AN EXPERIMENTAL STUDY OF BARRELING AND FEM BASED SIMULATION IN COLD UPSETTING OF ALUMINUM

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Abstract: The deformation behaviour of solid aluminium cylinders under axisymmetric compression over different aspect ratios without using any lubricant was examined. Two different aspect ratios namely 1.0 and 1.5 were prepared and cold upset forged. In the light of the previous studies, the calculations were made with the assumption that the curvatures of deformed specimens were in the form of a circular arc. The measured radius of curvature of the bulge was found to confirm with calculated values obtained using experimental data. The relationship was also established the top and maximum diameters. AA6082 was used as test material and experiments were carried out on 150 metric ton capacity hydraulic press. Bulging profile and effective strain distribution of the billets were also obtained a commercially FEM program called DEFORM 3D.

Key words: Barreling, Upset forging, Aluminium, DEFORM 3D.

1. INTRODUCTION

Upsetting is of interest for theoretical and experimental studies as a metal forming process. It is a basic process which can be varied in many ways. The existence of frictional constraints between the dies and the workpiece leads to barrelling of the cylinder and lateral expansion of the specimen is maximum at equatorial section and minimum at end section (Fig.1). However the use of lubricants reduces the degree of bulging and under ideal lubrication bulging can be brought down to zero.

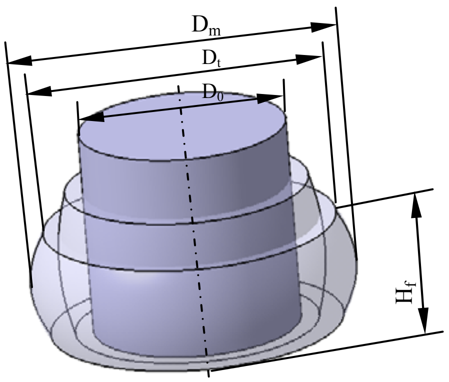


Fig.1 Barreling profiles at different stages and related dimensions.

The barreling shape of a cylinder under compressing testing has been quantitatively investigated by many researchers. Kulkarni&Kalpakjian (1969) conducted an experimental study of barreling in the upsetting of aluminum billets with and without lubrication. Based on their measurements, they concluded that the profile of the barreled billets can be assumed as an arc of a circle and the shape of the barrel is affected by the initial h_0/d_0 ratio and by the friction conditions. Resting on the work by Latham&Cockcroft (1966) who had suggested the profile of the barreled surface as an approximation of an arc of a circle, the researchers used ratio of current height to current radius of curvature of specimen as a parameter (H_{ur}) to characterize the extent of barreling. Schey et al (1982) announced that, the shape of the barrel is affected by the geometrical factors such as, the h_0/d_0 ratio, reduction ratio and diameter ratios. They expressed that a power law can represent the barreling profiles of steel and aluminum specimens well for both low and high friction conditions. Gupta&Shah(1985) and Tseng el al. (2001) found out that the barreled shape can be reasonably characterized as the arc of a circle or a circular curvature. Malayappan&Narayanasamy (2003) aimed to find a relationship between the measured radius of curvature of the barrel and new geometrical shape factor based on contact diameters, barrel diameters, initial height and hydrostatic stress while using a die with constraints at one end. Baskaran& Narayanasamy (2008), in their theoretical and experimental studies, prepared billets which having three different aspect ratios namely 0.5, 0.75, 1.0 and cold upset forged. The calculations were made with the assumption that the curvature of the barrel followed the form of a circular arc. Barreling behavior of truncated billets of aluminium, zinc and copper were studied by Abu Thaheer&Narayanasamy (2008) and barrel radius was defined a power law equation changing with stress ratio.
In the presented study deformation behaviour of solid aluminium cylinders under axisymmetric

compression over different aspect ratios under dry as well as lubricated conditions without using any lubricant were investigated. Process was simulated a commercial FEM programme and strain distributions of the billets were presented.

2. EXPERIMENTAL STUDY

AA6082 has been chosen as an experimental material. AA6082 has excellent strength, corrosion resistance and cold formability, thus extensively used by the automotive industry. Cylindrical specimens of 25 mm diameter and 25 and 37.5 mm lengths were prepared from the bar, so the aspect ratios of specimens were obtained as 1.0 and 1.5 respectively. Specimens were annealed for 2h at 425^{o}C and allowed to cool in furnace. The upper and lower dies were made of 1.2344 hot worked steel and hardened in 53HRc and their surfaces were ground. The experiments were carried out on a 150 metric ton capacity hydraulic press with 5 mm/s ram speed. The upset forging tests were conducted at room temperature under unlubricated conditions and the specimens were carefully cleaned with acetone so as to provide a similar friction condition before deformation. Extreme care was taken to place the axis of the cylindrical specimen concentric with the axis of the ram. Compressive upsetting was carried out up to a true height strain (ln h_o/h_f) of 0.8 Loads were recorded by using a pressure-current transducer and experiments were automatically stopped. The upper plate of the press accomplished previously determined and adjusted position by means of true height strains. Two specimens were used for each strain value. After the experiments, the following parameters were measured: 1) the height of the deformed specimen (h_f); 2) the top and the bottom diameters of the specimen (D_t) and 3) the maximum diameter of the part (D_m).
Assuming volume constancy during deformation and barreling, and stresses were calculated in each case using the simple expression as:

$$\sigma = 8F/\pi\left(\frac{3h_0 d_0^2}{h_f} - D_m^2\right) \qquad (1)$$

where σ is the compressive stress, F is the load, h_0 and d_0 are the initial height and the initial diameter of the cylinder, and D_m and h_f are the maximum diameter and the height of the barrel after each stage of loading.
On the other hand, according to Narayanasamy& Pandey (2000) the simplified expression for the radius of the circular arc of the barrel can be written as follows:

$$R_b = H_f^2/4(D_m - D_t) \qquad (2)$$

3. RESULTS AND DISCUSSION

True strain versus experimental load curves is given in Fig.2. Inıtial stages of the process, load values are quietly closer each other but expecially after the true strain value ε_t=0.4 (ε_t=ln h_o/h_f) billets having smaller aspect ratio gives higher compressive loads as expected.

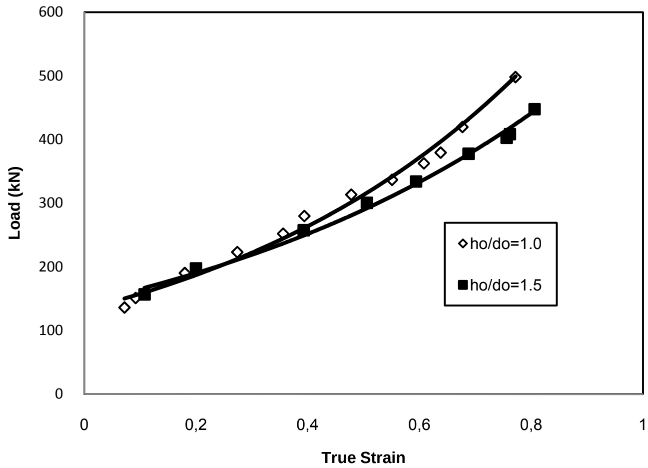


Fig. 2. Variation of load versus true strain

DEFORM-3D is a powerful process simulation system designed to analyze the three-dimensional (3D) flow of complex metal forming processes such as closed die forging, open die forging, machining, rolling, extrusion and upsetting. DEFORM-3D is a practical and efficient tool to predict the material flow in industrial forming operations without the cost and delay of shop trials.
Complex multiple deforming body capability with arbitrary contact allows users to simulate mechanical joining and coupled die stress analysis. Nowadays, DEFORM is the most widely used simulation program in the world by leading research institutes and manufacturers.
In the current simulation in order to ensure that the simulation agrees actual upsetting process as possible, the analysis was carried out for 40000 mesh number of each part.
Effective strain distrubitions for the parts deformed different true strain values for for two different aspect ratios are given in Fig. 3.
According to color scale true strain values are closer the computer results. Effective stress distributions are also given in Fig.4 and results obtained from the color scale values are strictly closer to calculated ones.

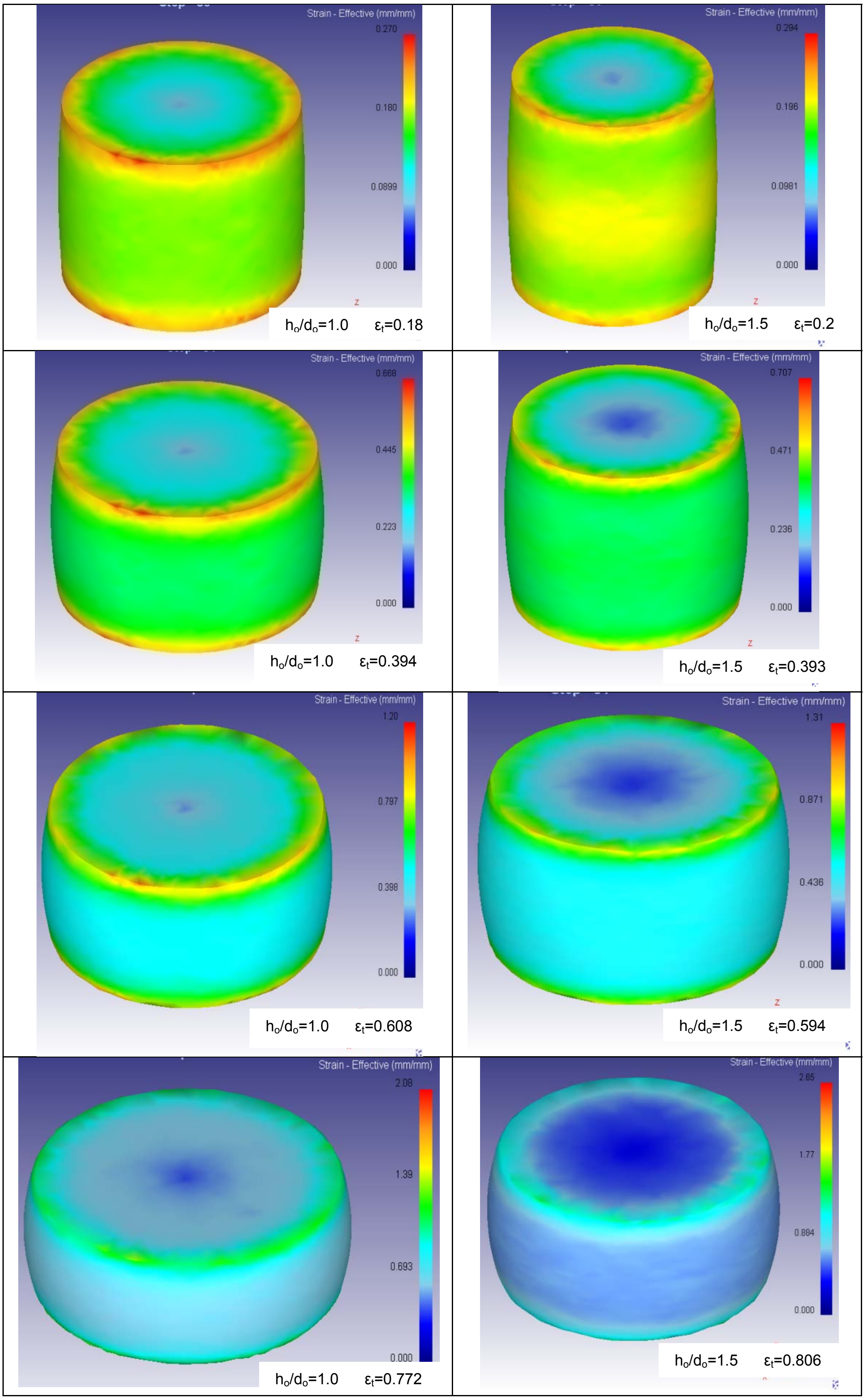


Fig. 3. Strain distribution of the billet with different deformation degrees

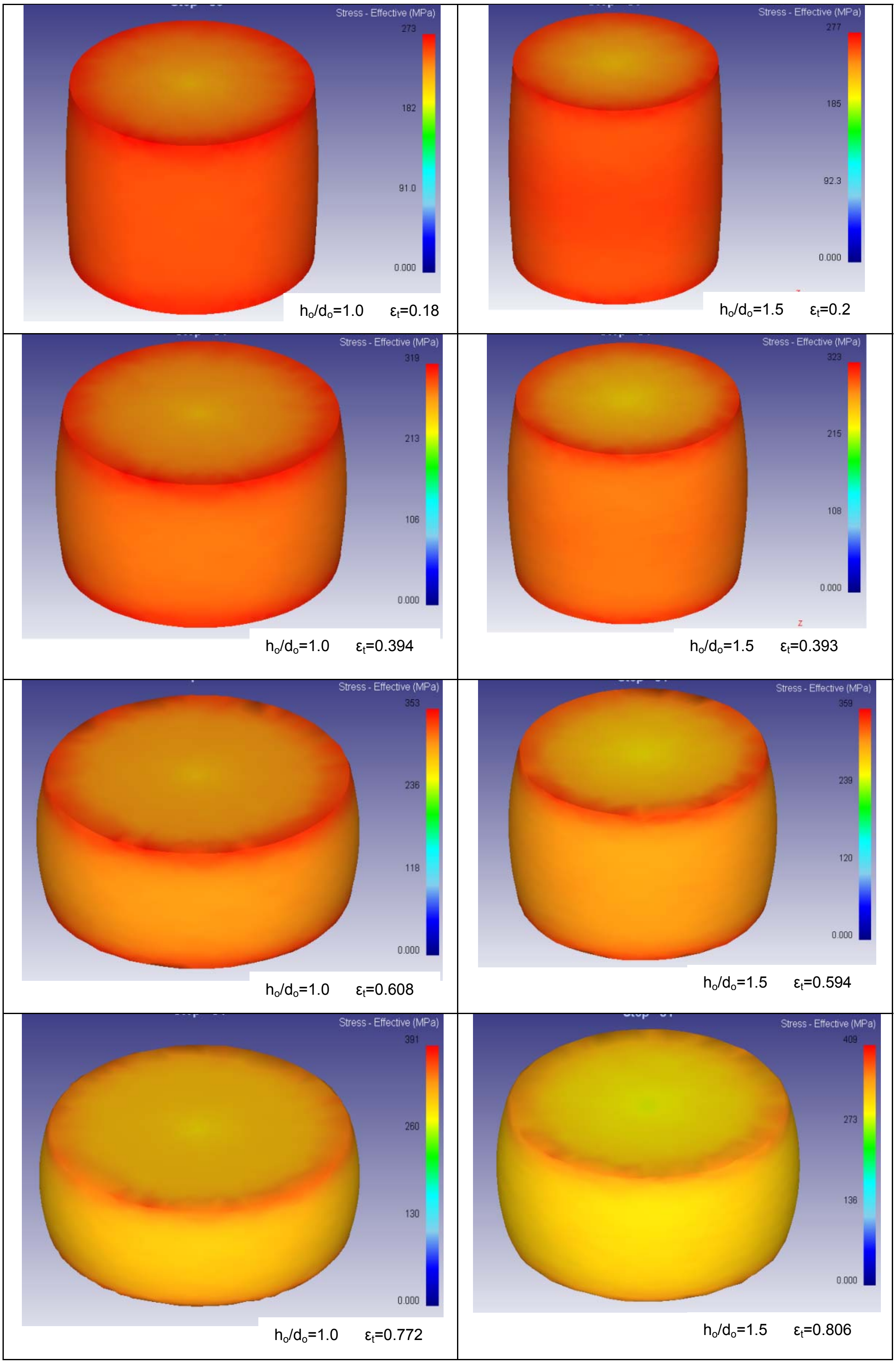
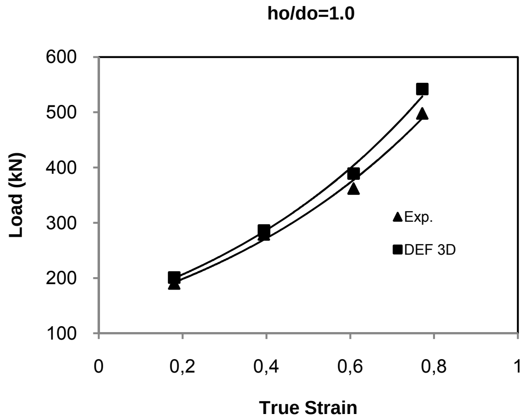
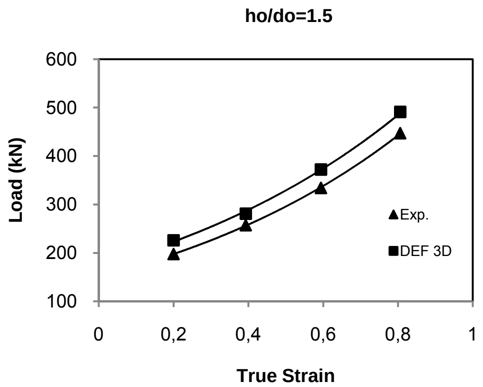


Fig. 4. Effective Stress distribution of the billet with different deformation degrees

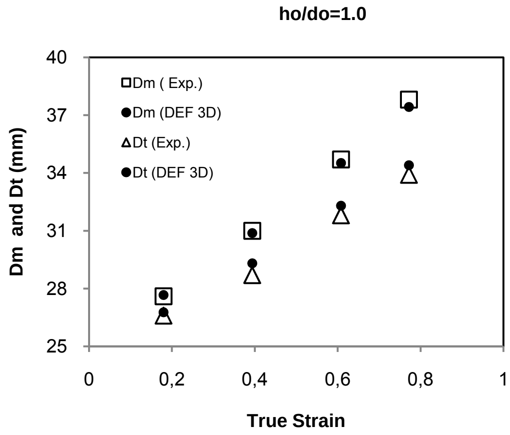


a)

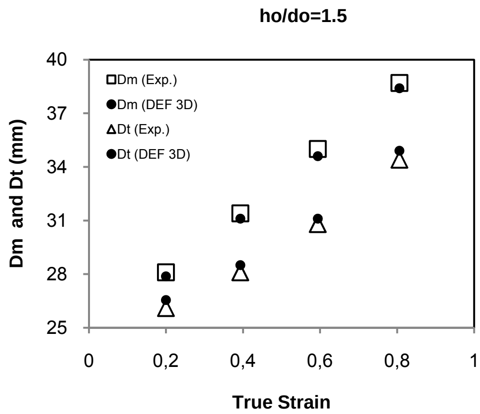


b)

Fig.5. Comparison between theoretical and experimental load values for two aspect ratios a) h_o/d_o=1.0 b) h_o/d_o=1.5



a)



b)

Fig.6. Maximum and top diameter values for both measured from experiments and obtained from DEFORM 3D. a) h_o/d_o=1.0 b) h_o/d_o=1.5

Load values obtained from experiments and DEFORM 3D were compared and results were given in Fig.5 a) and b). Load values obtained from the programme gives higher values for both h_o/d_o=1.0 and h_o/d_o=1.5 samples. The difference between load values obtained from experiments and DEFORM 3D is max. 9% for the billets having aspect ratio of h_o/d_o=1.0 and 12% for the h_o/d_o=1.5. This difference is acceptable and pres capacity which is important criteria for forming can be found in short time.

D_m and D_t values obtained from the experiments and DEFORM 3D were compared in Fig.6 a) and b). According to diagram the maximum and the top diameter values obtained form the programme gives very realistic results especially for D_m values. The differences between the actual dimensions and the theoretical results are varying from 0.07 to 0.61 mm.

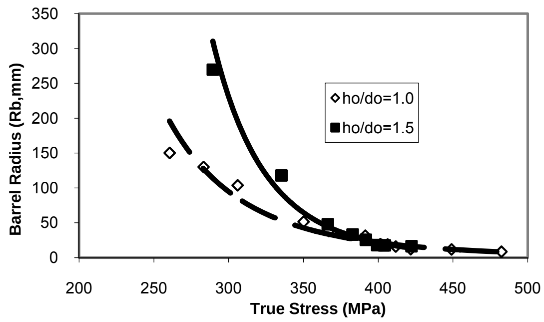


Fig.7. The variation of the barrel radius with the true stress

The calculated barrel radius form Eq.2 plotted against the calculated true stress in MPa from Eq.1 and given in Fig.7. Increasing the aspect ratio from 1.0 to 1.5 significantly increased the barrel radius when subjected to the same stress. As the values of the stress increase the barrel radius decreases exponentially. According to diagram the higher the aspect ratio the lower the barreling. Because the higher the cylinder for a fixed diameter the less is the barrel arc, and for an infinitely high cylinder, therefore, there would be no barrelling in theory but this phenomena is invalid especially because of the buckling in practice.

Figure 8 and Figure 9 show the change of shape geometry of cylinder during deformation in different h_o/d_o ratios. As seen in the figures, the difference between maximum and the top diameter is remarkable and measurable. According to diagrams by decreasing the height of the cylinder the difference between maximum and top diameter increases. This result is consistent with the study of Ebrahimi & Najafizadeh (2004). The diameter and height of billet were chosen bigger than that of used by Ebrahimi by keeping h_0/d_0=1.5 because sensitivity of this method will increase by the increase in dimensions of the cylinder as stated in the mentioned study. In the presented study, the dimensions of the billets with aspect ratio of 1.5 are five times greater than billets used by Ebrahimi & Najafizadeh (2004).

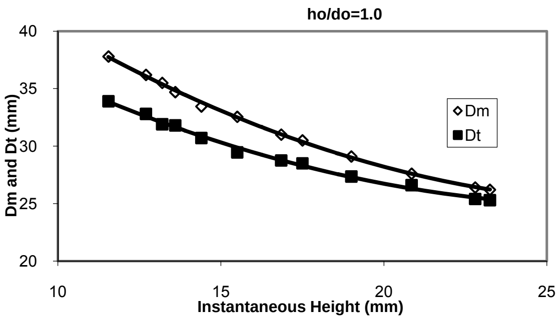


Fig. 8. Change of maximum and top diameter versus height of cylinder during deformation for h_o/d_o=1.0

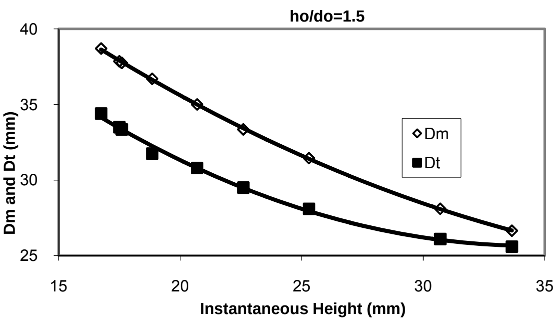


Fig. 9. Change of maximum and top diameter versus height of cylinder during deformation for h_o/d_o=1.5

As mentioned before a non-dimensional H_{ur} parameter was suggested Latham&Cockcroft (1966) and was found suitable by the other researchers to explain the extent of barreling. Kulkarni & Kalpakjian (1969) had shown that the proposed parameter H_{ur} varies linearly with percentage reduction and it's insensitive to h_o/d_o but the present results see in Fig.10 reveal that H_{ur} varies with h_o/d_o as stated previously by Gupta (1985).

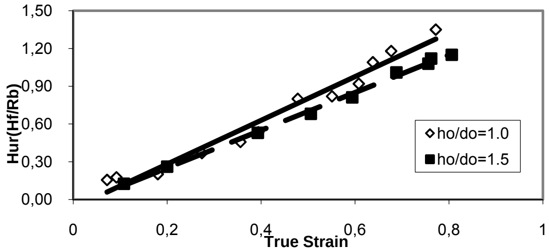


Fig. 10. The variation of H_{ur} with the aspect ratio

4. REFERENCES

1. Abu Thaheer, A.S., Narayanasamy, R. (2008). *Comparison of barreling in lubricated truncated cone billets during cold upset forging of various metals*, Materials & Design, 29, pp. 1027-1035, ISSN 0261-3069.
2. Baskaran, K., Narayanasamy, R. (2008). *Some aspects of barreling in elliptical shaped billets of aluminum during cold upset forging with lubricant*, Materials & Design, 29, pp. 638-661, ISSN 0261-3069.
3. Ebrahimi, R., Najafizadeh, A. (2004). *A new method for evaluation of friction in bulk metal forming*, *Journal of Materials Processing Technology*, 152, pp. 136-143, ISSN 0924-0136.
4. Gupta, N.K., Shah, C.B. (1985). *Barreling of a short cylinder in compression*, International Journal of Machine Tool Design Research, 26, No. 2, pp. 137-146, ISSN 0020-7357.
5. Kulkarni, K.M., Kalpakjian, S. (1969). *A study of barreling as an example of free deformation in plastic working*, ASME Journal of Engineering for Industry, 91, pp. 743-754.
6. Latham, D.J., Cockcroft, M.G. (1966). *The effect of stress system on the work ability of metals*, NEL Report No. 216, National Engineering Laboratory, February, Scotland.
7. Malayappan, S., Narayanasamy, R. (2003). *Some aspects on barreling in aluminium solid cylinders during cold upset forging using a die with constraints*, Journal of Materials Processing Technology, 135, pp. 18-29, ISSN 0924-0136.
8. Narayanasamy, R., Pandey, K.S. (2000). *A study on the barreling of sintered iron performs during hot upset forging*, Journal of Materials Processing Technology, 100, pp. 87-94, ISSN 0924-0136.
9. Schey, J.,Venner, T.,Takomana, S.L. (1982). *Shape changes in the upsetting of slender cylinders*, ASME Journal of Engineering for Industry 104, pp. 79-83. ISSN 0022-1817.
10. Tseng, A., Horsky, J., Raundesky, M., Kotrbacek, P. (2001). *Deformation behavior of steels in mushy state*, Materials & Design, 22, pp. 83-92, ISSN 0261-3069.

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