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In-situ straining observation on crack initiation and growth in an intermetallic $Al_{67}Mn_8Ti_{25}$ alloy①

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Abstract: In-situ straining SEM observations of an intermetallic $Al_{67}Mn_8Ti_{25}$ alloy were carried out on sheet specimens containing notch with root radius about 100 μm. The results show that the crack initiation occurs at notch root along grain boundary, and it grows very rapidly in transgranular manner. During the crack growing, some crack branches and segments are formed. Occasionally when the crack propagates in the direction close to grain boundary, it grows intergranularly along a part of boundary. The observed crack propagation process indicates that the alloy is very brittle at ambient temperatures.

Key words: Al_3Ti alloys; in-situ observation; crack propagation **Document code**: A

1 INTRODUCTION

A manganese-modified Al_3Ti version with the $L1_2$ structure, $Al_{67}Mn_8Ti_{25}$ intermetallic alloy, shows limited ductility in bending or tension although it exhibits good deformation characteristics when tested in compression and is known to fail predominately by transgranular cleavage[1~4]. Studies were conducted on the fracture behavior of this alloy under the conditions of pre-existing crack[5,6]. However, there is little information regarding the early stage of crack initiation and subsequent propagation, the fracture behavior, such as transgranular cleavage and intergranular failure, was only observed on fracture surface.

The object of this study is to observe the initial development of cracks at a microstructural scale and therefore an in-situ SEM straining experiments are conducted in tension with incremental loading condition. In order to confine the processes of interest to well-defined regions, notched specimens are utilized. Observations regarding the initiation and propagation of cracks are discussed in this paper.

2 EXPERIMENTAL PROCEDURE

The $Al_{67}Mn_8Ti_{25}$ (mole fraction, %) alloy for the present study was taken from a d40 mm ingot prepared by vacuum induction melting using high purity aluminum, manganese and titanium. The as-cast material was subjected to a homogenization treatment at 1 050 ℃ for 60 h. In order to refine grain size, the homogenized alloy was hot-pressed to a total reduction of about 40% using two or three re-heating cycles at 950 ℃ and finally annealed for 2 h at 950 ℃ followed by slowly cooling. X-ray diffraction using CuKα monochromatic radiation showed a single phase of $L1_2$ structure, but a small amount of second phase was observed by optical microscopy. The second phase existed at grain boundaries and within the grains.

In-situ tensile straining experiments were conducted with sheet specimens (4 mm width and 12 mm length) containing notches with root radius about 100 μm and a length of 2.5 mm. Specimens were spark erosion machined from the forged blocks into about 0.5 mm thick slices. Prior to testing all specimens were subjected to a mechanical polishing procedure with the final

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polishing utilizing a solution of 0.05 μm colloidal diamond particles. In the end, the sample thickness were in the range of 0.2 to 0.3 mm.

To prevent catastrophic failure, the specimen was glued to an Al base sheet with cohesive paste. The aluminum sheets (each approximately 30.0 mm × 5.0 mm × 0.3 mm) were also notched in the middle of length direction. The notch (about 2.5 mm deep) was electrodischarge machined. The schematic drawing of sticked specimen is shown in Fig.1.

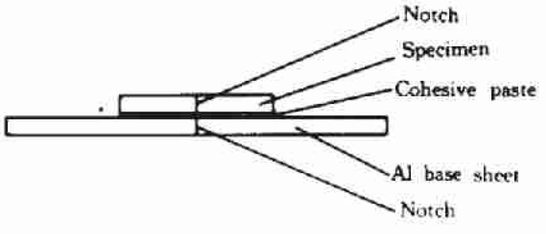

Fig.1 Schematic of glued specimen

Straining experiments were conducted in a HITACHI S-520 Scanning Electron Microscope (SEM) equipped with a tensile testing substage with a 196 N maximum load capacity. The aluminum base sheet was gripped by two miniature screw grips. The composite specimen was step loaded with a screw-driven system.

3 RESULTS AND DISCUSSION

The microstructure of $Al_{67}Mn_8Ti_{25}$ alloy mainly consists of equiaxed single phase grains, 80 − 100 μm in size, mixed with a little second phase. Although a ductility minimum was noted for this intermetallic alloy in uniaxial tension and three-point bending at room temperature[7,8], macroscopic plasticity was not evident in tensile conditions. It is speculated that a ductility minimum can not present in this slice. Thus, loading of specimens should be very slow in order to observe the crack initiation and growth. When samples were loaded with sufficiently small load increments it was possible to directly observe crack initiation at notch roots prior to catastrophic failure.

Fig.2 shows a crack initiated at the notch

Fig.2 Crack initiated at notch root

root with a small loading, as marked by arrow A. Upon increasing the load, there was a short delay of approximately 0.8 s, followed by the crack propagating very quickly. Fig. 3 shows that crack grew by transgranular cleavage. During crack growing the unstable crack propagation occurred and some crack segments formed, as marked B. It seems that the fracture surface consists of many cleavage facets in different altitude. When a crack passed from one grain to another there was a change in the orientation of the cleavage crack. Sometimes the evidence of intergranular failure was noticed in the path of the crack propagation. If the crack crossed the boundary, the crack would usually be transgranular. If the crack was in some cases oriented coincidentally to the grain boundary, some intergranular growth could occur along a part of boundary. Because of being confined with cohesive paste and uncontinued stress, the crack propagation was limited in some grain boundary (see Fig.3 arrow C). With the first crack growing, the second crack was also initiated inside the sample at the same loading event, as marked D. The second crack passed two grains and stopped at a grain boundary. Upon increment a little load, the two cracks combined each other at arrow E, followed by the crack propagating rapidly to the other side of specimen.

The overall appearance of the fracture surface of in-situ observed sample is shown in Fig.4 (a). Examination of the fracture surface at the place around the notch root where crack initiated, Fig.4(b), shows intergranular fracture over a short distance (see arrow F) before cleavage beginning. The fracture surface consists almost

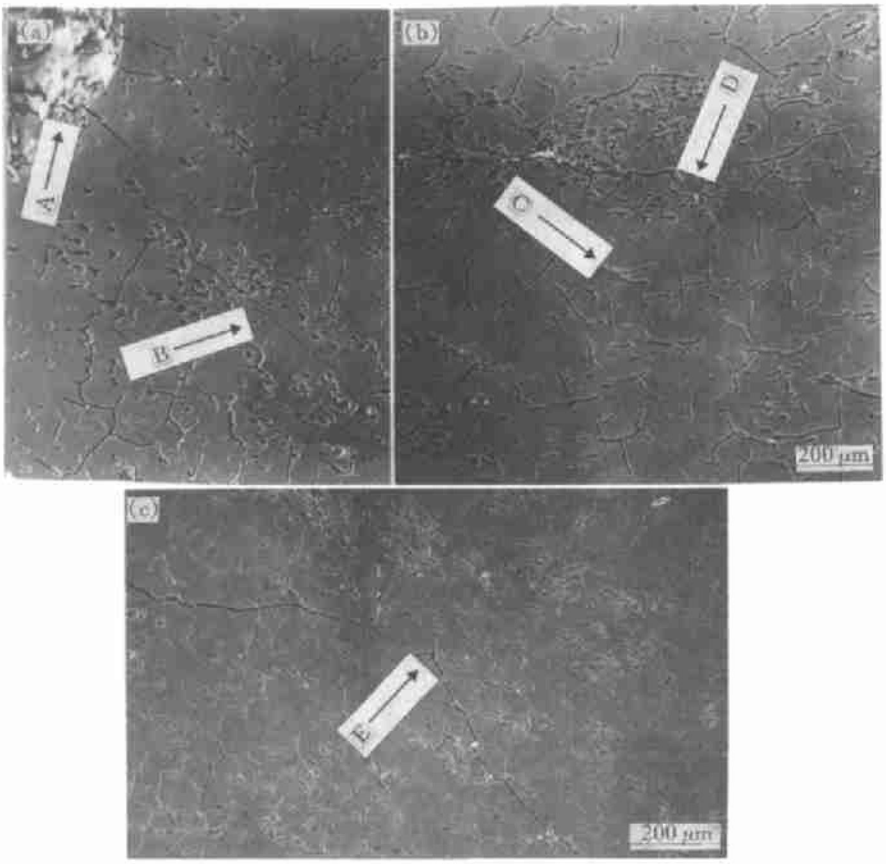

Fig. 3 Cracks growing by transgranular cleavage
(a)—First stage of crack propagating; (b)—Cracks limited in boundaries; (c)—Final stage of crack propagating

entirely of transgranular cleavage facets, and some facets look like that of higher altitude which perhaps correspond to the crack segments as seen at B in Fig. 2. As the crack passes from one grain to another there is a change in overall orientation of the cleavage facets with sometimes slight evidence of intergranular decohesion. This observation is in agreement with the in-situ observation of crack growth process.

Notwithstanding the limited tensile ductility of 0.2% at room temperature obtained in $Al_{67}Mn_8Ti_{25}$ alloy[8], the fact remains that this alloy is very brittle, and no plastic deformation occurs in tension virtually. If the crack initiation starts, the failure proceeds by transgranular cleavage. Therefore, it is very difficult to determine the crack growth rate. In-situ observation of crack initiation shows that no evidence of plastic straining precedes crack initiation at the notch root of the sample. Crack initiates along the boundary and extends to about 100 μm. Upon incrementing a load, the crack growth becomes transgranular. However, it should be clear that crack initiation and growth will associate with the cleavage strength and boundary strength. The transgranular cleavage process is related to the surface energy of cleavage planes. The cleavage energy of several low index planes for the $Al_{67}Mn_8Ti_{25}$ alloy have been calculated by Empirical Electron Theory of Solids and Molecules (EET)[9]. The obtained cleavage energies are 3.12, 4.17 and 4.87 J/m^2 for the {110}, {100} and {111} crystallographic planes respectively. Obviously the {110} plane has the

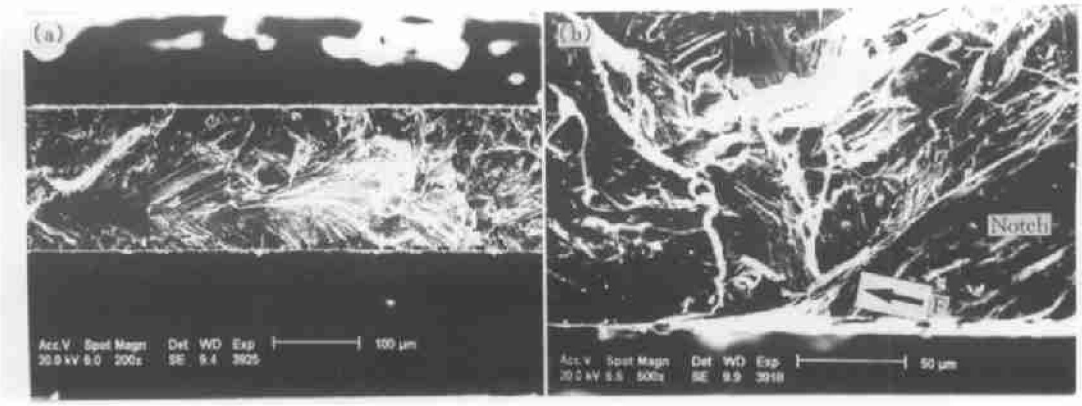

Fig.4 Fracture surfaces of in-situ tensile specimens of $Al_{67}Mn_8Ti_{25}$ alloy
(a)—Overall appearance of fracture surface; (b)—Failure occurred initially at notch root by intergranular decohesion and followed by transgranular cleavage

lowest surface energy among them. The crystallographic orientation of the cleavage planes of $Al_{67}Mn_8Ti_{25}$ alloy have been determined with the electron backscatter diffraction (EBSD)[10]. Among the 13 cleavage facets examined on the fracture surface at room temperature, 7 are {110} type, 4 {100} type, 1 {111} type and 1 {112} type . Therefore, the preferred cleavage plane should be the {110} crystal plane. Because of the randomness of orientation between the different grains, the crack propagates in a zig-zag path.

The experiments have shown that crack initiation at the notch root will result in immediate transgranular growth. The orientation of crack growth should be along the lowest cleavage strength crystallographic planes. This appearance of the fracture surface suggests transgranular cleavage fracture. During the crack growth, it is possible that new crack could also occur in other planes which have relatively low surface energy. Some crack segments are formed in the process of crack growth. Within a grain, many segments have the same orientation. These parallel segments perhaps be in accordance with different cleavage facets in fracture surface of the $Al_{67}Mn_8Ti_{25}$ alloy. Their crystallographic indices are possibly identical.

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