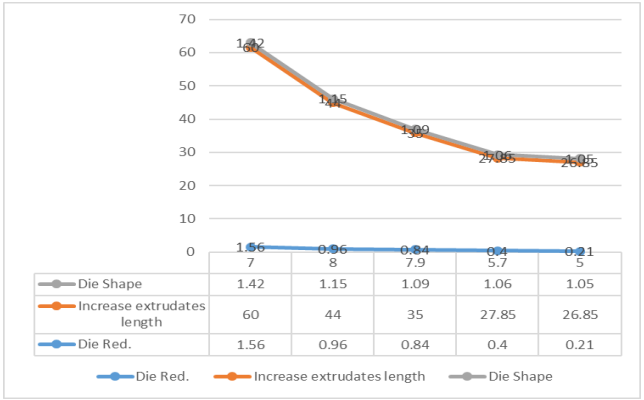


Figure 2. Effect of circular die profiles for Inner Extrusion Pressure Ratio, $\frac{P_i}{\sigma_f}$ on Die Reduction in Area

Figure 3 showed that longer extrudate lengths especially when die reduction in area is between R* = 1.56 and 0.96 have an impact on required extrusion pressure (Table 4). Additionally, it can be observed that die reduction in area determines the dimensional values of the effects of die shape and die land length on the inner extrusion pressure; this increases with increase in the die reduction in area of the extruded circular-shaped lead product at a given die land length and vice versa. Both the results of the die shape and die reduction in area indicates that the die profile and die land length influences extrusion pressure and this have a significant effect in extrusion processes especially for engineers in choosing an optimal die shape that minimizes extrusion pressure. In order to preserve acceptable metallurgical quality and the structure of the extrudates, die designers employed this parameter when creating extrusion dies. A correct selection of die land length is necessary, provided that excessive pressure building at the die entry is avoided. Similar results have been obtained in the past by [5, 8, 9, 10].



	7	8	7.9	5.7	5
Die Shape	1.42	1.15	1.09	1.06	1.05
Increase extrudates length	60	44	35	27.85	26.85
Die Red.	1.56	0.96	0.84	0.4	0.21

Figure 3. Effect of Die shape for Inner Extrusion Pressure Ratio, $\frac{P_i}{\sigma_f}$ on Die Reduction in Area $lnR*$

Figure 4 results of the plot of the ram pressure on die reduction in area for extrudates deflection demonstrated that lower radius of curvature are obtained at decrease in die reduction in area. The reduction in area shows the ratio of distortion of the extrudates lead, and radius of curvature which indicated the extruded deflection as in Table 3. The extrudates deflections increases with increase in ram pressure and die reduction in area. Extrudates deflection known as the curvature of the product may be as a result of variations in forces acting on opposite sides of the die land lengths which is also due to the errors in die design and machining. The final dimensions of these deflected products, (Plate 3), had a reasonably good dimensional shape within ± 0.06 mm of the dimensions. The similarity to previous research by [9] suggested that the modest differences in frictional forces on the two opposing sides of the die land may be the cause of this.

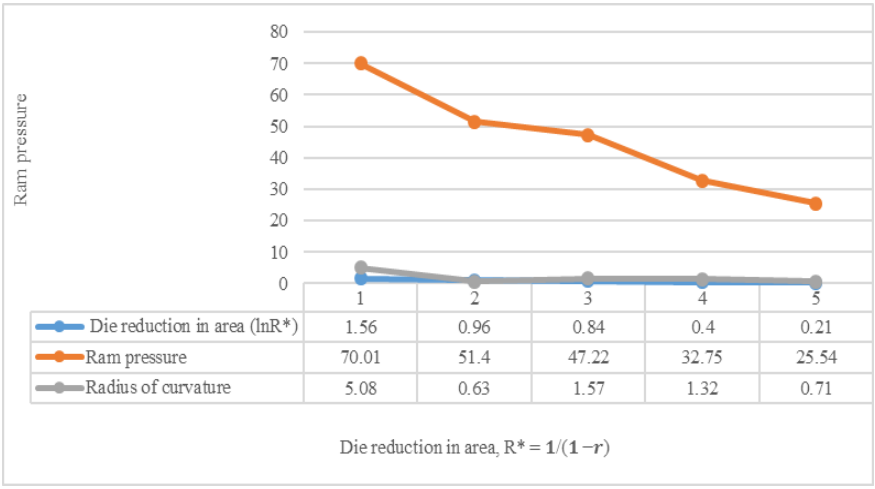


Figure 4. Effect of Ram Pressure and Die Reduction in Area, $lnR*$ on Extruded Deflection

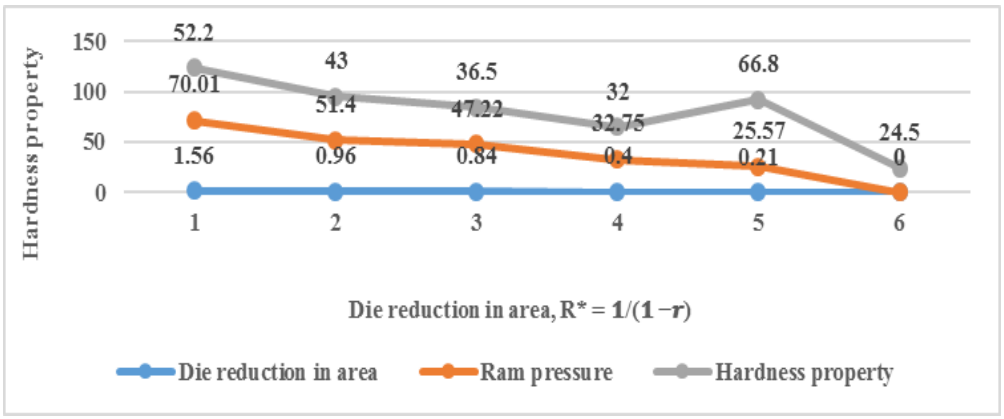


Figure 5. Graphical relationship between ram pressures against hardness property (H_{RC})

Figure 5 demonstrated that ram pressure increases with increased in die reduction in area and vise versa as the lead metal flows towards the die exit. This indicates that ram pressure increases with increase in die reduction in area, so do the hardness values, with greater average values of $66.8R_C$ for die reduction in area (R*) = 0.21 than average hardness values of $52.2R_C$ for die reduction in area (R*) = 1.56. It also shows average hardness values of $36.5R_C$ for die reduction in area (R*) = 0.84 and $32R_C$ for die reduction in area (R*) = 0.40, and this clearly shows decrease in ram pressure have significant effect in improvement of the hardness property of the extrudates. This hardness test is accordance with (ASTM, E18-22). The findings is similar to the earlier report by [9]. The effect of ram pressure on die reduction in area of the investigated piping showed that, piping increases with increased in ram pressure as well as decreased in die profile, and the increase in pressure is dependent on die reduction in area, with the severity of the piping

on die reduction in area in the order of R^*=0.96, R^*=0.84, R^*=0.40, and R^*=0.21. Some piping defects were showed in **Plate 4** for sample results of the extrudates product quality. The findings are similar to the reported works of [9].

Table 3. Effect of Ram Pressure and Die Reduction in Area on Deflection, Piping and Hardness Property of the Extruded Product Quality

Variable Die Diameter (d) (mm)	Die Reduction in Area, (lnR*)	Die Angle ($\propto$)	Radius of Curvature ($\boldsymbol{\rho}$) (mm)	$\left(\frac{P_i}{\sigma_f}\right)$	Hardness Property of the Extrudates, (H_{R_C})	Ram Pressure ($\boldsymbol{p}$) (Mpa)	Length of Billet Remaining (L_B) (mm)
11	1.56	90^0	5.08	2.68	52.2	P_3 = 70.01	24
						P_2 = 60.09	16
						P_1 = 50.14	8
						P_0 = 40.25	0
15	0.96	90^0	0.77	1.87	43.0	P_3 = 51.40	24
						P_2 = 42.57	16
						P_1 = 33.73	8
						P_0 = 24.90	0
16	0.84	90^0	1.57	1.70	36.5	P_3 = 47.22	24
						P_2 = 38.72	16
						P_1 = 30.22	8
						P_0 = 21.73	0
20	0.40	90^0	1.32	1.10	32.0	P_3 = 32.75	24
						P_2 = 25.69	16
						P_1 = 18.63	8
						P_0 = 11.57	0
22	0.21	90^0	0.71	0.85	66.8	P_3 = 25.54	24
						P_2 = 19.56	16
						P_1 = 13.55	8
						P_0 = 7.54	0

Lead Billet (24.5mm × 24mm)

Table 4. The Proportion of the Extrusion Pressure to the Pressure needed by the Die Shape for the Circular Cross Section of the Extruded Lead Product

Variable Die Diameter(d) (mm)	Variable Die Land, $\boldsymbol{L_D}$ (mm)	Die Reduction in Area (lnR*)	Total or Increase in Extrudates length ($\boldsymbol{L_T}$) (mm)	Perimeter of Die, ($\boldsymbol{C_c}$) (mm)	Perimeter of Extruded, ($\boldsymbol{C_x}$) (mm)	Die Shape Factor, ($\boldsymbol{K_x}$)
11	7.0	1.56	60.00	36.0	142.0	1.42
15	8.0	0.96	44.00	46.0	118.0	1.15
16	7.9	0.84	35.00	47.8	102.0	1.09
20	5.7	0.40	27.85	51.4	95.7	1.06
22	5.0	0.21	26.85	54.0	97.7	1.05

4 CONCLUSIONS

The following conclusions were drawn at the end of the study; The impact of the circular die profiles on inner extrusion pressure ratio increases with increase in die reduction in area of the extrudates, inner extrusion pressure ratio on die reduction in area is less than the maximum extrusion pressure ratio with empirical constants for the die angle as a' = 0.56 and b' = 1.36. Both the results of the die shape and die reduction in area indicates that the die profile and die land length influences extrusion pressure. The

impact of inner extrusion pressure and ram pressure on deflection demonstrated that when ram pressure rises and die area decreases, the extrudates' deflections or radius of curvature also increase as metal flows towards the die exit. The relationship between die reduction in area and ram pressure in the studied hardness survey values around the circumferential solid surface positions of the extrudates have improved greatly with an increase in ram pressure and a reduction in die area. The relationship between die reduction in area and ram pressure in the studied piping shows that piping rises as ram pressure increases and is dependent on die reduction in area.

REFERENCES

1. Ikumapayi, O.M., Oyinbo, S.T., Bodunde, O.P., Afolalu, S.A., Okokpujie, I.P. and Akinlabi, E. T. (2019). The effects of lubricants on temperature distribution of 6063 aluminum alloy during backward cup sextrusion process. *Journal of Materials Research and Technology*, vol. 8, no. 1, pp. 1175-1187.
2. Kumar, A.V., Lamalasetti, C.H.R. and Kesava Rao, V.V.S. (2018). A study on the effect of ram speed in cold extrusion on the properties of nano sic reinforced 6061 aluminum alloy. *International Journal of Mechanical Engineering and Technology*, vol. 9, no. 13, pp. 1309-1318.
3. Qamar, S.Z. (2018). Die Defects and Die Corrections in Metal Extrusion. *Mechanical and Industrial Engineering Department, Sultan Qaboos University, Muscat 123, Oman, Metals*, vol. 8, no. 380, pp. 1 -2.
4. Park, N., Song, Y., Bae, G., Jung, S., Song, J., Lee, J., Choi, S., Lee, H. and Sung, H. (2020). Evaluation of the effect of ram speed for extrusion of Al6063 based on ALE-based finite element analysis of L-shaped sample. *18th International Conference Metal Forming Project, Procedia Manufacturing*, vol. 50, pp. 673-676.
5. Oyinbo, S.T., Ikumapayi, O.M., Ajiboye, J.S. and Afolalu, S.A. (2015). Numerical Simulation of Axisymmetric and Asymmetric Extrusion Process Using Finite Element Method. *International Journal of Scientific & Engineering Research*, vol. 6, no. 6, pp. 1246-1259.
6. Gundu, T., Tuleun, L., Injor, O. (2014). Effect of Pocket Die Bearing Geometry on Direct Cold Extrusion Process Responses. *American Journal of Mechanical Engineering*, vol. 2, no. 3, pp. 65-69.
7. Adeosun, S.O., Sekunowo, O.I. and Gbenebor, O.P. (2014). Effect of Die Entry Angle on Extrusion Responses of Aluminum 6063 Alloy. *International Journal of Engineering and Technology*, vol. 4, no. 2, pp. 127-128.
8. Workie, F. and Tesfaye, A. (2021). Analytical and Numerical Analysis of Extrusion Force, Stress and Strain Development during Extrusion Al6063-SiC Composite. *Composite Materials*, vol. 5, no. 1, pp. 1-16.
9. Onuh, S.O., Ekoja, M. and Adeyemi, M.B. (2003). Effects of die geometry and extrusion speed on the cold extrusion of aluminum and lead alloys. *Journal of Material Processing Technology*, vol. 132, pp. 274-285.
10. Adeosun, S.O. (2013). Extrusion Characteristics Dependence of Wrought Aluminium Alloy on Extrusion Variables. *American Journal of Materials Science*, vol. 3, no. 4, pp. 77-83.
11. Fall, F. (2004). Extrusion Analysis 1 and Problem, pp. 19-25.
12. Ugheoke, B.I. (2006). Design, Construction and Performance Evaluation of a Laboratory Extrusion Rig. *AU Journal of Technology*, vol. 9, no. 3, pp. 175-180.
13. Narayanan, R.G. (2024). IITG M.P. Groover, Fundamentals of modern manufacturing: Materials, Processes, and systems.

14. Zaid, A. (2015). Correlation and Regression Analysis. *The Statistical, Economic and Social Research and Training Centre for Islamic Countries (SESRIC), OIC accreditation certification programme for official statistics, Kudüs Cad, Diplomatik Site, Oran, Ankara – Turkey*, no. 9, pp. 1-5.

15. Kya, L.T., Ngor, P.Y. and Awang, Z. (2009). Statistics for First and Second Students of higher learning, Oxford Fajar, Sdn. Bhd. First publication, 4 Jalan permaju U1/15, Seksyen U1 Hilcom Glenmarie Industrial Park, 40150 Shah Alaum, Selangor Darul Ehsan, pp. 142-147.

16. Nurul and Syahrullail (2017). A new approach to cold extrusion process, Dimples indentation on sliding contact surface and palm oil as an alternative lubricant. *Scientia Iranica B*, vol. 24, no. 6, pp. 2875-2886.

17. Serope, K. and Steven, S. (2009). Manufacturing Engineering and Technology, 6th edition, vol. 15, pp. 360-363.

18. Nahm, H.S. (2011). Quality characteristics of West African shea butter (Vitellaria paradoxa) and approaches to extend shelf-life. *Master's thesis in Food Science, State University of New Jersey, Brunswick*, pp. 9-10.