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INVESTIGATION ON PREDICTION OF FORMING LIMIT FOR COLD UPSETTING BY UTILIZING ENERGY FRACTURE CRITERION

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Abstract

The forming limits are studied for cold upsetting of high strength aluminium alloy in the present paper. Different geometry ratio and frictional conditions are investigated in the forgeability test to evaluate the forming limits and also to obtain the various strain paths. The critical fracture value can be obtained by integrating along the strain path till free surface crack initiation. To predict the damage evolution of cold upsetting, the computer-aided evaluation of forming limits is obtained by using the finite-element software DEFORM-3D and the modified Cockcroft-Latham criterion. The predicted theoretical limit strains agree quite well with the experimental results.

Keywords: forming limit, fracture energy criterion, strain path, finite element method.

1 Introduction

Ductile fracture is the most common mode of failure in cold forging. It is a complicated phenomenon that is dependent on process parameters such as stress, strain, friction, as well as influential material parameters. To predict ductile fracture of materials, there are several ductile fracture criteria proposed for study of mechanisms and occurrence of ductile fractures 〔1~4〕. One of the earliest attempts was made by Freudenthal 〔1〕. Later, the criterion of Cockcroft-Latham 〔2〕 defined the critical value of maximum tensile plastic work. The modified Cockcroft-Latham criterion, which has been evaluated to be the most suitable criterion for the free surface fracture compared with several other criteria 〔5〕, is adopted in this study. The critical fracture values can be obtained by integrating along the strain paths. Therefore, the numerical prediction of forming limits can be obtained by using the finite-element software DEFORM-3D together with the modified Cockcroft-Latham criterion.

2 Theoretical basis

The proposed modified Cockcroft-Latham criterion, used to simulate and predict the limit strains and strain paths numerically in this study, can be expressed as,

$$C = \int_0^{\bar{\varepsilon}_f} \sigma^* \, d\bar{\varepsilon} = \int_0^{\bar{\varepsilon}_f} \sigma_\theta \, d\bar{\varepsilon} \qquad \text{where } \alpha \text{ is the strain ratio, } \alpha = -d\,\varepsilon_z / \varepsilon_\theta$$

$$= \frac{K}{\sqrt{3}} \left(\frac{2}{\sqrt{3}}\right)^{n+1} \int_0^{\varepsilon_f} (2-\alpha) \left[\left(\sqrt{\alpha^2-\alpha+1}\right)\varepsilon_\theta\right]^n d\varepsilon_\theta \tag{1}$$

Assume the strain ratio α is a constant along the strain path, then eq.(1) can be transformed into eq.(2) to predict the limit strain theoretically.

$$\varepsilon_f = \left[\frac{(\sqrt{3})^{n+2}\,(n+1)}{(2)^{n+1}(2-\alpha)\left(\sqrt{\alpha^2-\alpha+1}\right)^n} \frac{C}{K} \right]^{\frac{1}{n+1}} \tag{2}$$

where C is the critical fracture value, σ^* is the maximum tensile stress, σ_θ is the circumferential stress, $\bar{\varepsilon}_f$ is the critical effective strain, K is the material constant of plastic flow, n is the strain-hardening index.

3 Experimental Details

By using ring compression test and forgeability test, we obtained the experimental limit strains and strain paths for cold upsetting of aluminium alloy 2017-F, which were used for the numerical prediction of the forming limits and strain paths in this study. The interfacial frictional conditions were represented by constant shear friction factor (m). The limit strains and the strain paths can be obtained, expressed in terms of axial and circumferential strain components at the equator of the specimens, by using various aspect ratio and frictional conditions. The critical fracture value can be obtained from eq.(1) by integrating along the strain path . To measure the local strains, the square grids were marked, as shown Fig.1, at the equator of the cylinder specimen by using electrical chemical etching method.

4 Results and discussion

The various strain paths are shown in Fig.2, with three different lubrication conditions and the aspect ratio 1.0. It shows that the slope α of the strain path gets steeper and shorter as the friction factor increases, leading to a lower limiting strains. The workability is poorer as the friction factor increases. This may be attributed to the increases of the consumption of nonhomogeneous deformation due to severe interfacial frictional condition.

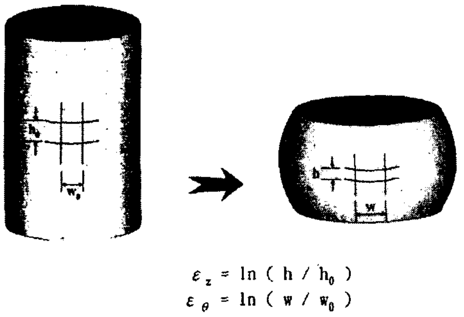

Fig 1. Schematic of square gridding at the equator of specimen in upsetting.

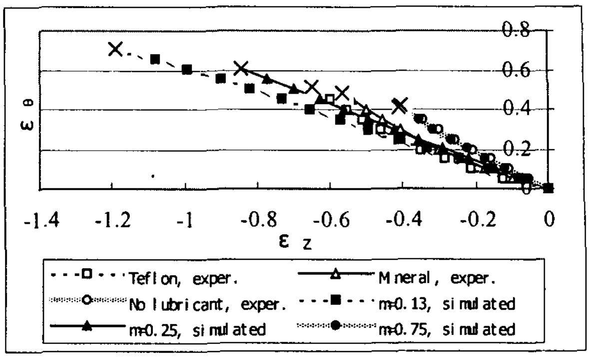

Fig. 2 Comparison of strain paths between experimental data and simulated results with geometry ratio 1.0.

According to eq.(1), the critical fracture values can be calculated by integrating along the strain paths. The average critical fracture value is 124.53MPa. Fig.3 shows the predicted fracture lines, including the simulated fracture line y2 (= -0.416X+0.249), and theoretical fracture line yl (= -0.460X+0.236), calculated from eq.(1), eq.(2) respectively. It is evident that the predicted limit strains are in good agreement with the experimental data .

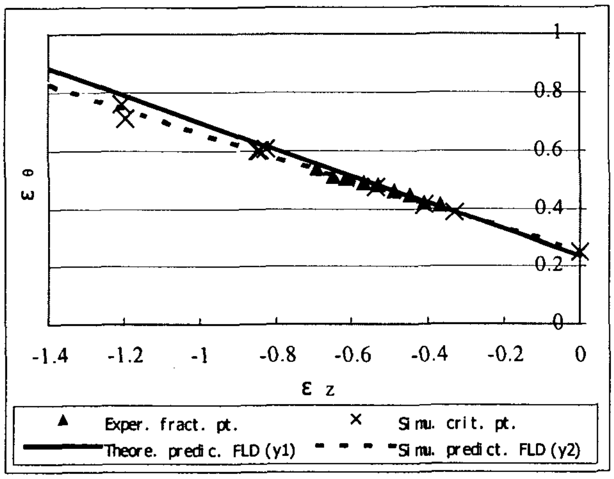

Fig. 3 The forming limit diagram of experimental results and theoretical prediction for Al-2017F.

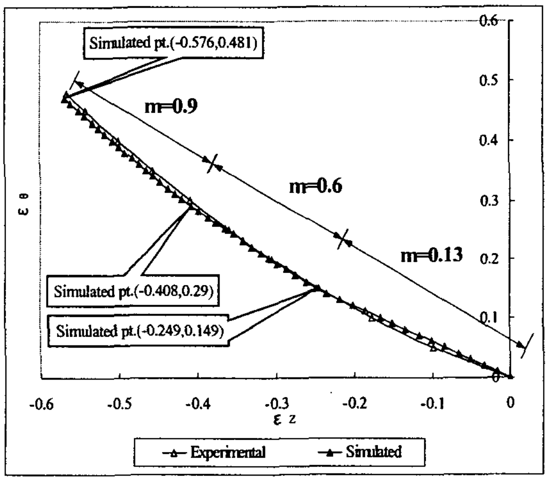

Fig. 4 Variation of interfacial friction factor along the strain path in upsetting.

Fig.4 shows a comparison between the experimental result and the simulated prediction of strain path for geometry ratio 1 with mineral oil lubrication. We found that the friction factor increases while the height reduction ratio increases in upsetting process. This means the friction factor is not a constant. The interfacial surface is in poor lubricated condition since the lubricant film is broken due to the high compressive stress at the severe height reduction.

5 Conclusion

The strain path and limit strains are greatly affected by the specimen geometry ratio and interfacial friction condition from the experimental results. Compared with the results of the computer simulation, we found that the interfacial friction factor was not a constant. It becomes to poor friction condition at the severe height reduction because of the broken Lubricant film due to the high compressive stress . The predicted limit strains, simulated by using finite-element method and the modified Cockcroft-Latham criterion, are in good agreement with the experimental results.

6 Acknowledgement

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7 References

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