# Shear Failure of Al-Cu Single Crystals

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ABSTRACT

Al-Cu single crystals with different microstructures were deformed in this investigation. Shear band formed and the strain localized in the shear band. It caused crack nucleation in it, then shear failure took place along the shear band. It was found that the shear band simply consisted of slip. A new possible micromechanism was proposed based on the observations.

KEYWORDS

Shear failure; shear band; Al-Cu single crystal.

INTRODUCTION

Ductile fracture usually results from voids nucleation, growth and coalescence. But it is not uncommon that it results from fast shear. For example, fast shear often results in premature failure in high strength aluminium alloys (Chen and Li,1987; Chen and knott,1981;Forsyth and Smale,1971;Embury and Nes,1974; Chung et al.,1977;King et al.,1981). In general, shear band preceded shear failure. The micromechanism for shear band formation and shear failure is still unknown. For understanding this phenomenon, Al-Cu single crystals with different microstructures have been deformed, careful observation and analysis were carried out in this investigation.

Shear failure of single crystals has been studied since twenties of this century (Elam,1927;Karnop and Sachs,1928). In sixties, Beevers and Honeycombe (1962a,b), Price and Kelly (1964a,b) and others have done some work. Recently Chang and Asaro (1981) has studied the shear bands of single crystals. Some explanations have been proposed, but none of them got common approval. The results of this investigation showed some new aspects of the phenomenon. A new possible mechanism was proposed based on the observations.

## EXPERIMENTAL

The material used in this investigation was melted in vacuum induced furnace with high purity aluminium (99.999%) and copper (99.999%). The chemical composition of the material showed 2.94% Cu. Single crystals were produced by the modified Bridgman method. The specimen sizes were 4x4 or 5x2 $mm^2$ cross section bars after polishing.

Crystals were solution treated in the salt bath at 525$^{o}$C for 15 hours, then quenched in cold water. Aging was carried out in air, followed by air cooling, as detailed in Table 1.

Table 1. Specimen identification and aging treatment

| Crystal code | Aging treatment | Microstructure |
|---|---|---|
| Q-1<br>Q-2 | stored in liquid nitrogen | as-quenched |
| GP1-1<br>GP1-2 | 130$^{o}$C 48 hours | GP1 |
| GP2-1<br>GP2-2 | 165$^{o}$C 48 hours | GP2 |
| θ'-1 | 220$^{o}$C 20 hours | θ' |
| θ-1 | 250$^{o}$C 72 hours | θ |

Crystals orientations were determined by back-reflection Laue technique.

Tensile deformation was conducted with a MTS 880 machine. Average cross-head speed was 0.2mm/min. A HITACHI S530 scanning electron microscope was used for surface observation.

## RESULTS AND DISCUSSION

Crystal orientations and stress-strain curves of the testing will be published elsewhere. In this paper, the results related to the slip characteristics, shear band formation and shear failure were presented.

All five different heat treated crystals exhibited shear bands and failed along the shear bands. A photograph of θ'-1 crystal was presented in Fig.1. A clear shear band and the initiation of the shear failure at the edge of the crystal were revealed in this picture. Fig.2 is a scanning electron micrograph of GP1-1 crystal. The conjugated shear bands in the necking region of the crystal were shown in this picture.



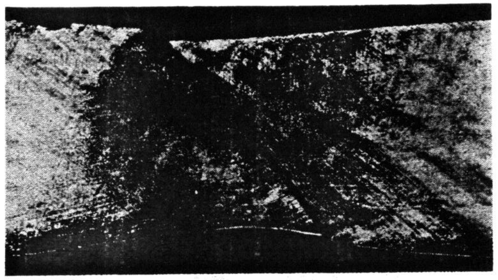

Fig.1. Photograph of θ'-1 crystal

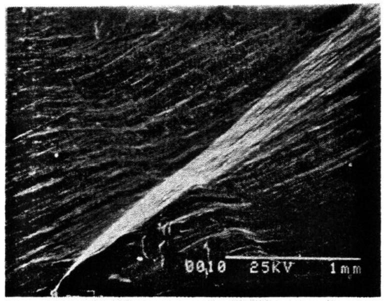


Fig.2. Scanning electron micrograph of GP1-1 crystal

Slip lines were revealed clearly in Fig.1 and Fig.2. The shear bands' orientation did not coincide with the orientation of slip lines. The shear failure always took place along the shear band. In Fig.1 and Fig.2, large steps at the edge of the crystals were observed, cracks initiated at this place. Figure 3 showed slip structure in the shear band of GP1-1 crystal.

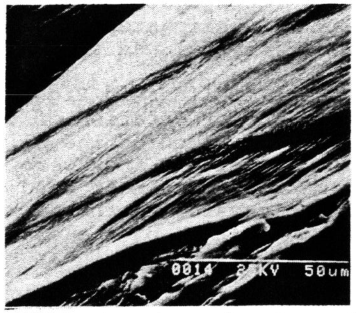


Fig.3. Slip structure in shear band of GP1-1.

With high magnification, a fine slip step pattern within the shear band could be revealed, Fig.4. The slip pattern of dark region in Fig.3 was shown in Fig.5.

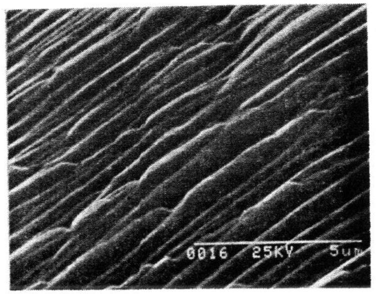


Fig.4. Slip steps within shear band of GP1-1 crystal.

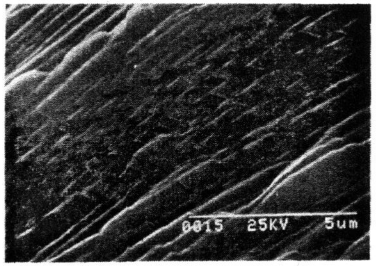


Fig.5. Slip pattern of dark region in Fig.3.

Slip pattern of cross area of conjugated shear bands in Fig.2 was shown in Fig.6. A very fine slip steps of cross area of conjugated shear bands of GP1-2 crystal was shown in Fig.7.

It is easy to recognize the slip lines in Fig.1 and Fig.2. Slip lines are crystallographic. The orientation of the shear band did not coincide with the orientation of the slip line, they were not crystallographic. therefore, they were called " macroscopic " shear band. The macroscopic shear band was usually initiated at the edge of the crystal in the necking region, then propagated to the opposite edge of the crystal. The shear band was approximately along the maximum shear stress planes.

After the shear band formation, the strain localized in the band



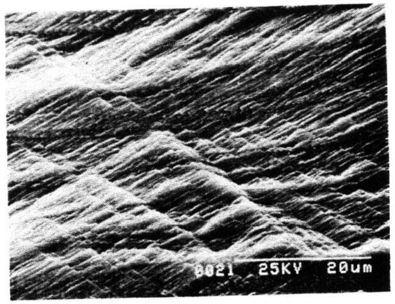


Fig.6. Slip pattern of cross area of conjugated shear bands in Fig.2.

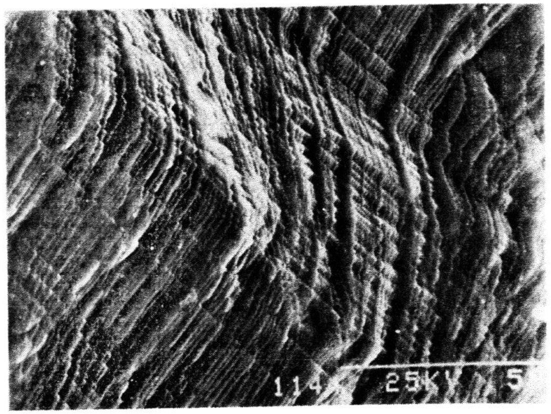

Fig.7. Slip pattern of cross area of conjugated shear bands of GP1-2 crystal.

instead of uniformly distributed in the gauge length during the deformation. Intensive shear strain within the band, especially at the edge of crystal, resulted in the formation of small cracks in the band. The shear failure finally took place through propagating the small cracks along the shear band. Due to the highly localization of the strain in the shear band the nominal fracture strain was still very low while the shear failure took place.

Surprisingly, the slip pattern in the shear band was simple and regular. The deformation process within the macroscopic shear band was definitely crystallographic. It is not " turbulent flow " as in fluid mechanics but orderly simple slip pattern.

## CONCLUSIONS

The shear failure of Al-Cu single crystals was preceded by the shear band formation.

The macroscopic maximum shear stress influenced the direction of the shear band.

The crack initiated in the shear band, then propagated along the shear band causing failure.

The slip pattern within the shear band was simple and regular in Al-Cu single crystals.

## REFERENCES


Beevers, C.J. and R.W.K. Honeycombe (1962). Phil. Mag., 6, 763.

Beevers, C.J. and R.W.K. Honeycombe (1962). Acta Metall., 10, 17.

Chang, Y.W. and R.L. Asaro (1981). Acta Metall., 29, 241.

Chen, C.Q. and H.X. Li (1987). Mat. Sci. Tech., 3, 125.

Chen, C.Q. and J.F. Knott (1981). Met. Sci., 15, 357.

Chung, N., J.D. Embury, J.D. Evensen, R.G. Hoagland, and C.M. Sargent (1977). Acta Metall., 25, 377.

Elam, C.F. (1927). Proc. Roy. Soc. Lond., A115, 133.

Embury, J.D. and E. Nes (1974). Z. Metallkd., 65, 45.

Forsyth, P.J.E. and A.S. Smale (1971). Eng. Fract. Mech., 3, 127.

Karnop, R. and G. Sachs (1928). Z. Phys., 49, 480.

King, J.E., C.P. You, and J.F. Knott (1981). Acta Metall., 29, 1553.

Price, R.J. and A. Kelly (1964). Acta Metall., 12, 159.

Price, R.J. and A. Kelly (1964). Acta Metall., 12, 979.