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Investigation of Barreling Radius and Top Surface Area for Cold Upsetting Ofaluminum Specimens

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Abstract: *In this work cold upset forging experiments have been conducted on aluminum 6063 specimens without constraints and without use of lubricants. Strain behavior, barreling radius and top surface area characteristics have been studied and analyzed. The experimental data have been validated adopting finite element method and response surface methodology. The research fraternity has to their credit many such publications. Sensitivity analysis of behavior of key indices is a new innovation in this work. Intermittent work hardening, barreling radius and top surface area have been analyzedusing sensitivity analysis and recorded. Stress,Strain distribution photographs have been placed in the appendix. The deduced observations will aid shopfloor forging manufacturing process and tools development.*

Keywords: *Aspect Ratio, Barreling Radius, Deformation behavior, Regression equation, Top surface Area, Upset Ratio.*

I. INTRODUCTION

There has been a persistent endeavor by manufacturing industries to adopttometal moving in place of metal machining due to high yield of material, repetitive accuracy in quality and advantages in mechanical properties. Producing machine parts and structural parts for shock or sudden impact load applications by forging is a common practice. Upsetting and open die forging is one of the significant processes in the metal forming area. Ductile materials like Aluminum have been widely used for making rivets, fasteners and many other parts for a wide range of applications like consumer goods, automotive parts, structural, aeronautical and marine sectors. Taking cognizance of these developments the research fraternity has been focusing onstudying physical and mechanical characteristics of upset forging of aluminum billets and blanks.

In this work the non-linear changes in top surface area dimensions,intermittent work hardening and the barreling radius behavior for cold upsetting of aluminum 6063 material without constraints and without lubrication has been detailed by conducting sensitivity analysis of the experimental observations. This paper is organized into several sections. The next section details the literature survey. The third section explains the problem background.Section four details the experimental study and results. The fifth section enunciates the sensitivity analysis for validating experimental data. The sixth part is the concluding part followed by the list of references. The appendices contain the illustrations, which showcase the stress,strain distribution.

II. LITERATURE SURVEY

Studying characteristics of cold upset forging of aluminum specimens have been a matter of considerable interest for the research fraternity. A number of publications have been made in this area of research interest. A few of them are enunciated here which bear some relevance to this work.

Banerjee [1] studied the axisymmetric loading of aluminum cylindrical work pieces for various aspect ratios and determined that the barreling profile approximates a circular arc and its radius follows a power law with true axial stress. He conducted the experiments with and without lubricant and proposed that forming energy is minimum with Teflon used as dry lubricant. Gupta and Shah [2] worked on deformation behavior of aluminum and low carbon steel short cylinders of various diameters and height to diameter ratios, loaded axially in a simple compression test without using any lubricant. The results of their work reveal that an arc of a circle can approximate the profile of a deforming specimen only after the onset of folding.

Narayanasamy and Pandey[3] conducted experiments to generate data on the upset forging of solid cylinders of annealed aluminum. The curvatures of the barreled aluminium cylinders measured physically were found to conform closely to the values calculated using the experimental data.

Malayappan and Narayanasamy [4] worked on cold upsetting of aluminum cylinders using die set with constraints..Malayappan and Narayanasamy [5] determined in their work that friction plays a major role in all bulk metalforming processes, except in a few isolated cases such as die-less wire drawing. Narayanasamy et al. [6] in their work generated data on cold upsetting of truncated cone billets of un lubricated and annealed commercial aluminum, copper and zinc alloys. Malayappan et.al [7] conducted experiments to generate data on the cold upset forging of solid cylinders of annealed aluminium using different lubricantswith dies at both ends. Manisekar and Narayanasamy [8] conducted similar work on square and rectangular billets of aluminum.

Cetinarslan[9] studied the barreling phenomenon that occurs at the upsetting of a cylindrical specimen using aluminum 7075 and the effect of aspect ratio (h/d) on varying of abarrel contour were in this study. Progression of barreling contour and variation of total surface area according to the increase of barreling was investigated for different aspect ratios and friction value and surface roughnesshave been determined. BaskaranandNarayanasamy[10] carried out work togenerate data on cold upset forging of commercially pure aluminum elliptical billets with white grease as lubricant applied on both sides in order to evaluate the bulging characteristics. Baskaran and Narayanasmay[11] in their paper examined the effect of various stress ratio parameters on cold upset forging of commercially pure aluminium solid billets of irregular shapes using graphite mixed with oil as lubricant applied on both sides under plane and triaxial stress state conditions.

III. PROBLEM BACKGROUND

In this study deformation behavior of solid aluminium6063 cylinders under axisymmetric compression over different aspect ratios without using any lubricants and without constraints are investigated. Data obtained in experimental work have been validated by conducting simulation using finite element method. Sensitivity analysis have been conducted to study barreling radius, load and strain, top surface area and the observations deduced will aid shop floor tooling and manufacturing in the area of upset forging. This is an important contribution of this work.

IV. EXPERIMENTAL STUDY

4.1 Blank Specification and Geometry

Aluminum 6063 is used in our study. This material is used for many applications in industry as it lends it self to cold formability. Cylindrical blanks of 25 mm diameter and six each of 25, 20 and 15 mm lengths were prepared for aspect ratios 1.0, 0.8 and 0.6 respectively. The undeformed blanks are shown in Fig.1.The chemical compositions of the specimen material is given in Table 1.The blank dimensions are detailed in Table 2.

Table 1

Chemical Composition of specimen material

Fe%	Si%	Cu%	Mn%	Mg%	Zn%	Tn%	Cr%
0.35	0.2-0.6	0.10	0.10	0.45	0.10	0.100.10	

Table 2

Specimen Details

Sl.no.	Diameter (d)mm	Height (h)mm	Aspect ratio(h/d)	Blank number
1.	25	25	1.0	L1,L2,L3,L4,L5 and L6
2.	25	20	0.8	M1,M2,M3,M4,M5 and M6
3.	25	15	0.6	S1,S2,S3,S4,S5 and S6

Fig.1. Specimen of Aluminum 6063 for various aspect ratios- 1.0, 0.8 and 0.6

4.2 Experimental Set up

The experiments were carried out on a 10000 KN capacity Universal testing machine. The setup is shown in Fig.2.

Fig.2.Experimental Setup

4.3. Experiment Procedure

The upset forging tests were conducted at room temperature without lubrication. Blanks were cleaned before each trial. Extreme care is taken to place the blanks concentric with the axis of the machine ram. No lubricants were applied. Before cold upsetting of the blanks, the initial dimensions such as original diameter (d_0) and original height (h_0) were measured. Listed hereunder was the experimental procedure carried out.

1. Place the blank in the machine table.
2. Apply load until desired upset ratio was obtained.
3. Load applied is noted down.
4. The following dimensions were measured before each experiment.
    i. Original diameter
    ii. Original height
5. The following dimensions were measured after each experiment
    i. Upper diameter
    ii. Major diameter of cylinder
    iii. Height of the upset cylinder

Using Auto CAD 2007 software, barrel radius was measured. Fig.3a and 3b shows the front view of the billet before deformation and Fig.3c and 3d shows the shape after deformation.

Nomenclature

d_0 original diameter of a cylinder, mm h_0 original height of a cylinder, mm
d_1 upper diameter of a cylinder, mm h height of upset cylinder, mm
$d_2$major diameter of a cylinder, mm R radius of barreling surface, mm

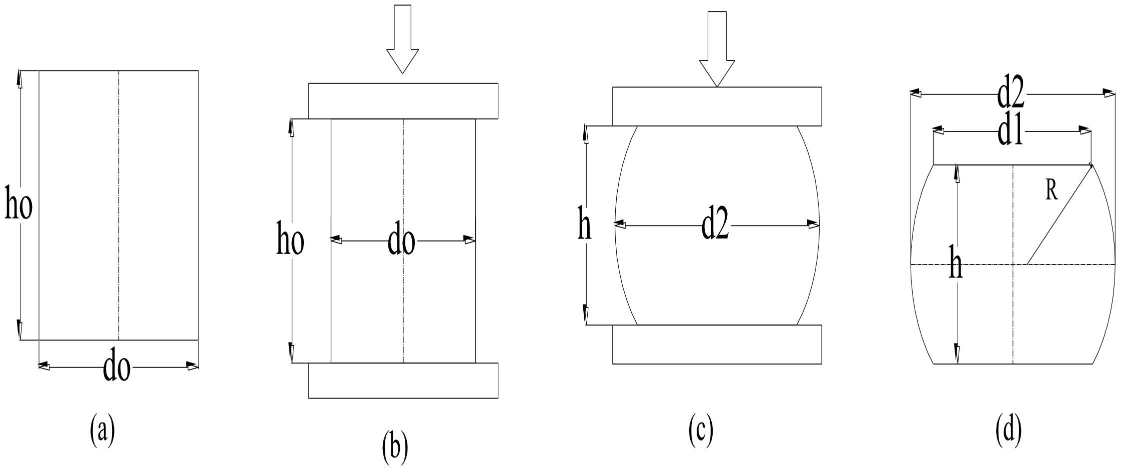


Fig.3. (a) Initial position, (b) Before deformation, (c) After deformation, (d) Final position

The blanks at different stages of upsetting for different aspect ratios and upset ratios are shown in fig.4.

Fig.4.Deformed specimen for various aspect ratios -1.0, 0.8 and 0.6

4.4. Results of Experiments

A comparison of the three aspect ratios, 1.0,0,8 and 0.6 as illustrated in fig.5led to the following observations.

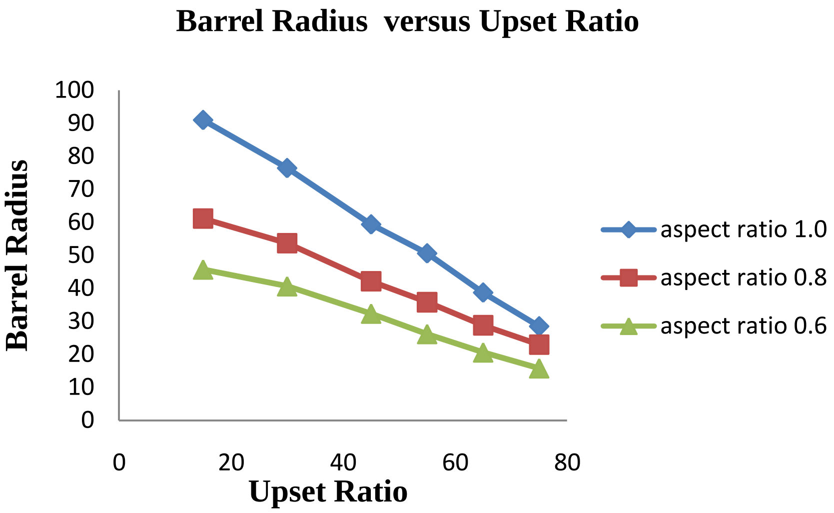


Fig.5.Variations of barreling radius vs. upsetting rate for aspect ratio - 1, 0.8 and 0.6.

Higher the aspect ratio higher upset ratios lead to lower barrel radius and at lower upset ratios results in higher barreling radius. For lower aspect ratios higher upset ratios lead to lower barrel radius and lower upset ratios results in relatively higher barrel radius. In general lower upset ratios results in higher barrel diameters for all aspect ratios. Fig.6 depicts the variation in top surface area for various upset ratios and aspect ratios.

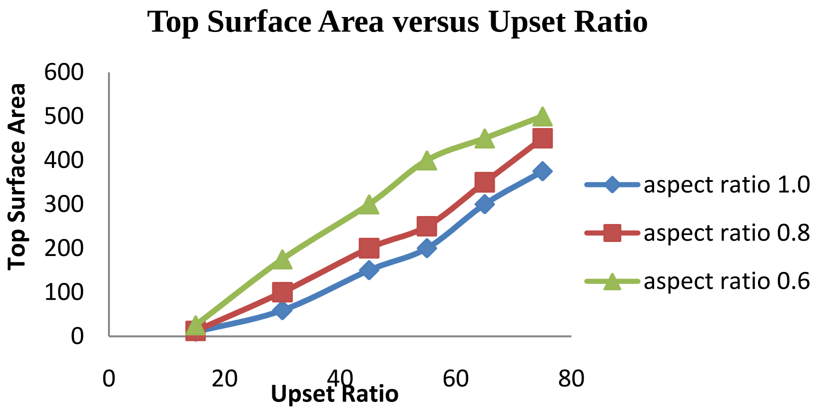


Fig.6. Variations of total surface area vsupsetting rate for the aspect ratio - 1.0, 0.8 and 0.6

Irrespective of aspect ratios the top surface area is higher for higher upset ratios and lower for lower upset ratios.Fig. 7 illustrates the relation ship between load and strain. As it is common knowledge the strain is higher at higher loads and lower at lower loads irrespective of aspect ratios.

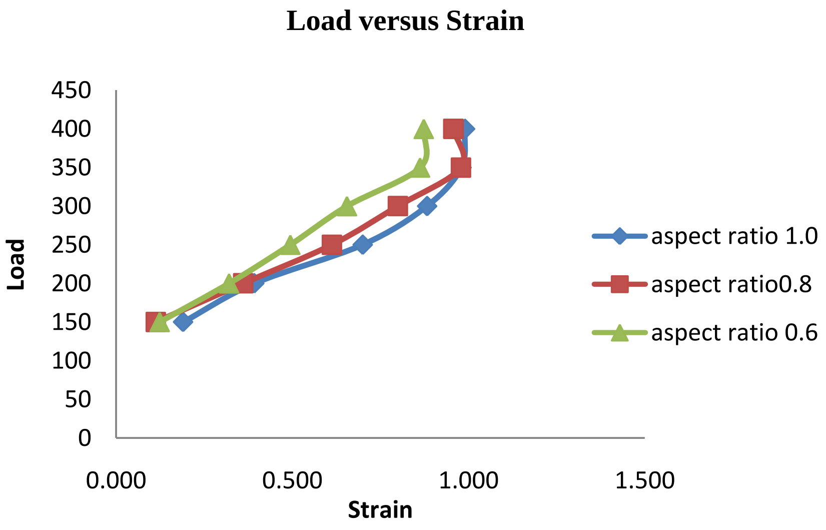


Fig.7. Variation of Load vs. Strain for aspect ratio-1.0, 0.8 and 0.6.

V. VALIDATION OF RESULTS

In order to validate the experimental results response surface method was employed to arrive at regression models and its coefficients employing the non- linear least –squares (Full quadratic) method.Barreling radius was obtained as functions of upset ratio and aspect ratio and the barreling load was obtained as functions of aspect ratio and barreling radius. The regression analysis output is listed hereunder:

Estimated Regression Coefficients for barrel radius

```
Term           CoefSECoef       T      P
Constant       41.655  26.7156   1.559  0.145
aspect        -94.044  66.2473  -1.420  0.181
upset           1.390   0.3543   3.923  0.002
aspect*aspect  152.849  41.7827   3.658  0.003
upset*upset     -0.017   0.0047  -3.585  0.004
aspect*upset    -1.726   0.3719  -4.642  0.001
```

Estimated Regression Coefficients for load

```
Term             CoefSECoef       T      P
Constant       189.753    9.472   20.032  0.000
aspect          89.059   12.955    6.874  0.000
barrel        -206.872   18.629  -11.105  0.000
aspect*aspect    1.145   10.999    0.104  0.919
barrel*barrel   21.706   25.812    0.841  0.417
aspect*barrel   61.125   25.560    2.391  0.034
```

Fig.8 shows the variation of barreling radius as a function of aspect ratio and upset ratio.

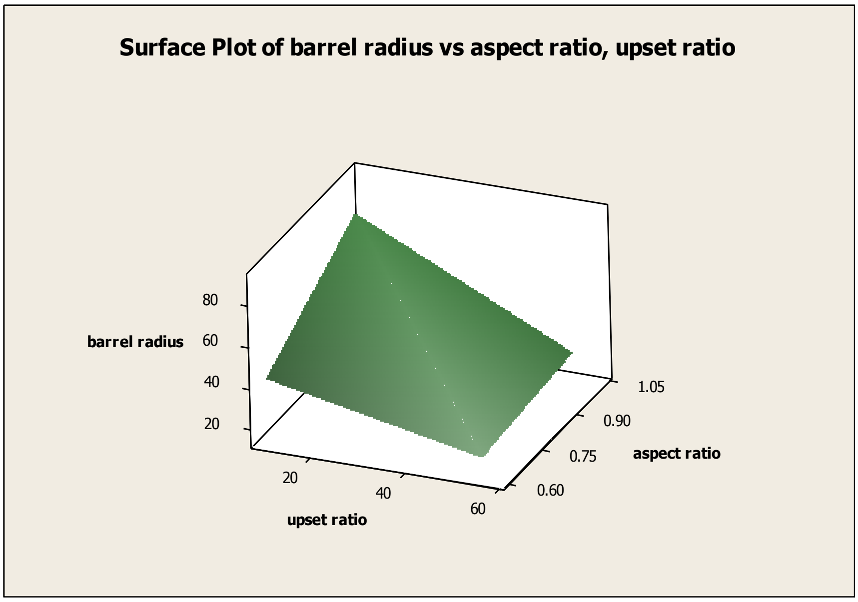


Fig.8. Barreling radius as a function of aspect ratio and upset ratio

The respective contour plot is shown in fig. 9.

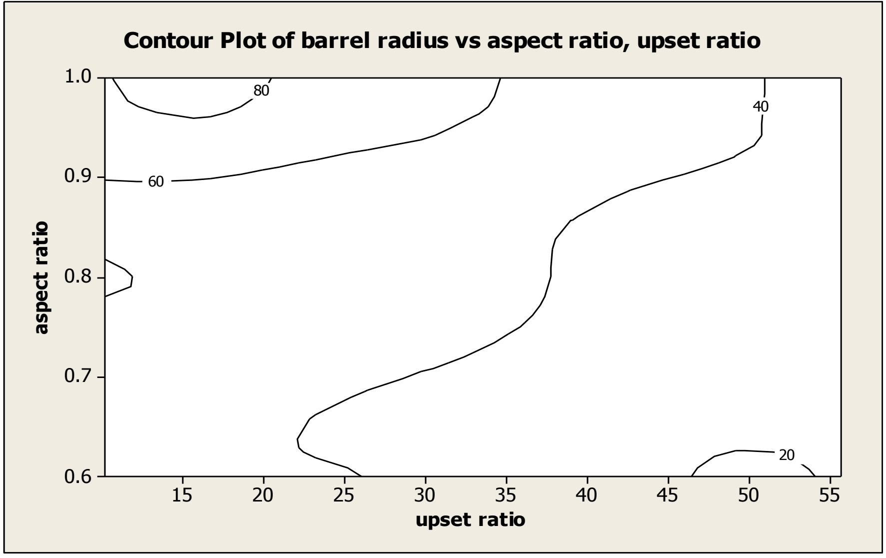


Fig.9. Contour plot for barreling radius as a function of aspect ratio and upset ratio.

Fig.10 shows the variation of load as a function of aspect ratio and barrel radius.

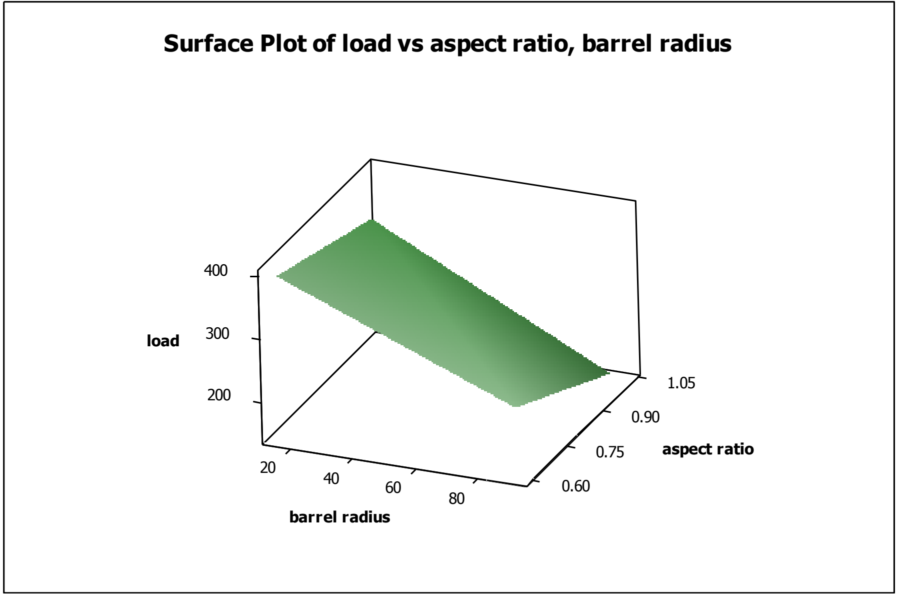


Fig.10. Load as a function of aspect ratio and barrel radius

The respective contour plot is shown in fig. 11.

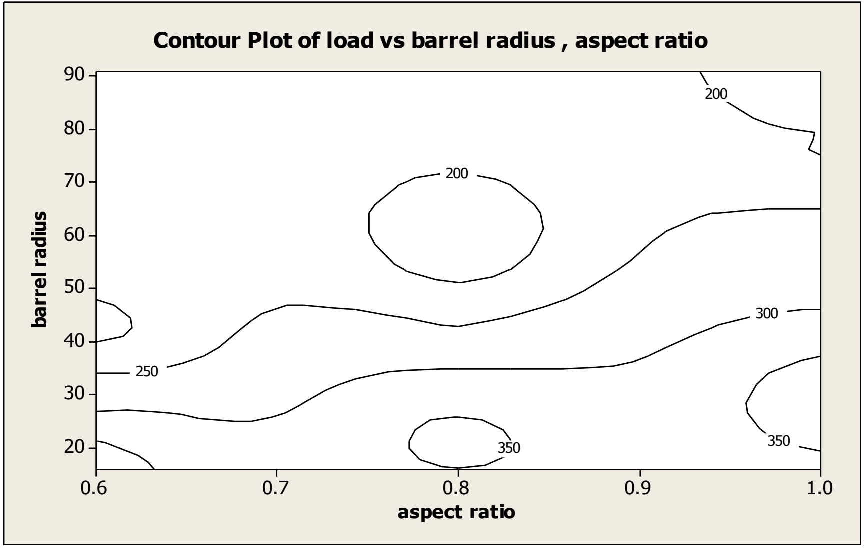


Fig.11. Contour plot for Load as a function aspect ratio and barrel radius

It can be seen that the increase in upset ratio is more pronounced compared to increase in aspect ratio resulting in increase in barrel radius as depicted in fig. 8.Likewise the increments of aspect ratio are more pronounce compared to load for increase in barrel radius.

Owing to Montgomery et al [12].the above contour plot suggests the regression equation,
Barrel radius = 41.655 -94.044 X aspect ratio +1.390 X upset ratio + 152.849 (aspect ratio)^2
-0.017 (upset ratio)^2- 1.726 X aspect ratio X upset ratio and
Load = 189.753 + 89.059 X aspect ratio – 206.873 X barrel radius + 1.145 (aspect ratio)^2
+21.706 X (barrel radius)^2+ 61.125 X aspect ratio X barrel radius
$R = 16.901 + 12.426 \times (h/d) + 0.406 \times e + 75.237\,(h/d)^2 - 8.587\times10^{-4}\times e^2 - 1.35\times(h/d)\times e-$ (1)
$L = 577.131 - 129.902\times (h/d) - 13.749\times R + 72.585 \times (h/d)^2 + 0.013\times(R)^2 + 8.550\times(h/d)\times R$ (2)
The comparison of experimental results is illustrated in fig.12.

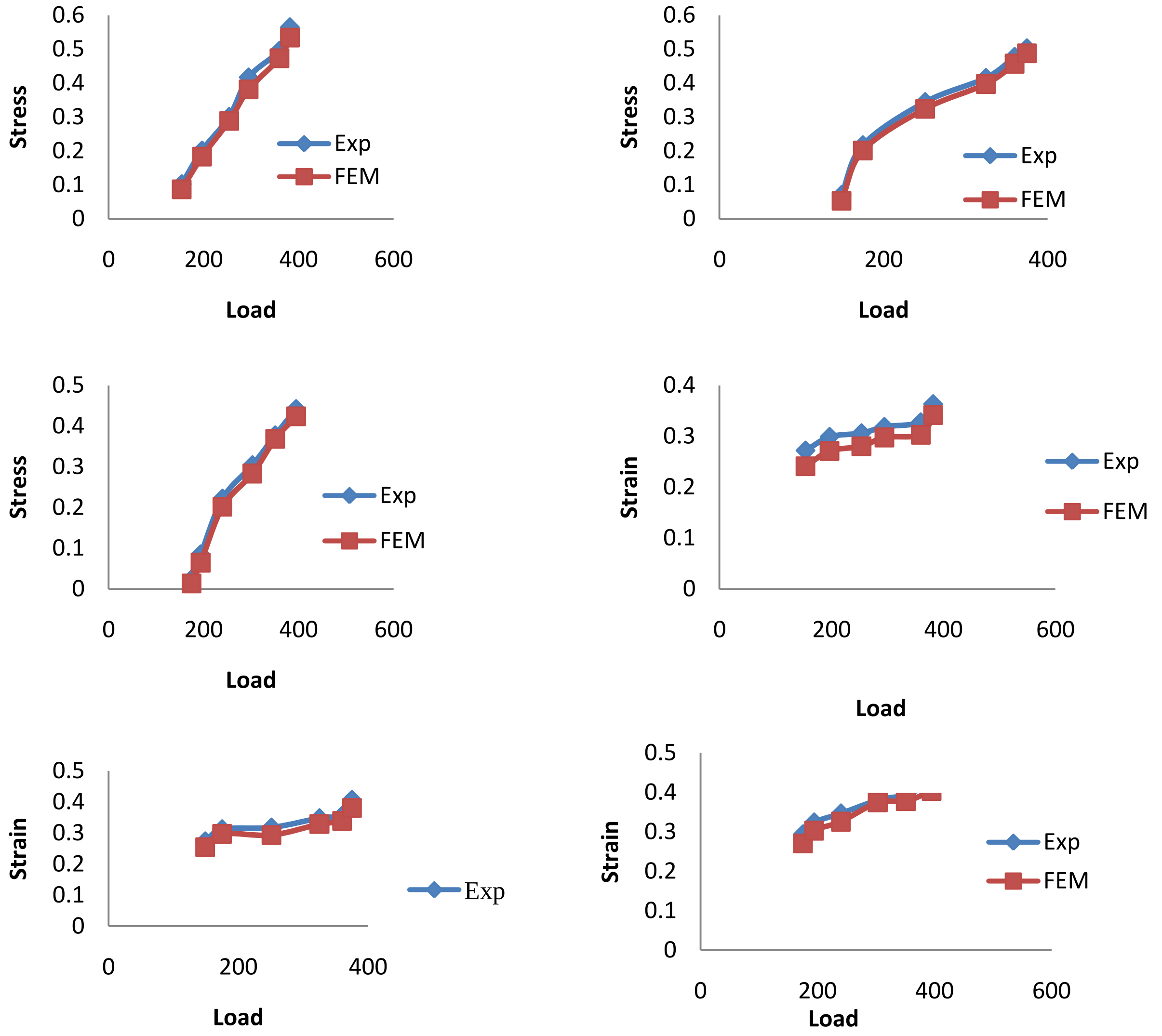


Fig.12.Comparison of experimental results and FEM values

It can also be seen from the illustration below that the experimental and simulated barrel radius are same.

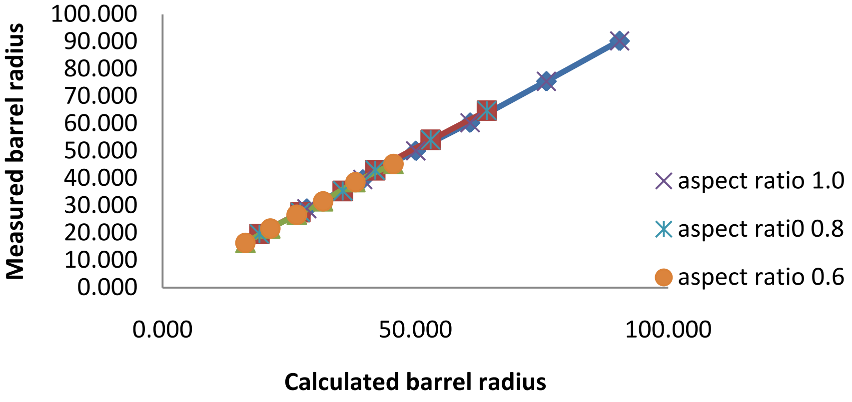


Fig.13. Graph of the measured barrel radius versus calculated barrel radius.

VI. SENSITIVITY ANALYSIS

Aluminum rivets and other fastening materials are widely used in industrial applications. The manufacturing process involves multistage production and progressive die operations. The top surface area is a critical dimension for the finished product, as it has to mate with the rivet hole. Many conclusions emanate from this study will facilitate tool design for rivets and fasteners. This study reveals that the surface area increases with increase in aspect ratio and upset ratio. There is no appreciable difference in characteristics between aspect ratio 0.6 and 0.8. There is a steep and linear increase in top surface area beyond upset ratio of 40 %. Relatively higher top surface area results for aspect ratio of 1.0 beyond upset ratio of 40 %. These are illustrated in Fig.14.

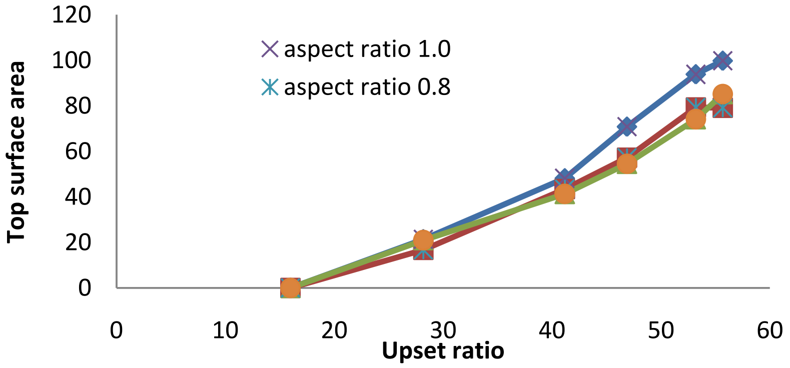


Fig. 14. Sensitivity graph of the Upset ratio versus Top surface area

The stress – strain characteristics by both experimental method and by simulation using finite element method shows that the increase in aspect ratios results in increase in strain. For upset ratios 20 % to 30 % there appears to be a characteristic plastic region. This is inferred as latent and sporadic work hardening. Similar phenomena are also observed in upset ratios 40 % to 50 %.

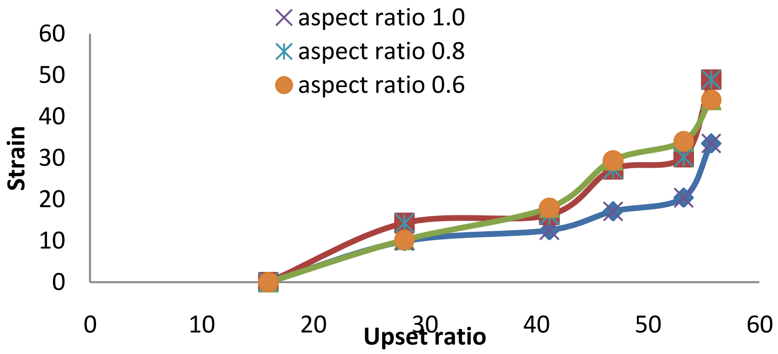


Fig.15. Sensitivity graph of the Upset ratio versus strain

A study of the sensitivity of barrel radius reveal that the barreling radius show a steep and linear decline until up to upset ratio of 40 % and further decline is observed to be non linear from 40 % to 50 %. Sudden drop in barrel radius is observed after upset ratios of 50 %.

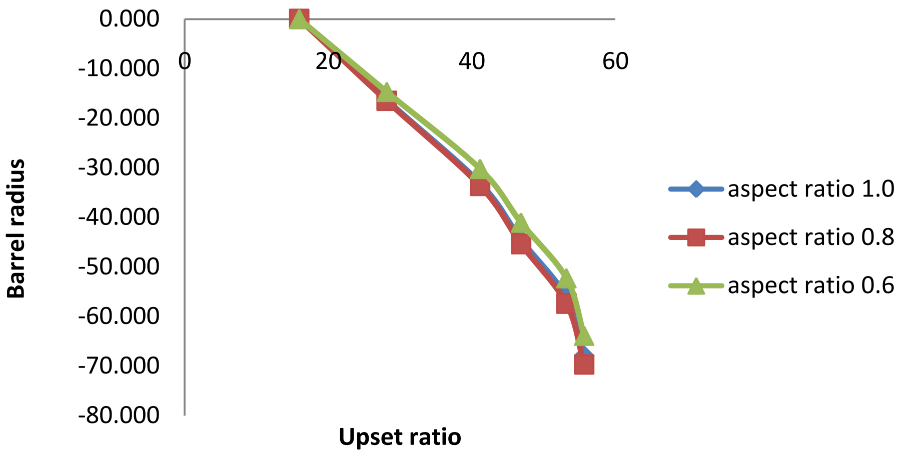


Fig.16. Sensitivity graph of the Upset ratio versus barrel radius

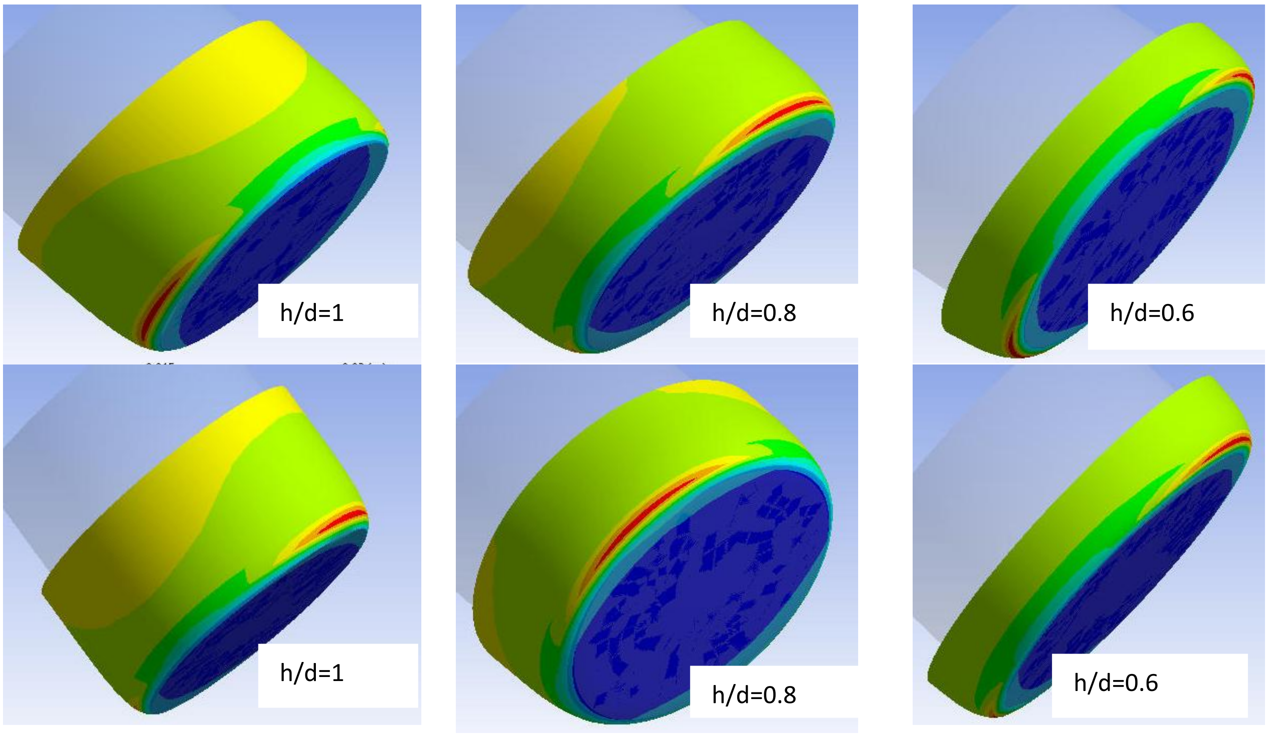
Stress, strain distributions are illustrated in Appendix 1.

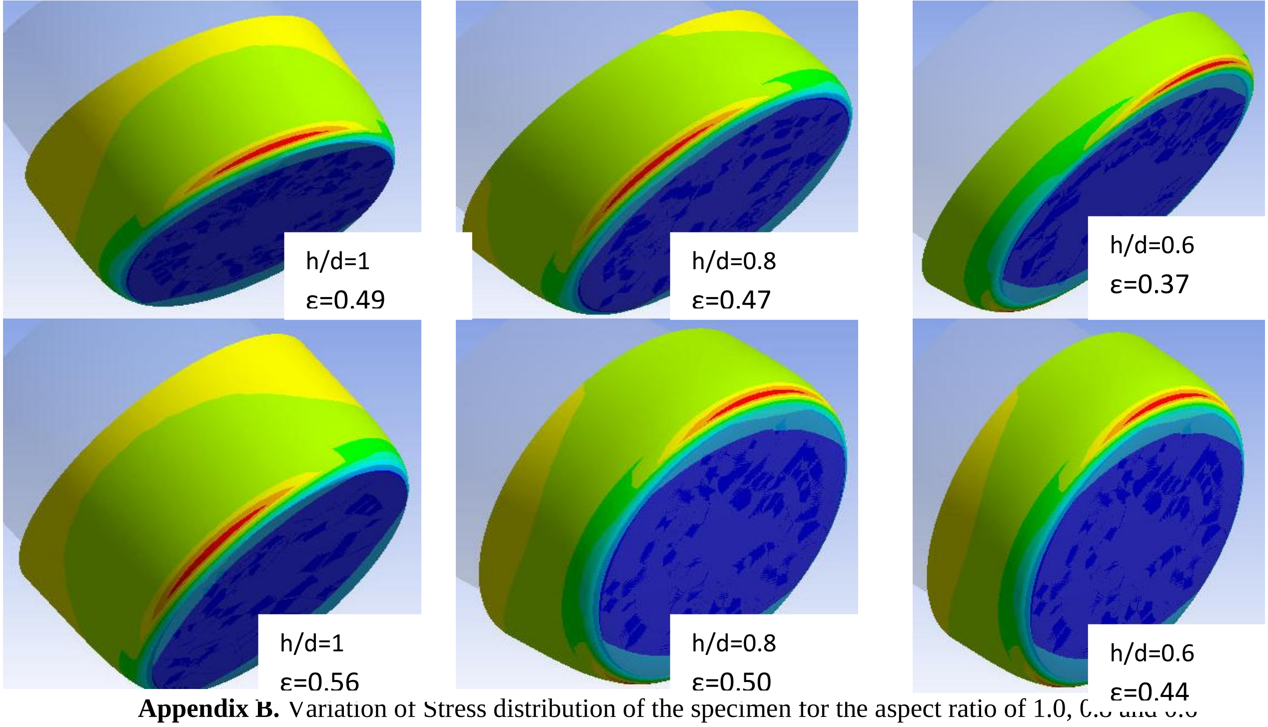
VII. CONCLUSIONS

In this work the characteristics of barreling radius, strain and top surface area have been studied for Aluminum 6063 material specimens. Some important inferences made will have direct application in shop floor production situations. The non linearchanges in top surface area dimensions will form the basis in design of forging tools and design of statistical tolerance for the manufactured products. Intermittent work hardening inferred from no change in strain for increase in upset ratio will demand suitable increase in load requirements for forgingprocess.The barreling radius behavior for various upset ratios will aid development of tooling and product deign and development.

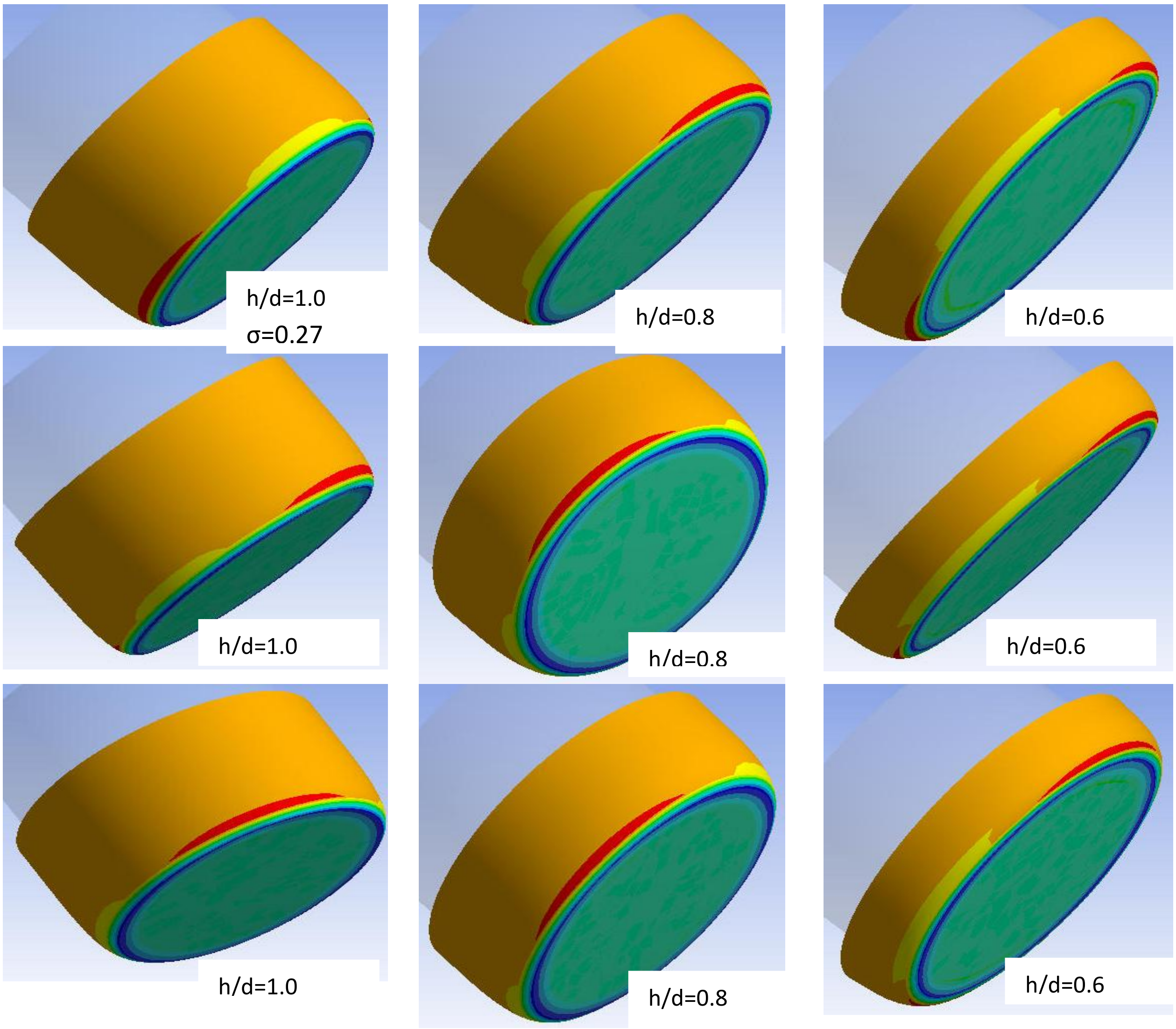
Further work exists in the areas of microscopic study of intermittent work hardening and study of parabolic behavior of changes in barrelingradius and top surface area for aluminum 6063 material specimen

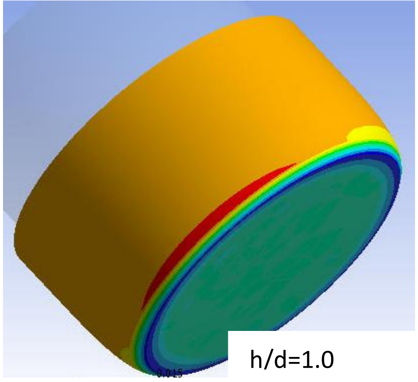
Appendix A Variation of Strain distribution of the specimen for the aspect ratio of 1.0, 0.8 and 0.6

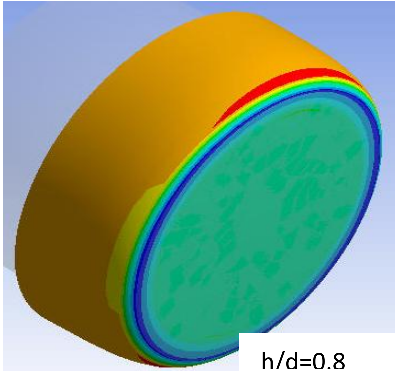


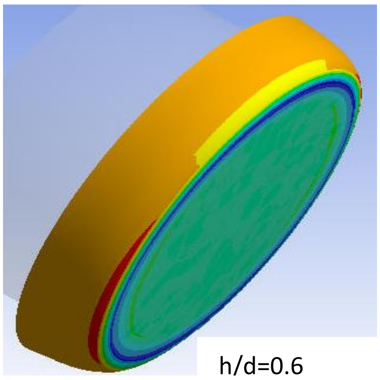


Appendix B. Variation of Stress distribution of the specimen for the aspect ratio of 1.0, 0.8 and 0.6




h/d=1.0


h/d=0.8


h/d=0.6

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