IFERP

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 1, Issue 6, October 2016

Utilization of Damage Criteria to Improve the Formability of the Billets in Cold Forging

[1] HariKrishna ch[2] SrinivasaRaju P[3]SrinivasaRao G
[1][2][3] Department of Mechanical Engineering,
[1][2][3]Shri Vishnu Engineering College for Women, Vishnupur, Bhimavaram, India - 534202
[[1]harinitw@gmail.com,[2]sri_raju76@yahoo.com, [3]srinivasaraog@svecw.edu.in

***Abstract:--* The investigation of ductile fracture plays a significant role in achieving the required deformation without the failure of the specimen. Three cylindrical billets with different aspect ratios (height (h) to the diameter (d)) namely h/d=0.5, h/d=0.75 and h/d=1 were considered for the analysis. To increase the level of deformation without failure three different lubricants namely grease, molybdenum disulphide and grease were employed at the faces of the billet. A series of experiments were carried out in conjunction with the finite element modeling for different aspect ratios and different lubricants. The cylindrical billets were deformed plastically in between the two rigid dies to different strain limits. The true plastic strain at which the billet has fractured is termed as critical damage and this value was predicted using Normalized Cockroft-Latham, Cockroft-Latham, and Brozzo and Freudenthal workability criteria's. The accuracy of the workability criteria's with respect to the cylindrical billets of different aspect ratios was closely monitored in predicting the critical damage. An effort to improve the formability of the material enabled the effective utilization of the material and the processing conditions.**

***Index Terms:* — critical damage, ductile fracture, forging, lubrication.**

I. INTRODUCTION

In the bulk metal forming processes such as forging where larger plastic deformations are possible, the possibility of fracture is also likely to be more. This problem is more predominant in cold working condition. For the affective utilization of the material and the processing conditions, the fracture must be avoided. The study of ductile fractures minimizes the chances of failure in the cold upset forging process which improves the formability of the material. Several authors made experimental investigations on the formability of the bulk deformation processes and sheet metal working. Jha [1] et al. made experimental investigations to examine the formability of copper powder strips under cold working condition. The theoretical investigations made by Jha were in close agreement with the experimental results. The study on the flow pattern of the copper powder strips helped in investigating the fracture limit of the powder preforms. By assuming the state of triaxial loading, a detailed investigation on the damage of round bars, doubly grooved flat plate, dog bone specimen was carried out by Liang [2]. Liang termed the damage as deterioration of the material when it undergoes plastic deformation causing fracture in the material. By conducting the finite element studies, Liang determined the crack paths of the specimens. The experimental results revealed that fracture envelope is based on the combined effect of the hydrostatic pressure and Lode angle. A comparison between coupled and uncoupled damage models has been made by Zheng et al. [3] from the experimental and finite element investigations to predict the ductile fracture in the material by conducting the tensile and compression tests. They notified that only the coupled damage models which are based on the evolution and history of the damage could predict the ductile fracture accurately compared to the uncoupled damage models.

Application of finite element methods and neural networks reduces the extent of experimentation. Kim et al. [4] predicted the ductile fractures in simple solid cylindrical upsetting process by considering the cockroft-Latham workability criteria. With the aid of neural networks, the damage values for different levels of deformations were predicted without applying finite element simulations. Venkata reddy et al. [5] combined the damage criteria's of continuous damage mechanics [6] (developed based on the microscopic defects such as void coalescence, growth and nucleation) with the damage criteria based on hydrostatic stress component [7] for the die design of the drawing process. They explained that the hydrostatic stress criteria was able to predict the ductile fracture accurately which reduced the complexity when compared to the other two criteria's and also for the quality design of the die..

The investigation of hoop stresses and hydrostatic stresses aid in determining the magnitude of critical damage near the region of fracture. Gouveia et al. [8] predicted the critical damage of the material by employing uncoupled damage models such as cockroft-Latham [9] and oyane [10]. According to them, the accuracy of the critical damage

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 6, October 2016

value depends on the damage criteria employed and the type of the geometry considered for the investigation.

Several authors termed the value of critical damage as a material constant and it can be changed based on the condition of heat treatment. The critical damage value may be a material constant but the effort to increase the formability of the material has not been made in the earlier studies. This has been the major limitation because the increase in formability of the material by proper lubrication will make effective utilization of the material and processing conditions. The present work aims at increasing the formability of the material to attain higher plastic strains. Three different solid cylindrical specimens of different height (h) to the diameter (d) ratios namely h/d=1, h/d=0.75 and h/d=0.5 and three different lubricants namely grease, molybdenum disulphide and white grease were employed at the faces of the billet. The billets were upset between the two rigid dies to predict the fracture limit and to validate the assumption that critical damage value is a material constant [11, 12]. Even though there are some limitations in uncoupled damage models, they are widely used because of their simplicity. The finite element software DEFORM 2D was incorporated with the uncoupled damage criteria, the solver can easily predict the fractured zones and the values thus obtained can be easily validated with the empirical results.

II. DUCTILE FRACTURE CRITERIA

The ductile fracture of a material depends on the combination of stresses, strains, and strain rate. This led to the development of several workability criteria which are useful for predicting the critical damage. Freudenthal [13] proposed a workability criteria based on the critical plastic work per unit volume.

$$\int_0^{\varepsilon_f} \sigma_{eff}\, d\varepsilon = C_1 \qquad (1)$$

Where σeff is the true stress, dε is the effective strain increment and εf is the true plastic strain. Cockroft and Latham [9] realized the significance of the largest tensile stress which is responsible for the fracture and developed a fracture criteria based on tensile energy per unit volume.

$$\int_0^{\varepsilon_f} \sigma_1\, d\varepsilon = C_2 \qquad (2)$$

Where σ1 is the largest (tensile) principal stress =σθ circumferential stress) for axisymmetric cylindrical compression test.The normalized version of the above criteria can be expressed as

$$\int_0^{\varepsilon_f} \frac{\sigma_1}{\sigma_{eff}}\, d\varepsilon = C_3 \qquad (3)$$

In view of the importance of the largest principle stress and hydrostatic stress (σm), Brozzo et al. [14] developed damage criteria by combining these two stresses

$$\int_0^{\varepsilon_f} \frac{2\sigma_1}{3(\sigma_1 - \sigma_m)}\, d\varepsilon = C_4 \qquad (4)$$

C1, C2, C3………………………….. Ci is the values of the critical damages.

III. CRITICAL DAMAGE EVALUATION:

Solid cylindrical test specimens of different aspect ratios were compressed between two rigid flat dies. For each and every lubrication condition and aspect ratios 10 samples were taken and were deformed to different height reductions. Three different types of lubricants namely grease, molybdenum disulphide and white grease were employed at the die/billet interface for the process. As the material undergoes plastic deformation, a bulge near the equatorial region can be observed. When this plastic deformation becomes severe, the material damages and a crack will appear on the surface of the cylindrical specimen. To avoid uncertainties in the process, three samples were deformed to the level of strain at which the billet has started cracking and mean value readings of the failure strain was taken as constraint. The non-uniform distribution of the cylinder is because of the high friction between the contact surfaces of the billet and the dies. The level of deformation at which the material fractures differs with the friction conditions. By proper lubrication, the cylindrical billets can be deformed to higher levels without failure utilizing the material and processing conditions effectively.

Commercially available software DEFORM 2D was used for the finite element investigation to evaluate Ci for the damage models in section. II. The dies were modeled as rigid and the billet as plastic material. The flow stress equation (5) was given as input to the finite element software [15].

$$\sigma = 720\varepsilon^{0.22} \qquad (5)$$

The value of the friction between the die and billet corresponding to the lubricants applied was taken from the standard ring compression test [15]. The magnitude of the friction obtained from the ring compression test for the

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 1, Issue 6, October 2016

lubricants grease, molybdenum disulphide and white grease are 0.24, 0.29 and 0.44 respectively. This value was defined at the die/billet interface for conducting finite element studies.

After noting down the strain at which the billets have failed from the experimental readings, the billets were reduced to the same strain level using finite element simulations. By giving workability criteria's such as Cokroft-Latham, Normalized cockroft-Latham, Fruedenthal and Brozzo as input to the finite element software Deform 2D, the simulations were conducted for different height reductions as in the case of experiments and the value of the critical damage was noted down. After performing both the experimental and simulation studies, the results were compared in the Fig. 1 and the finite element results were validated with the experimental results.

IV RESULTS AND DISCUSSIONS

The stresses induced in the billet play vital role in analyzing the surface cracks when the deformation is severe. The path followed by axial stress, hoop stress and hydrostatic stress depends on the processing conditions such as material, tooling and lubrication. The starting and ending points of the curve depends on the level of deformation. If the deformation load is applied beyond fracture point then the nature of the curve may change.The axial stress will be compressive in nature and its value increases till the surface fracture appears on the billet and thereafter turns tensile. This is because once the material fractures, on further deformation, the load required for higher strain levels decreases and the axial stress becomes tensile in nature. When the axial stress becomes tensile in nature the hydrostatic stress also becomes tensile. This is because the axial and hydrostatic stresses increase or decrease together. The increase of tensile stresses near the equatorial region accelerates the probability of surface cracks. The magnitude of hoop stress is lower for grease compared to the molybdenum disulphide and white grease. This is because when grease was employed at the faces of the billet, a much uniform distribution of the material was achieved which resulted in less barrelling. This decreases the tensile stresses near the equatorial region compared to the

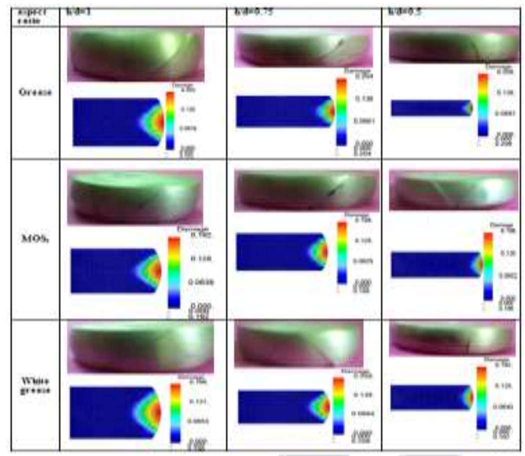
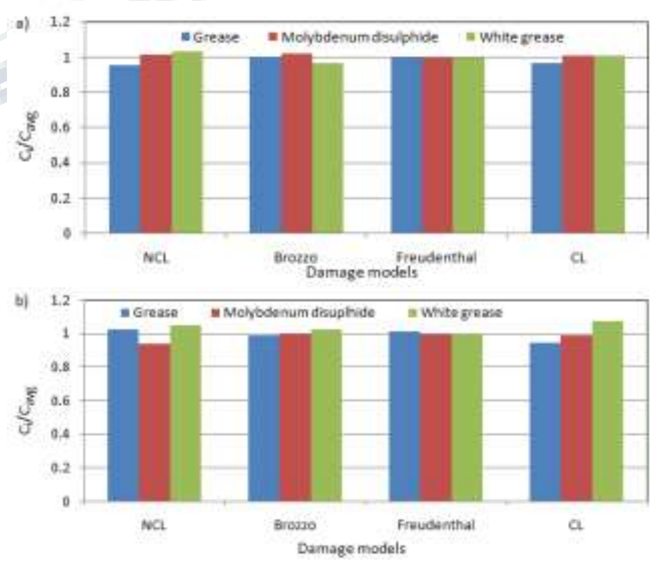


Fig. 1 Experimental and finite element (NCL damage) results showing surface cracks

Other lubrication conditions andthe rate of failure with respect to the effective strain also decelerates. To conclude that the damage model that has been considered for the present investigation is accurate, the critical damage value should be same in magnitude irrespective of any geometry, tooling used and lubrication. The critical damage value 'c_i' was evaluated for all the workability damage criterion's considered for the investigation. The average critical damage value 'c_{avg}' at fracture for different geometries and for different lubrication conditions was determined. In order to compare the four damage criteria the value of 'c_i / c_{avg}' was taken as reference.



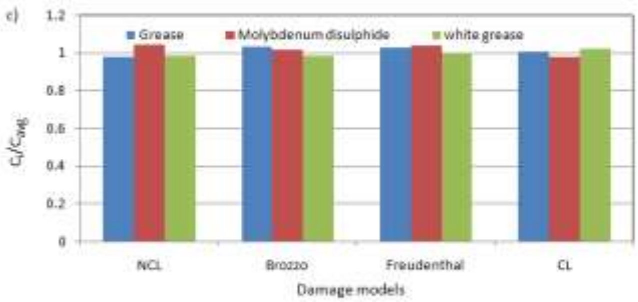


Fig.2 Normalized critical values at fracture, C_i/C_{avg} predicted based on four fracture criteria for different lubricants

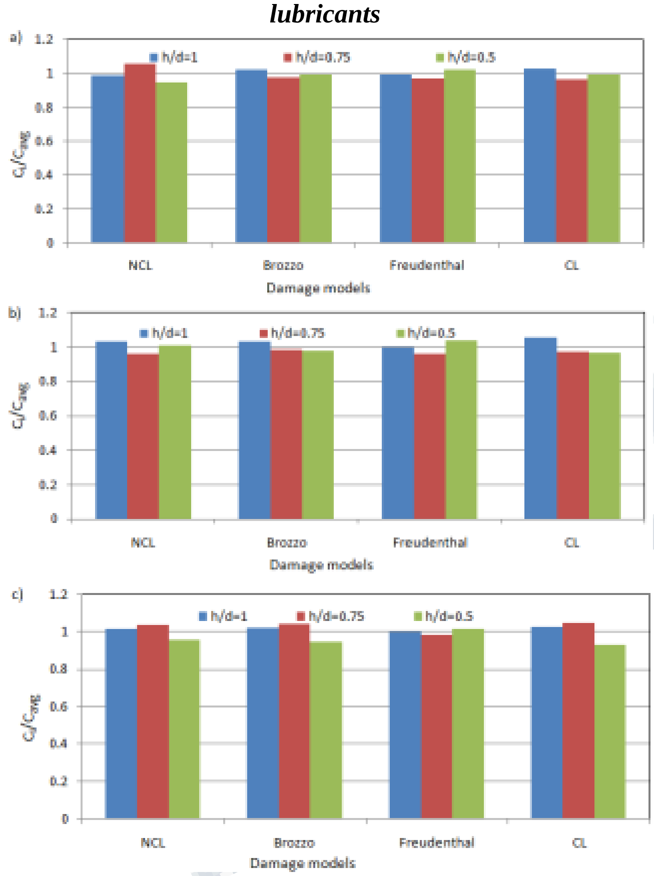


Fig.3 Normalized critical values at fracture, C_i/C_{avg} predicted based on four fracture criteria for different h/d ratios.

Fig. 2 and Fig. 3 illustrates that the deviations were approximately within a range of -10% to +10%. This shows that the aspect ratios and the lubrication don't have any impact on the value of the critical damage. Several authors [11, 12] conducted experiments on flanged specimen, tapered specimen and cylindrical specimens and concluded that only Freudenthal model was deviating much compared other damage criteria for flanged and tapered specimens. The accuracy of the damage model depends on the type of geometry considered for the investigation. Since in the present study, the billets deformed to the fracture level are solid cylinders, all the four damage criteria could validate the condition that critical damage is a material constant.

CONCLUSIONS

1. The rate of increase of damage with respect to the effective strain depends on the lubrication and also on the aspect ratios of the billet.
2. The value of the critical damage doesn't depend on the type of lubricant applied at the die/billet interface.
3. All the damage models considered for the investigation are accurate enough to predict the critical fracture.
4. The accuracy in predicting the critical fracture depends on the type of geometry considered.
5. Employing lubricant on the billet faces improved the formability of the material.

Predicting the ductile fracture made effective utilization of the material and process

REFERENCES

[1] A. K. Jha and S. Kumar, "Deformation characteristics and fracturing of sintered copper powder strips during cold forging," Journal of Mechanical Working Technology,vol. 16, pp 145-164, 2013

[2] X. Liang, "Damage accumulation and fracture initiation in un cracked ductile solids subject to triaxial loading," Internatioanl Journal of Solid Structures, vol. 44, pp. 5163–5181, 2007.

[3]C. Zheng, M. A. Jose, C Desa and FMA Pires, "A comparison of models for ductile fracture prediction in forging processes." Computational Methods in Material Science vol. 7, pp. 389 – 396, 2007.

[4]D.J. Kim, andB.M. Kim, "Prediction of Deformed Configuration and Ductile Fracture for Simple Upsetting Using an Artificial Neural Network", International Journal of Advanced Manufacturing Technology, vol. 19, pp. 336–342, 2012.

[5]N. Venkata Reddy, P.M. Dixit andG. L. Lal, "Ductile fracture criteria and its prediction in axisymmetric

drawing," International Journal of Machine Tools and Manufacturing, vol. 40, pp. 95–111, 2012.

[6] P.F. Thomason, "Ductile Fracture of Metals", first ed. London: Oxford, 1990.

[7]. N. V. Reddy, P. M. Dixit, and G. K. Lal, " Central bursting and optimal die profile for axisymmetric extrusion" Journal of Manufacturing Science and Engineering, vol. 118, pp. 579-581, 2010.

[8] B. P. P. A Gouveia, J. M. CRodrigues, and P. A. F Martins,"Ductile fracture in metalworking: experimental and theoretical research,"Journal Mater Process Technol, vol. 101, pp. 52-63, 2000.

[9] M. G. Cockcroft andD.J. Latham, "Ductility and the workability of metals," Journal of Institute of Metals,vol. 96, pp. 33, 1968.

[10] M. Oyane, T. Sato, K. Kokimoto andS. Shima, " Criteria for Ductile Fracture and Their Applications," Journal of Mechanical Working Technology, vol. 4, pp. 65-81, 1980.

[11] D. C. Kio, B. M. Kim, J. C. Choi, "Prediction of surface-fracture initiation in the axisymmetric extrusion and simple upsetting of an aluminium alloy," Journal of Materials Processing Technology, vol. 62, pp. 166, 1996.

[12]E. Taupin, J. Breitling, W. T. Wu, andT. Altan, " Material fracture and burr formation in blanking—results of FEM simulations and comparisons with experiments,"Journal of Materials Processing Technology, vol. 59, pp. 68, 2012.

[13]F. A. Freudenthal,"The Inelastic Behavior of Engineering Materials & Structures," John Wiley & Sons: New York, 1950.

[14] P. Brozzo , B. Deluca andR. Rendina, "Proceedings of the Seventh Biennial Conference of the International Deep Drawing Research Group," Amsterdam: Netherlands, 1972..

[15] Ch HariKrishna, M. J. Davidson and Ch Nagaraju,"Optimum process parameters for Enhanced uniform hardness distribution and barreling behavior in upsetting"Trans of Indian institute of metals, DOI 10.1007/s12666-014-0447-y, 2014.

