Journal of Manufacturing Technology Research ISSN: 1943-8095
Volume 4, Number 1/2

EFFECT OF EXTRUSION RATIO, DIE LAND LENGTH AND LUBRICATION ON HARDNESS AND SURFACE ROUGHNESS IN MULTI-HOLE EXTRUSION

***Ratnakar Das*[1]*, U. S. Dixit*[1 *]*, and S. Deb*[2]**

[1]Department of Mechanical Engineering,
Indian Institute of Technology, Guwahati, India
[2]Department of Mechanical Engineering,
Indian Institute of Technology, Kharagpur, India

ABSTRACT

This paper describes the effect of extrusion ratio, die land length and lubrication on the mechanical property and surface quality of the extruded products in a multi-hole extrusion process. Different multi-hole dies with different extrusion ratios are used. The micro hardness and surface roughness of the extruded products from centre hole as well as peripheral holes are studied thoroughly. The variations in micro hardness of the extruded products exist with different die land lengths. The lubrication also has significant effect on the surface roughness of the extruded products.

Keywords: Multi-hole extrusion; micro hardness; surface roughness

1. INTRODUCTION

The production of small-sized component with desired mechanical properties and accuracy has become a challenging task for the manufacturers in the recent years. The demand of high productivity along with better mechanical properties can be fulfilled by forming processes like multi-hole extrusion process. Multi-hole extrusion process is the process in which a die with more than one hole is used. This process is used to produce the products of small length and cross-section. The effect of different extrusion parameters such as extrusion ratio, die land length, lubrication, extrusion speed and extrusion temperature on the quality of the extruded products has been studied for both single-hole and multi-hole extrusion processes.

* Corresponding author, E-mail: uday@iitg.ernet.in

In earlier research work, more importance was given to die design for minimizing the extrusion load (Dodeja and Johnson, 1957; Johnson et al., 1958; Chen and Ling, 1968). In multi-hole extrusion, the number of holes and their locations on the die is an important process parameter in determining the extrusion load and quality of the extruded products. Other process parameters like die land length, die pockets and their geometry, extrusion speed, billet dimensions and lubrication conditions also affect the extrusion load as well as the quality of the extruded products.

Peng and Sheppard (2004) studied the influence of the number and distribution of the holes on extrusion parameters in multi-hole extrusion. Finite element simulations using FORGE3® were carried out to study flow pattern, pressure requirement and the temperature developed during extrusion. The peak extrusion load was found to increase with increase in number of holes for a given reduction ratio. The optimum value of eccentricity of hole helps in reducing the extrusion load. Chen et al. (2008) studied the bending of aluminum alloy tubes in multi-hole extrusion process with finite element analysis. Number of holes and their location on the die are crucial parameters for bending of the extruded profiles. Extruded tubes bend outward in two-hole extrusion and inward in three-hole extrusion and four-hole extrusion. Recently, Sinha et al. (2009) presented a simplified mathematical model of multi-hole extrusion process to estimate the ram force. They carried out experiments and studied the mechanical properties and variation in length of the extruded products. Fang et al. (2009) carried out comparative study between the experiments and FEM simulation on two-hole pocket die extrusion.

The multi-hole extrusion process is a less explored research area and limited parametric studies have been carried out so far. It is felt worthy to discuss some parametric studies on single hole extrusion process. Onuh et al. (2003) carried out experimental investigation on the effect of reduction, die angle and extrusion speed on the quality of the extruded product, extrusion pressure and the flow pattern of the cold extruded lead alloy and aluminum. The average hardness value of the extruded products was found to increase with increase in reduction and extrusion speed. Ajiboye and Adeyemi (2006) studied the effect of die land on extrusion pressure, flow pattern and hardness variations along the length of the extruded product of circular sections of lead alloy. Ajiboye and Adeyemi (2007) studied the effect of die land length on the extrusion pressure. They carried out upper bound analysis to obtain extrusion pressure for complex extruded I and T sections. The extrusion pressure was found to increase with increase in die land length for any extrusion ratio. The surface finish of the extruded parts plays a considerable role in the wear resistance and fatigue strength. Tiernan and Draganescu (2008) carried out statistical modelling of surface hardness and roughness in cold extrusion of aluminum to study the effect of die angle, reduction ratio and lubrication on hardness and surface roughness of the extruded products. Statistical analysis showed that the die angle is the most influential factor for surface roughness. Shahzad and Wagner (2009) studied the effect of the extrusion ratio on the development of microstructure, variation in crystallographic texture and mechanical properties of wrought magnesium alloy AZ80. It was observed that the finer the grain size, the higher are the yield and ultimate tensile strengths.

In the present experimental investigation the effect of extrusion ratio, lubrication and die land length on the hardness and surface roughness of the extruded product of lead and aluminum are studied. Aluminum is a commonly used material in extrusion industry. Although lead is a less commonly used metal, many researchers have used lead alloy as a model material in metal forming to understand the basics of the process.

2. EXPERIMENTAL PROCEDURE

A 200 kN universal testing machine (Make: FIE, Model: UTE 20) was used as an extrusion press. The container, die, punch and base plate were made of die steel (H13). The commercially available lead and pure aluminum were melted and casted in the permanent mould of 200 mm length and 24 mm diameter. Thereafter, cast lead and aluminum were machined to prepare billets of 20 mm height and 20 mm diameter. The billets of 30 mm height and 20 mm diameter were prepared for compression test. Annealing of the aluminum billets was carried out by holding at 345 ºC for 15 minutes and then gradually cooling to room temperature. Annealing of lead alloy billets was carried out by putting them in boiling water with a temperature of 100 ºC for about 45 minutes and gradually cooling to room temperature. Details of the dies used for extrusion of lead and aluminum are given in Table 1. For each die overall extrusion ratio is calculated as the ratio of the initial cross-sectional area of the billet to the total final cross-sectional area after extrusion.

Table 1. Die specifications for extrusion of lead and aluminum

Lead extrusion	Aluminum extrusion
Billet diameter = 20 mm	Billet diameter = 20 mm
Billet Length = 20 mm	Billet Length = 20 mm
Extrusion ratio = 35.55 (5-hole die) = 19.75 (9-hole die) = 13.67 (13-hole die)	Extrusion ratio = 4.94 (9-hole die)
Die land length = 10 and 3 mm	Die land length = 15 and 10 mm
Diameter of each hole = 1.5 mm	Diameter of each hole = 3 mm

Three different types of dies were used for the extrusion of lead as shown in Figure 1. The 5-hole die is shown with the extrusion set up and 9-hole and 13-hole die are shown individually. In 5-hole die (extrusion ratio, 35.55), one hole is at centre and other four holes are at the pitch circle diameter of 12 mm. In 9-hole die (extrusion ratio, 19.75), one hole is at centre and other eight holes are at pitch circle diameter of 12 mm. In 13-hole die (extrusion ratio, 13.67), one hole is at centre, four holes are at pitch circle diameter of 7 mm and other eight holes are at pitch circle diameter of 14 mm. The intention behind selecting these different types of dies is to study the difference in material properties like strength due to non-uniform material flow in multi-hole extrusion. Different die lands were produced on the dies to study their effects also on the mechanical properties of the extruded products. Low extrusion ratio was used for extrusion of aluminum in order to reduce the extrusion load. The container wall, die, punch and the specimen were cleaned with ethanol for extrusion without lubrication. MoS_2 was applied on the die, punch and container for extrusion with lubrication. After each test, the entire set up was removed from the machine and the extruded products were cut carefully for measurement of surface roughness and micro hardness. Three replicates were carried out at different conditions. Replicates are needed to assess the repeatability of the experiments. Three replicates are sufficient, if there is good repeatability in the process. More number of replicates may be required in case of poor repeatability.

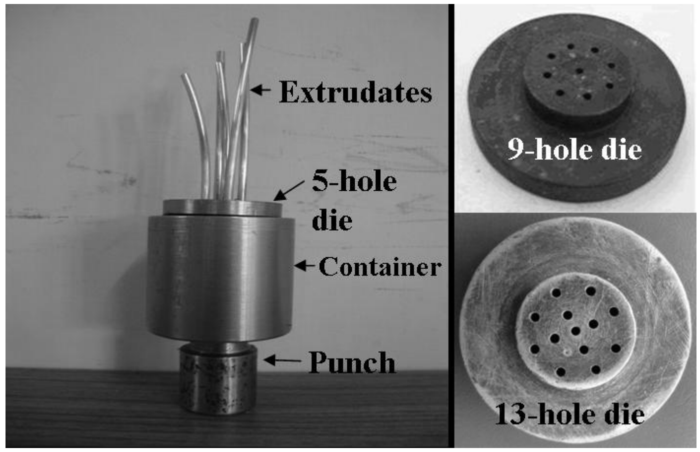


Figure 1. Extrusion set up and dies.

At each replicate, microhardness and surface roughness measurements were carried out at 4-5 places. The combined data of all measurements was used to make inference about average quality attribute along with the standard error in the estimate. The standard deviation was also estimated.

For measuring the centre line average (CLA) surface roughness values (R_a), Pocket Surf (Mahr, GMBH) was used. Its measuring range is 0.03–6.35 μm and accuracy is ±0.01 micron. The surface roughness evaluation length and cut off length were 2.4 and 0.8 mm respectively. The surface roughness of the extruded products was measured along the extrusion direction. Micro-hardness tests of extruded products were carried out by Vickers micro hardness tester (Make: BUEHLER, Model: MICROMET 2101). Due to small diameter of extruded products (1.5 mm for lead products and 3 mm for aluminum), they cannot be used directly for hardness measurement. The sample preparation was carried out to conduct the micro-hardness tests. A cold mounting method was used for the mounting of the extruded products with acrylic powder (self polymerizing resin) and acrylic liquid (self polymerizing liquid). The samples were polished to avoid the surface effect in micro hardness testing. Indentation was carried out with a load of 50 g for 10 seconds for the lead material and 100 g for 15 seconds for aluminum. The hardness values for lead and aluminum billets were 10.2 VHN and 39.5 VHN respectively. The compression tests were performed at very low strain rate (10^{-3} s^{-1}) on the lead and aluminum billets of 20 mm diameter and 30 mm length to obtain stress-strain data for experimental evaluation of yield stress. Concentric grooves of 1 mm depth and 0.5 mm width were made on the faces of the specimen in order to facilitate the retention of lubricant during compression testing. Engineering stress-strain curves for the specimens of lead and aluminum used for extrusion is given in Figure 2.

3. Results and Discussion

In this section the micro hardness and surface roughness of the extruded products are reported. The effect of different process parameters such as extrusion ratio, lubrication and die land length on the hardness and surface roughness are studied.

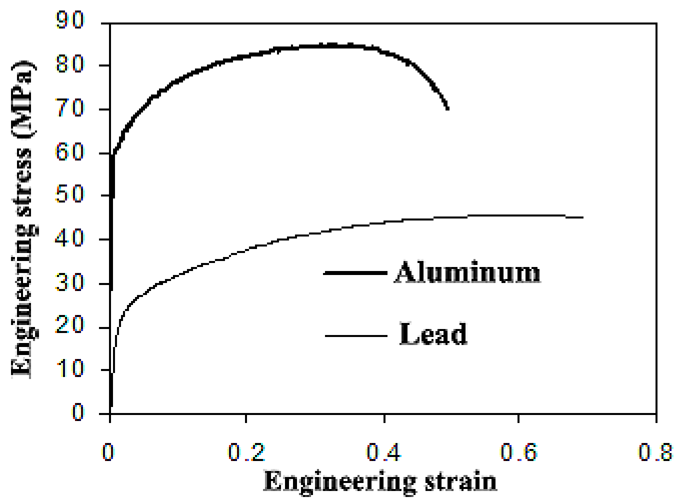


Figure 2. Engineering stress - strain curve of aluminum and lead.

3.1. Micro Hardness of Extruded Lead

As a part of the study on mechanical properties, the hardness of the extruded products are studied for different extrusion ratio, die land length and lubrication conditions. For the products from centre hole of the dies of different extrusion ratio with 10 mm die land length, the average hardness values are shown in Figures 3 and 4. For unlubricated dies, the hardness value ranges from 10.58 to 10.88 VHN with different extrusion ratio and for lubricated dies, it ranges from 10.55 to 10.75 VHN. Similar hardness values are observed for the dies with more number of holes with both lubricated and unlubricated conditions. The lubrication has no significant effect for the centre hole. More deviations in hardness values are observed for the extrusion ratio of 35.55 as compared to 19.75 and 13.67 for both lubricated and unlubricated conditions, which is expected as high extrusion ratio causes more strain hardening and proportionately more non-uniformity.

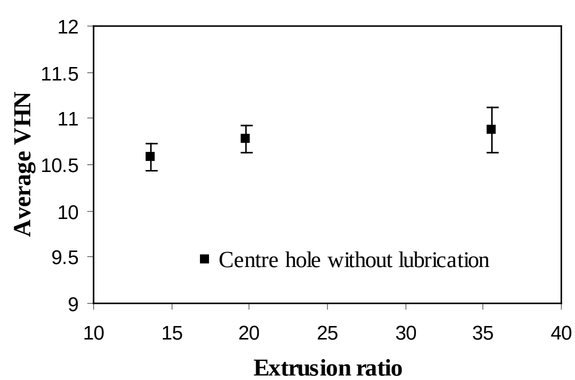


Figure 3. The hardness value (mean± standard deviation) for lead products from centre holes of unlubricated dies with 10 mm die land length.

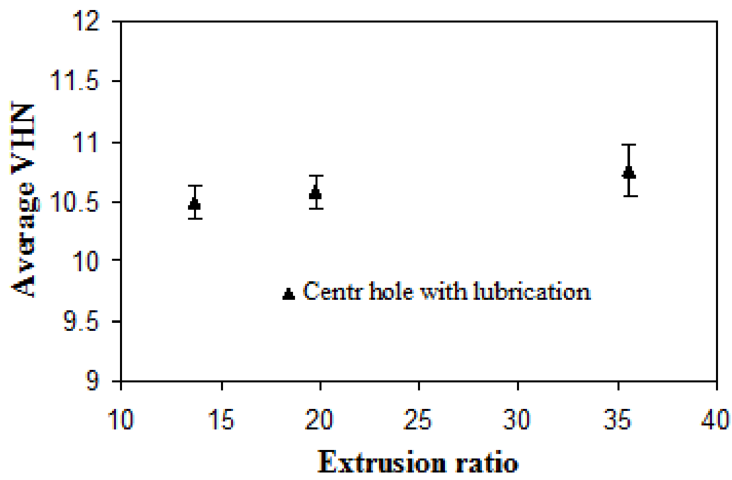


Figure 4. The hardness value (mean± standard deviation) for lead products from centre holes of lubricated dies with 10 mm die land length.

The hardness values of the products from the peripheral holes of dies of 10 mm die land length are shown for different overall extrusion ratios in Figures 5 and 6. It is seen that the micro-hardness of peripheral extrudates is less sensitive to extrusion ratio in comparison to micro-hardness of extrudates from central hole. It is observed experimentally that the metal flows more easily from the peripheral holes than from central hole, causing increased extrudate length from peripheral holes compared to central hole. A rigorous analysis by FEM can reveal the flow pattern. However, it appears that presence of many holes on periphery helps in the easy flow of metal, while in the centre, the metal observes obstruction and forms a wider dead metal zone. As a consequence, extrudate coming out from the central hole observes more strain hardening as compared to extrudate coming out from a peripheral hole. Hence, the effect of varying the extrusion ratio is experienced more by central hole than peripheral holes. This is the reason of lower variability of micro-hardness of peripheral extrudates with change of overall extrusion ratio as compared to micro-hardness of central extrudate. In 13-hole die, micro-hardness of inner peripheral extrudates is found to be greater than the micro-hardness of the outer peripheral extrudates. This further confirms that the more number of holes near the container wall offer lesser resistance to flow, causing lesser amount of strain hardening. For the same pitch circle diameter (PCD) also, the amount of strain hardening on the extruded products obtained from different holes shows slight deviation.

The deviation in the hardness value for peripheral holes is less as compared to centre hole for different extrusion ratio with both lubricated and unlubricated conditions. For example, the variation in the hardness for the centre hole is more (maximum of 11.9 VHN and minimum of 10 VHN) as compared to peripheral holes (maximum of 10.66 VHN and minimum of 10.32 VHN) for the extrusion ratio of 35.55 in lubricated condition. This may be attributed to complex flow behavior at the centre due to formation of dead metal zone.

Figures 7 and 8 show the average hardness values for extruded products through the dies with 3 mm die land length. The deviations in hardness values of the extruded products from the 3 mm die land length dies are less as compared to the 10 mm die land length dies.

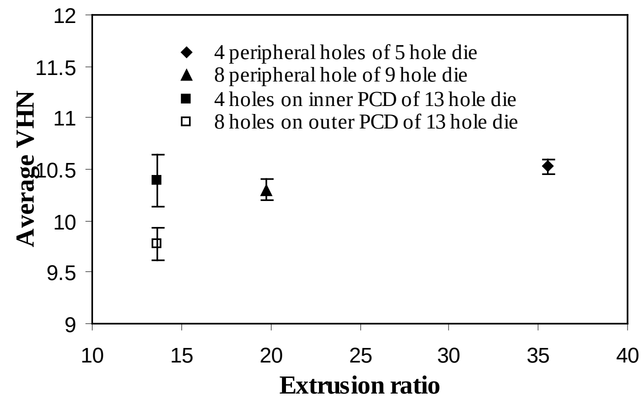


Figure 5. The hardness value (mean± standard deviation) for lead products from peripheral holes of unlubricated dies with 10 mm die land length.

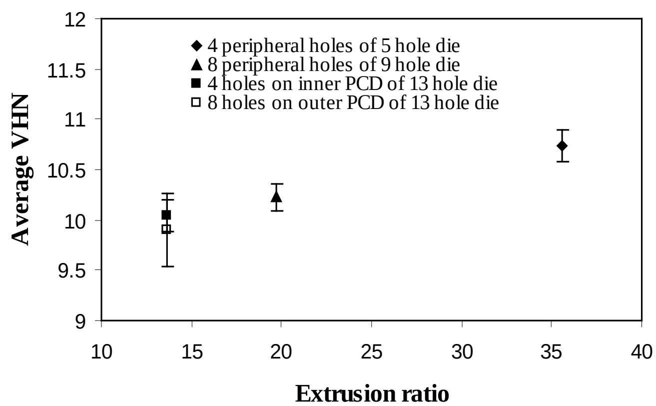


Figure 6. The hardness value (mean± standard deviation) for lead products from peripheral holes of lubricated dies with 10 mm die land length.

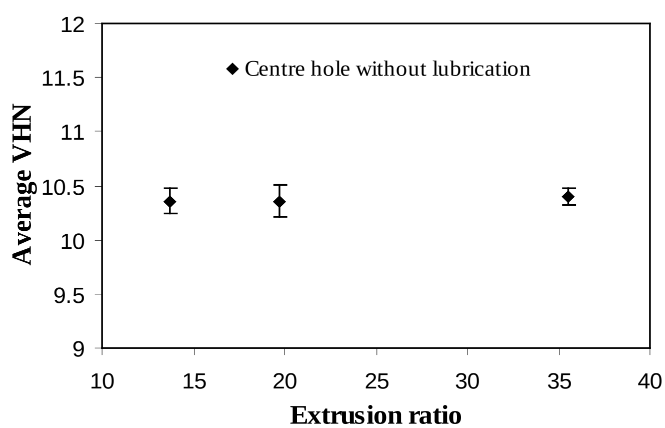


Figure 7. The hardness value (mean± standard deviation) for lead products from centre holes of unlubricated dies with 3 mm die land length.

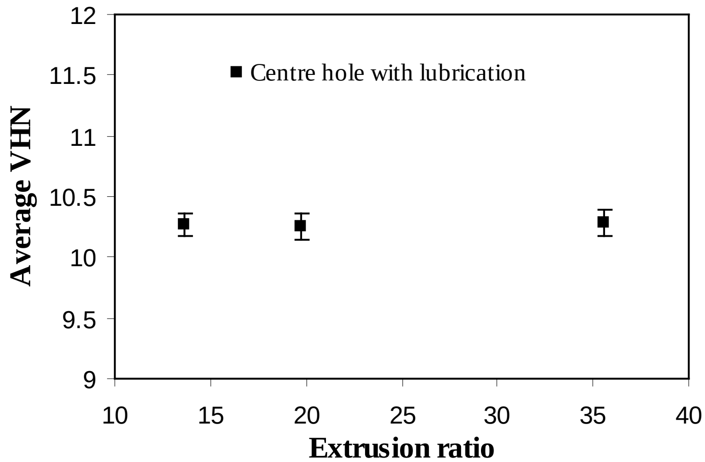


Figure 8. The hardness value (mean± standard deviation) for lead products from centre holes of lubricated dies with 3 mm die land length.

Low die land length also produces less variation in hardness value in the products coming through the peripheral holes in both lubricated and unlubricated conditions as shown in Figures 9 and 10.

The lower die land length produces less straining and work hardening on the extrudates. Consequently, the effect of extrusion ratio is less significant on hardness of the extruded products obtained from smaller die land length (3 mm) as compared to the products from larger die land length (10 mm).

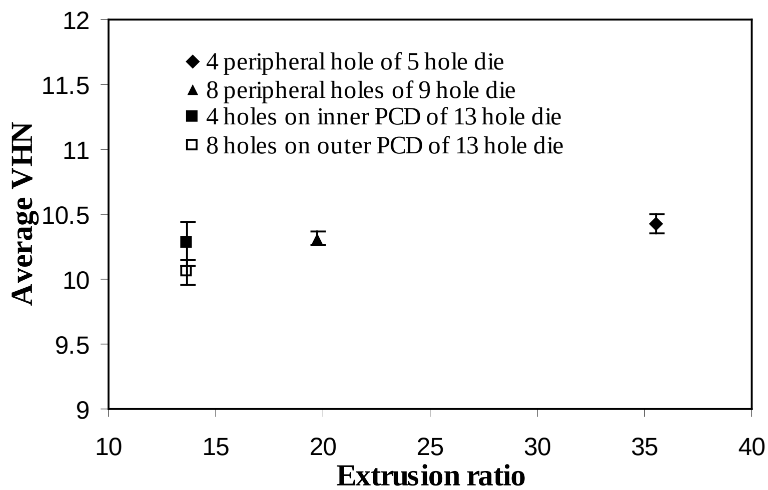


Figure 9. The hardness value (mean± standard deviation) for lead products from peripheral holes of unlubricated dies with 3 mm die land length.

In the replication of experiments some variations in average hardness value are observed. To assess the repeatability of the experiments, hypothesis testing is employed. A brief description of the application of hypothesis testing in manufacturing is available in (Dixit and Dixit, 2008).

At 95% confidence level, the variation in the average hardness among the replicates is insignificant. The results of hypothesis testing are not presented here to preserve brevity.

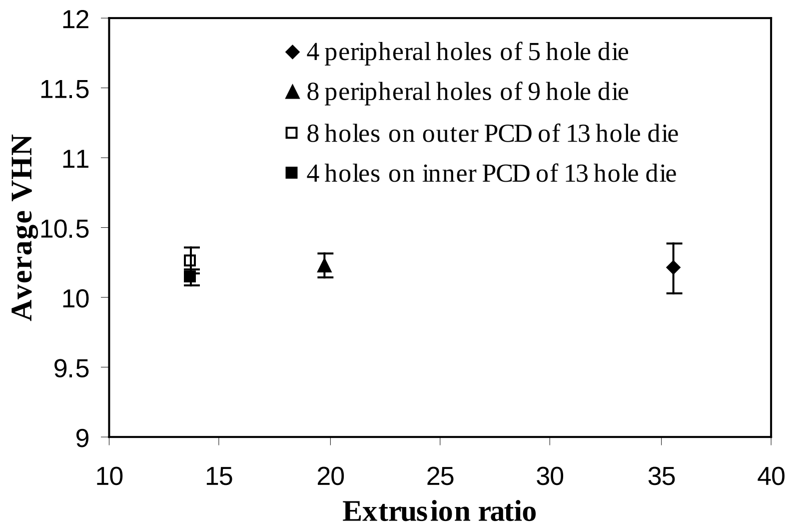
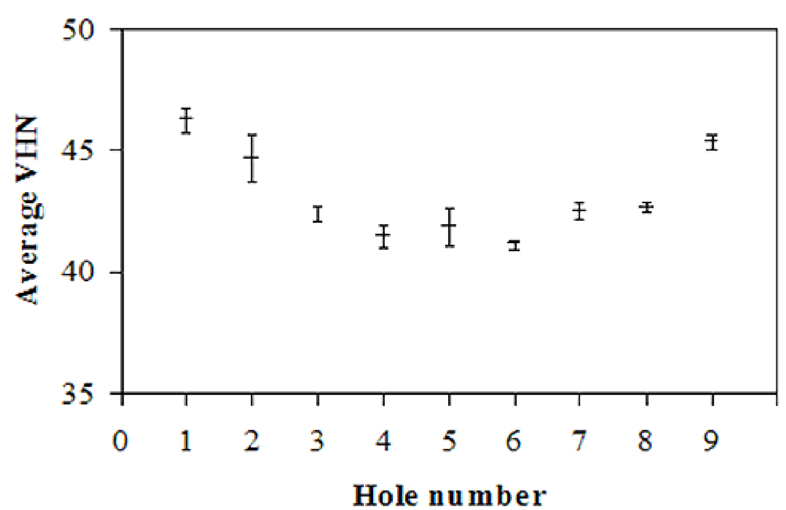


Figure 10. The hardness value (mean± standard deviation) for lead products from peripheral holes of lubricated dies with 3 mm die land length.

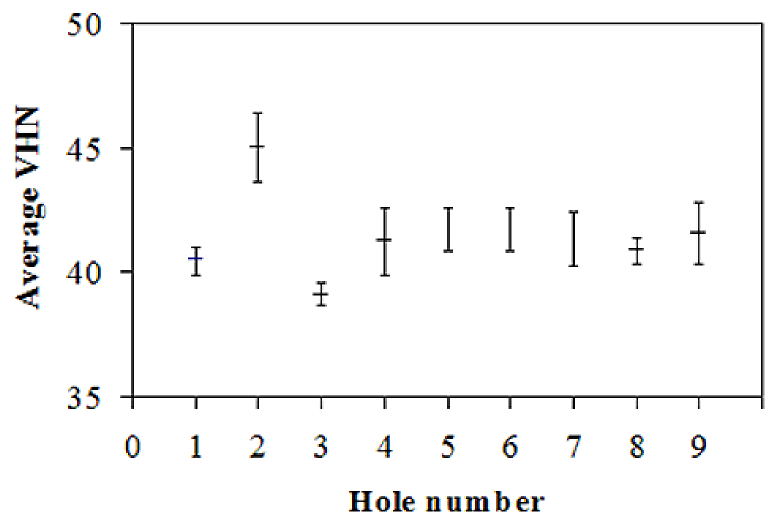
3.2. Micro Hardness of Extruded Aluminum

The multi-hole extrusion of aluminium was carried out with a die having 9 holes of 3 mm diameter each using MoS_2 as lubricant. Two dies one with die land lengths of 10 mm and another with die land lengths of 15 mm were fabricated. The average micro hardness values of the extruded products obtained from 15 and 10 mm die land lengths dies are shown in Figures11 (a) and 11 (b) respectively.



a

Figure 11. Continued on next page.



b

Figure 11. Micro hardness value (mean± standard deviation) of the extruded aluminum from the lubricated 9-hole die (hole number 9 is the centre hole) (a) 15 mm die land length (b) 10 mm die land length.

In case of multi-hole extrusion of aluminium with die having 15 mm die land length, the maximum and minimum hardness value of the extruded products are found to be 46.25 and 41.15 VHN respectively. For the die with 10 mm die land length, the maximum and minimum hardness values of the extruded products are found to be 45.05 and 39.5 VHN respectively. Average hardness values of the extruded products coming out from the dies with 15 mm die land length is 43.13 VHN, which is about 5% higher than the average hardness value of 41.32 VHN of the extruded products coming out from the dies with 10 mm die land length. A hypothesis testing using Student's *t*-test showed that the process has good repeatability at 95% confidence level.

3.3. Surface Roughness of Extruded Lead

From the past research work it was found that several process parameters like extrusion ratio, extrusion speed and type of lubrication affect the surface quality of the extruded products. However, for multi-hole extrusion, the extruded products coming out from different holes located at different pitch circle diameter of the die experience the process parameters differently. This affects the surface quality of the products. Table 2 and 3 show the surface roughness values of the extruded products with different extrusion ratio, lubrication condition and different die land length for lead. The surface roughness was measured along the length of the product. It is observed that lubricated dies always produce better surface quality, *i.e.*, lower roughness value.

The products coming out from centre hole of dies with 3 mm die land length have lower surface roughness value in lubricated condition. It is interesting to observe that extrusion ratio is also a parameter, which affects the surface roughness of an extruded product. From Table 2 it can be seen that for unlubricated die with 10 mm die land length, there is about 50% difference in roughness value for high and low extrusion ratio.

Table 2. Average surface roughness value of the extruded products from the centre holes of multi-hole dies with different extrusion ratio. (The values in bracket are standard error)

Extrusion ratio	Surface roughness (in μm)			
	No lubrication		Lubrication	
	10 mm die land length	3 mm die land length	10 mm die land length	3 mm die land length
35.55	0.608 (0.085)	0.501 (0.045)	0.5 (0.045)	0.35 (0.05)
19.75	0.396 (0.027)	0.465 (0.04)	0.403 (0.118)	0.385 (0.06)
13.67	0.405 (0.054)	0.371 (0.076)	0.371 (0.067)	0.346 (0.089)

Table 3. Average surface roughness value of the extruded products from the peripheral holes of multi-hole dies with different extrusion ratio. (The values in bracket are standard error)

Extrusion ratio	Surface roughness (in μm)			
	No lubrication		Lubrication	
	10 mm die land length	3 mm die land length	10 mm die land length	3 mm die land length
35.55	0.521 (0.086)	0.378 (0.017)	0.488 (0.063)	0.352 (0.062)
19.75	0.522 (0.086)	0.318 (0.097)	0.402 (0.061)	0.333 (0.055)
13.67 (Inner PCD)	0.434 (0.011)	0.373 (0.063)	0.4 (0.065)	0.365 (0.080)
13.67 (Outer PCD)	0.443 (0.08)	0.423 (0.049)	0.391 (0.05)	0.348 (0.071)

For unlubricated die with 3 mm die land length, there is as low as 3% difference in roughness value for high and low extrusion ratio. For the extruded products of the peripheral holes, with lubricated dies having 3 mm die land length, the effect of extrusion ratio is also quite significant (Table 3). It seems that increase in plastic deformation, increases the surface roughness of the extrudate. Mahadevan (2006) has observed the similar behaviour in axisymmetric cold forging process, where the surface roughness increased with increase in compression.

3.4. Surface Roughness of Extruded Aluminum

The effect of die land length and lubrication on the surface roughness of the extruded products of aluminium is studied and the average roughness values are reported in Table 4. The extruded products coming out from the holes of 9-hole die show variation in average surface roughness. With smaller die land lengths, *i.e.*, 10 mm, the difference between the maximum and minimum roughness value is about 60%.

For the die with 15 mm die land length, the difference between the maximum and minimum roughness value is about 30%. But on an average, the lower roughness value is observed for the extruded products coming out from the die with 10 mm die land length. Variation in the surface roughness of extrudates coming out from different holes is due to variation in flow pattern and lubrication.

Table 4. Average surface roughness of the extruded aluminum from lubricated 9-hole dies with different die land length

Hole No.	15 mm die land length		10 mm die land length	
	Average roughness (μm)	Std. error in roughness	Average roughness (μm)	Std. error in roughness
1	0.35	0.02	0.3	0
2	0.355	0.015	0.255	0.015
3	0.29	0.02	0.345	0.015
4	0.345	0.025	0.32	0.02
5	0.345	0.015	0.26	0.01
6	0.36	0.02	0.315	0.015
7	0.28	0.01	0.305	0.015
8	0.345	0.025	0.415	0.015
9 (center)	0.32	0.02	0.365	0.015

The process parameters like extrusion ratio, die land length, the location of holes in the die and lubrication affect the surface roughness of the extruded products. Selection of the dominating parameter(s) and/or their combination must be done properly in order to obtain the best surface finish.

CONCLUSION

Multi-hole extrusion of lead and aluminum are carried out with different dies having different extrusion ratio and die land length. For extrusion of lead with the dies having 10 mm die land length, the micro hardness value of the extruded products coming out from the centre hole is found to increase with increase in extrusion ratio. However, much variation in hardness is not observed with the extruded products coming out from 3 mm die land length dies as compared to 10 mm die land length dies. Extrusion ratio is found to be insignificant factor for micro hardness of the extruded products coming out from dies having 3 mm die land length. In the extrusion of aluminum, about 5% increase in average hardness is observed with the extruded products coming out from die with 15 mm die land length as compared to die with 10 mm die land length.

For both lead and aluminum extrusion, extrusion ratio, die land length and lubrication are found to be significant factors for surface roughness. At low extrusion ratio, the amount of plastic strain and consequently strain hardening is less. Low extrusion ratio may not produce the desired mechanical properties. In multi-hole extrusion, it is a difficult task to obtain the extruded products with uniform desired properties and quality as the flow pattern is not uniform. It is necessary to optimize process parameters for obtaining good quality products.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial help provided by All India Council for Technical Education (AICTE) from the project AICTE: 8023/RID/BOIII/NCP (21) 2007-2008, project identification number at IIT Guwahati being ME/P/USD/4. This paper is a revised version of the paper presented in 3rd International and 24th AIMTDR Conference, 2010, AUCE (A), Visakhapatnam, India. Authors gratefully acknowledge the organisers of the conference and the reviewers and editors of this special issue.

REFERENCES

Ajiboye, J. S., Adeyemi, M. B. (2006), “Effects of die land on cold extrusion of lead alloy”, *Journal of Materials Processing Technology,* 171, 428–436.

Ajiboye, J. S., Adeyemi, M. B. (2007), “Upper bound analysis for extrusion at various die land lengths and shaped profiles, *International Journal of Mechanical Sciences*, 49, 335–351.

Chen, C. T., Ling, F. F. (1968), “Upper bound solution to axisymmetric extrusion problems”, *International Journal of Mechanical Sciences*, 10, 863–879.

Chen, F. K., Chuang, W. C., Torng, S. (2008), “Finite element analysis of multi-hole extrusion of aluminum- alloys tubes”. *Journal of Materials Processing Technology,* 201, 150–155.

Dixit, P. M., Dixit, U. S. (2008), *Modelling of Metal forming and machining Processes by Finite Element and Soft Computing Methods*. Springer-Verlag London Limited.

Dodeja, L. C., Johnson, W. (1957), “The cold extrusion of circular rods through square multiple hole dies”, *Journal of the Mechanics and Physics of Solids,* 5**,** 281–295.

Fang, G., Zhou, J., Duszczyk. J. (2009), “FEM simulation of aluminum extrusion through two-hole multi-step pocket dies”. *Journal of Materials Processing Technology,* 209, 1891–1900.

Johnson, W., Mellor, P. B., Woo, D. M. (1958), “Extrusion through single hole staggered and unequal multi-hole dies”, *Journal of Mechanics and Physics of Solids,* 6,203–222.

Mahadevan, P. (2006), “Numerical and experimental study of axisymmetric cold forging process”, *M.Tech Thesis, IIT Guwahati.*

Onuh, S. O., Ekoja, M., Adeyemi, M. B. (2003), “Effect of die geometry and extrusion speed on cold extrusion of aluminum and lead alloys”, *Journal of Materials Processing Technology,* 132, 274–285.

Peng, Z., Sheppard, T. (2004), “Simulation of Multi-hole die extrusion”, *Materials Science and Engineering A*, 367, 329–342.

Shahzad, M., Wagner, L. (2009), “Influence of extrusion parameters on microscopic and texture development and their effects on mechanical properties of the magnesium alloy AZ80”, *Materials Science and Engineering A*, 506, 141−147.

Sinha, M. K., Deb, S., Das, R., Dixit, U.S. (2009), “Theoretical and experimental investigations on multi-hole extrusion process”. *Materials and Design,* 30, 2386–2392.

Tiernan, P., Draganescu, B. (2008), “Statistical modeling of surface hardness and roughness in cold extrusion of aluminum”, *International Journal of Manufacturing Research,* 3(.4), 452– 470.