APPLICATION OF A SMALL PUNCH TEST TO THE EVALUATION OF DEFORMATION AND FRACTURE CHARACTERISTICS IN A 2091 ALUMINUM ALLOY PLATE

Hajime KATO *, Tatsumi TOZAWA *, Yoshimasa TAKAYAMA *, Hideo WATANABE * and Toshiharu TAKAHASHI * *

Department of Mechanical System Engineering
Faculty of Engineering, Utsunomiya University
2753 Ishii-machi, Utsunomiya, Tochigi 321-8585, Japan
**Graduate Student, Utsunomiya University

ABSTRACT The load versus deflection curves are changeable due to loading directions for a 2091 aluminum alloy plate, resulting from different crack initiation and growth behavior. In addition, the fracture surface becomes the most brittle for the specimens tested in the loading direction of T. It was found that the small punch test unable to be also useful for the evaluation of deformation and fracture characteristics of materials with markedly microstructural anisotropy.

Keywords: *Al-Li alloy, microstructural anisotropy, small punch test, deformation and fracture behavior, acoustic emission*

1. INTRODUCTION

Al-Li series alloys have superior specific strength and elastic modulus in comparison with conventional alloys, which are of interest for advanced aero-space applications. But these alloys are well-known to have markedly microstructural anisotropy. Therefore, it is very important to investigate the influence of microstructural anisotropy on the deformation and fracture behavior of these alloys[1].

In some circumstances, the amount of material available for testing is limited so that conventional test specimens with standard dimensions cannot be prepared. In this case, one opinion is to machine a relatively small flat specimen which can then be tested by small punch loading[2].

During the past decade, an acoustic emission method has been utilized as a testing one in order to examine the process of deformation and fracture on various materials or a monitoring one for structural integrity evaluation and so on[3].

In this paper, a small punch test has been carried out for the specimens which were machined from various parts of a 2091-T8 aluminum alloy plate. The changes in the deformation and fracture behavior due to different directions of small punch loading and the corresponding acoustic emission behavior have been examined. The main purpose in this study is to discuss whether the small punch test is useful for the evaluation of the deformation and fracture behavior of materials with markedly microstractural anisotropy or not.

2. EXPERIMENTAL PROCEDURE

A 2091-T8 aluminum alloy plate was used for this research, which was in the under-aged condition. The dimensions of the plate were 300 mm in length, 300 mm in width and 22 mm in thickness. The chemical composition of the alloy is listed in Table 1.

Table 1 Chemical composition of 2091 aluminum alloy used in this study (mass%).

Material	Cu	Li	Mg	Zr	Fe	Si	Al
2091	2.04	1.83	1.42	0.11	0.05	0.06	Bal.

The small flat samples were at first machined from various parts of the plate into the shape of 10 × 10 × 1.0 mm^3 in three directions which were parallel and/or perpendicular to the rolling direction as shown Fig.1. Thereafter, each specimen was polished with emery papers and subsequently finished by electropolishing to prepare into a final thickness of 0.5 mm. Three sorts of given names here were expressed as S (direction of thickness), L (rolling direction) and T (direction of width), which correspond to the directions of punch loading normal to the flat surface specimen, respectively. Furthermore, S1 and S3 mean the specimens in the central part of the thickness and in the surface of the plate, respectively, and S3 means the specimen in the middle part between S1 and S3. On the other hand, each subscript in L and T denotes a distance from the central line of the thickness to the central line of the specimen as given in the figure.

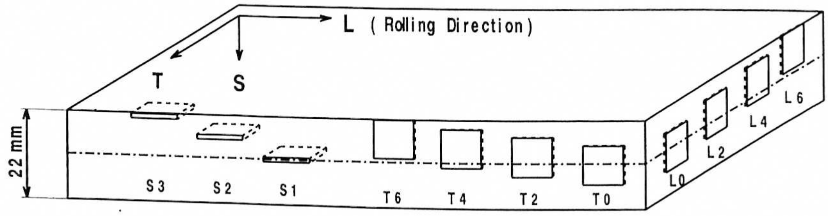

Fig.1 Schematic drawing of the various parts machined from a 2091 aluminum alloy plate and the given names.

Figure 2 illustrates the schematic drawing of a small punch testing apparatus and the block diagram of acoustic emission measuring system. Loading to the flat specimen was conducted by punching a small harden steel ball of which the sphere diameter was 2.5 mm. The small punch test has been performed using the Instron-type testing machine at a cross-head speed of 8.3 × 10^{-6}m・s^{-1} (0.5 mm/min). Grease containing MoS_2 was used as a lubricant at the ball-specimen interface to make the friction as low as possible.

Acoustic emission signals were detected by a piezoelectric transducer having a resonant peak of 140 kHz and passed through a band-path filter of 100 to 200 kHz. The acoustic emission count rate was measured at intervals of one second. The threshold voltage was kept at 50 μ V.

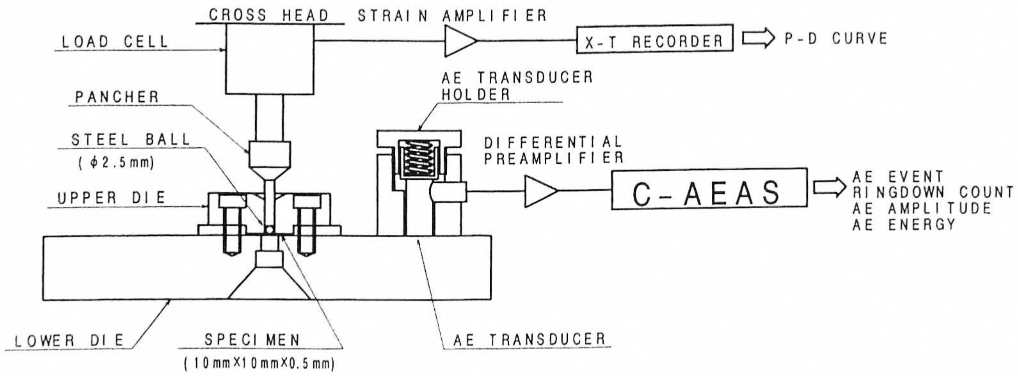

Fig.2 Schematic drawing of a small punch testing apparatus and the block diagram of acoustic emission measuring system.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 A typical load versus deflection curve during a small punch test.

A typical load versus deflection curve during a small punch test is presented in Fig.3. The load versus deflection curve increases linearly in the elastic deformation process. After that, this curve rises showing a concave one with a large negative radius of curvature, and, when the amount of deflection is above a certain value, the curve increases indicating inversely a convex curve with a positive radius of curvature. After reaching the maximum value, P_{max}, the load drops abruptly. As seen from this figure, the deformation behavior in the small punch test is divided roughly into four regions: elastic bending deformation (region Ⅰ), plastic bending deformation (region Ⅱ), membrane stretching deformation (region Ⅲ) and necking deformation to fracture (region Ⅳ) [4,5].

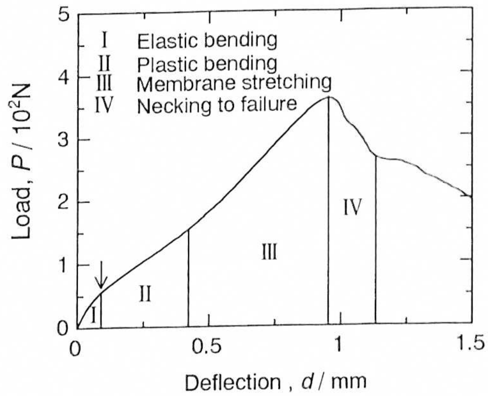

Fig.3 A typical load versus deflection curve during a small punch test[5].

3.2 Changes in load as a function of deflection during a small punch test and the corresponding acoustic emission behavior for S1, L0 and T0.

Figures 4, 5 and 6 represent the changes in load as a function of deflection during a small punch test and the corresponding acoustic emission behavior for S1, L0 and T0, respectively. In S1, the load versus deflection curve increases showing a smooth concave curve with a positive radius curvature up to the position of a plus marker (+) in the figure and, after increasing somewhat, the load reaches at the maximum load. In L0 and T0 (Figs.5 and 6), the load increases smoothly up to the first peak load as well as in S1. However, thereafter, some distinctly serrated loads tend to be observed in the load versus deflection curves differently to the curve of S1. It was understood that these serrated loads appear because another other cracks initiate and propagate discontinuously.

Acoustic emission signals are scarcely detected in the early stage of deformation for each specimen. The signals are abruptly recorded approximately at the position of a plus marker (+) for S1, whereas the signals are abruptly recorded just before the load shows the first peak load for L0 and T0. The observation on the surface by SEM revealed that an abrupt increment of acoustic emission signals corresponds to the first crack initiation.

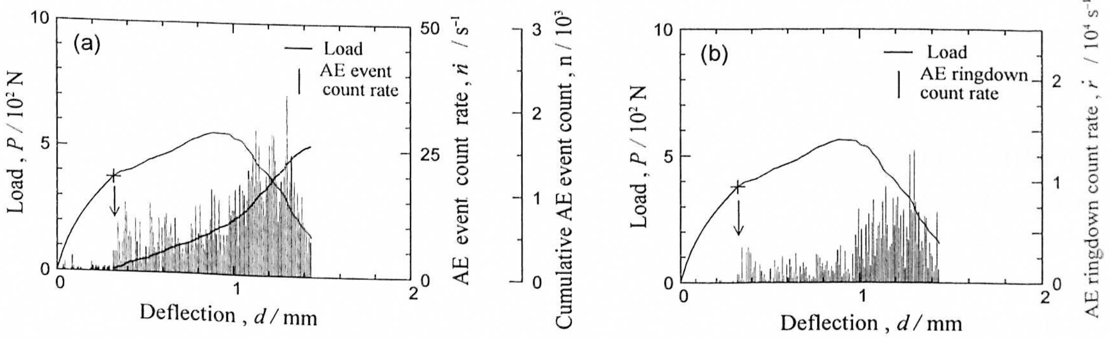

Fig.4 Load versus deflection curve and the corresponding AE behavior for S1.

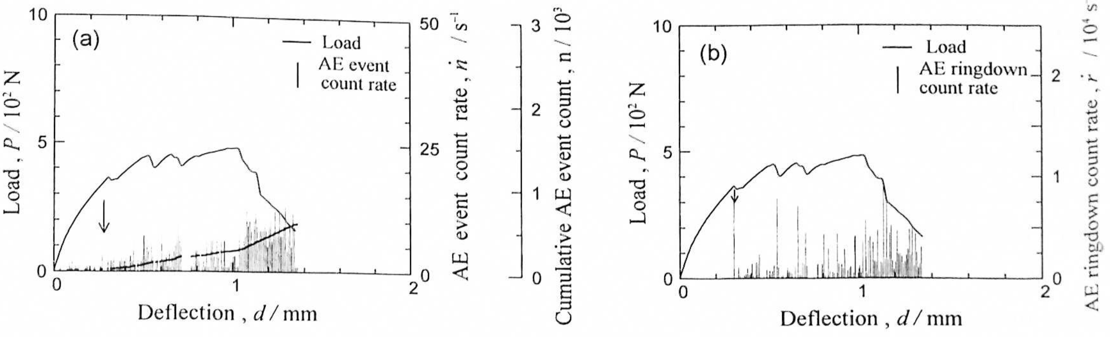

Fig.5 Load versus deflection curve and the corresponding AE behavior for L0.

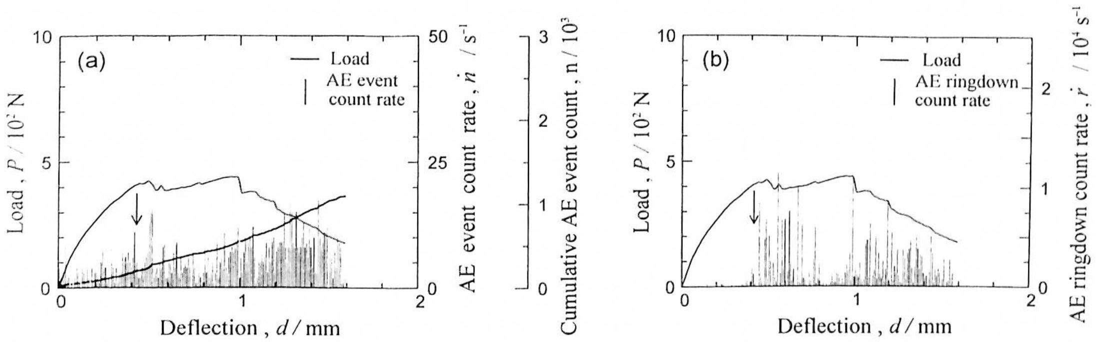

Fig.6 Load versus deflection curve and the corresponding AE behavior for T0.

3.3 Macroscopic views of fractured specimens

Figure 7 (a) , (b) and (c) show the macroscopic views for S1, L0 and T0 fractured in the small punch test , respectively. In S1, fracture takes place on the whole by the same mode. Furthermore, although pancake-like microstructures were thinner in the order of S1, S2 and S3, almost no difference in the mode of fracture was observed among three specimens. In each specimen of S, it was indicated that the fracture mode is almost independent of microstructural anisotropy and also fracture is comparatively ductile on the whole.

On the other hand, in L0, cracks tend to initiate at first in a particular direction, that is, T direction represented in Fig.1 and also a lot of intergranular cracks were observed on the fracture

(a) (b)

(c)

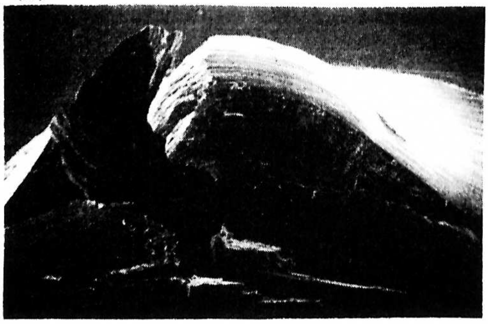

Fig.7 Changes in macroscopic views of the specimens fractured due to three loading directions.
(a) : S1
(b) : L0
(c) : T0

surface. Consequently, it was understood that, in L, cracks tend to initiate due to the tensile stress in the S direction rather than that in the T direction.

Moreover, in T0, cracks occur especially in the L-direction. More intergranular cracks were observed in the fracture surface and also fracture was more brittle than in L0. Figure 8 represents the macroscopic views of surface cracks observed approximately at the crack initiation for T0 and T6, respectively. It was understood that there is a distinct difference between the surface cracks of two specimens, results from the different microstructures.

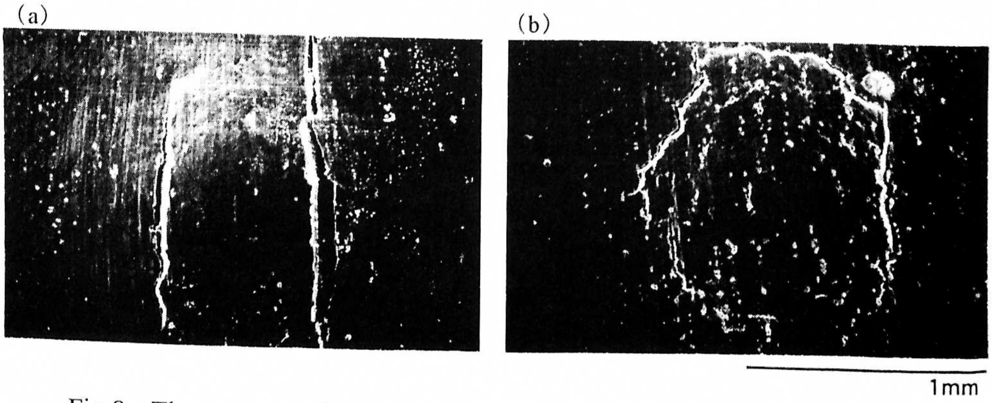

Fig.8 The macroscopic views of surface cracks observed approximately at the crack initiation for T0 (a) and T6 (b).

4. SUMMARY

A small punch test has been carried out for a 2091 aluminum alloy plate (thickness of 22 mm) having markedly microstrutural anisotropy. The deformation and fracture processes are changeable due to loading directions applied to a flat specimen in the small punch test. As a result, it was found that the small punch test is useful for the evaluation of deformation and fracture characteristics in Al-Li series alloys and furthermore an acoustic emission method is a very useful one to detect the first crack initiation in the small punch test.

ACKNOWLEDGMENTS

We wish to thank Mr. J. Yamaguchi for his experimental collaborations. We acknowledge with gratitude the financial support by the Light Metals Education Foundation.

REFERENCES

[1] S. Ohsaki: J. Jpn. Inst. Light Metals, 45(1995),660.

[2] J. M. Baik, J. Kameda and O.Buck: Scripta Metall., 17(1983),1443.

[3] JSNDI: *Acoustic Emission*, (1990),57.

[4] J. Kameda: Bulletin Jpn. Metals, 25(1986),520.

[5] K. Kato, T. Tozawa and Y. Takayama: Progress in Acoustic Emission Ⅷ, JSNDI,(1996),169.