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MICROSTRUCTURE EVOLUTION IN SUPERPLASTIC Al/Mg/Al CLAD SHEET

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ABSTRACT

Recently, weight saving of automobiles has been strongly required to solve the global environmental problems. Mg alloys are one of the promising candidates as a new material for automobile components. However, the application of the Mg alloys is limited due to their poor corrosion resistance. In the authors' preliminary study, an Al/Mg/Al clad sheet was fabricated by hot extrusion and subsequent hot forging. The clad sheet exhibited a high corrosion resistance and excellent superplasticity. More specifically, the elongation of the clad sheet was as high as 550%. Importantly, despite that the elongation of Al itself was only 40% without cladding with Mg, the ductility of Al was greatly improved in the form of the clad sheet. In the present study, in order to clarify the mechanism of the superplastic deformation of the Al part in the clad sheet, the microstructure evolution of the Al during the tensile deformation is investigated. The tensile tests were conducted at a temperature of 573 K and at a strain rate of 1.0×10^{-3} s^{-1}. The Al exhibited fiber-type texture at the beginning of the tensile deformation, and brass-type texture after the elongation of 50%.

KEYWORDS

Mg alloy, Superplasticity, Cladding, Al

INTRODUCTION

Mg alloys have been gaining attention because of their excellent properties e.g. light weight, good recyclability and high electromagnetic shielding. However, their practical applications have been limited due to their poor corrosion resistance. In the authors' previous study, in order to solve this problem, Al coating on Mg alloy by hot extrusion has been proposed, and the Al-coated Mg alloy plate was fabricated (Tokunaga, Matsuura, & Ohno, 2012). The plate was hot-rolled and an Al/Mg/Al clad sheet was fabricated. No cracks or debondings were observed at the Al/Mg interface. The sheet exhibited a high corrosion resistance in a comparable level as pure Al. Also, the sheet exhibited a large and uniform elongation of 550% in a tensile test at a temperature of 573 K and at a strain rate of 1.0×10^{-3} s^{-1} without any breakings or debondings of the Al part (Tokunaga, Matsuura, & Ohno, 2014).

Mg alloys have been known to exhibit a superplastic characteristic when the grain size is small. However, it is known that the pure Al does not generally exhibit the superplasticity. As mentioned above, the Al-coated Mg alloy sheet exhibited 550% of elongation in the authors' previous study (Tokunaga et al., 2014). However, the pure Al itself showed only 40% of elongation, while the Mg alloy itself exhibited 800% of elongation. Thus, it has been demonstrated that the pure Al was superplastically elongated when it was bonded with the Mg alloy. Generally, deformation mechanism of the superplasticity of the Mg alloy is known as a grain boundary sliding. On the other hand, the mechanism of the superplastic elongation of the pure Al is still unclear. The purpose of the present study is investigation of the deformation behavior of the Al part in the Al/Mg/Al clad sheet during tensile deformation.

EXPERIMENTAL

An Al/Mg/Al clad sheet was fabricated by hot extrusion followed by hot forging. The AZ80 Mg alloy (Mg–8.2 mass%Al–0.56 mass%Zn–0.44 mass%Mn) was used for the substrate of the clad sheet and a pure Al with 99.99% purity was used for the surface parts sandwiching the substrate. The temperature, the extrusion speed and the reduction ratio for the hot extrusion were 553 K, 2 mm/min and 92%, respectively. The temperature, the initial strain rate and the reduction ratio of the hot forging were 523 K, 0.84 s^{-1} and 85% respectively. The detailed procedures of the sheet fabrication are described in the authors' previous study (Tokunaga et al., 2014). The Al/Mg/Al clad sheet was wire-cut with an electric discharge machine to make tensile specimens having a gage length of 5.0 mm, a width of 1.2 mm and a thickness of 1.5 mm. The tensile direction was perpendicular to both the extrusion and the forging directions. The tensile tests were conducted at a temperature of 573 K and at a strain rate of 1.0×10^{-3} s^{-1}. In order to make temperature of the specimen uniform before starting the tensile tests, the specimens were held in a furnace for 10 minutes. The strain was calculated from the displacement of crosshead. After the tensile tests, the microstructure and crystallographic orientations were investigated by Electron Back Scattered Diffraction (EBSD) analysis.

RESULTS AND DISCUSSION

Microstructure Evolution of the Al Part During Superplastic Elongation

In order to investigate the tensile behavior of the Al, microstructure evolution of the Al part in the Al/Mg/Al clad sheet during the superplastic elongation was investigated. The sheets were tensile-tested at 573 K and at 1.0×10^{-3} s^{-1}. The thickness of the Al coating layer changed from approximately 130 to 90 μm before and after the test. The test was stopped at several strains and the specimen was water-quenched to investigate the microstructure evolution process during the elongation. Then, the microstructure and crystallographic orientation were examined by EBSD analysis.

Figure 1 illustrates the microstructure and crystallographic evolutions during the tensile test. TD and RD indicate the tensile and forging directions, respectively. The black and white boundaries in the images represent high (more than 15°) and low (2° to 14°) angle boundaries.

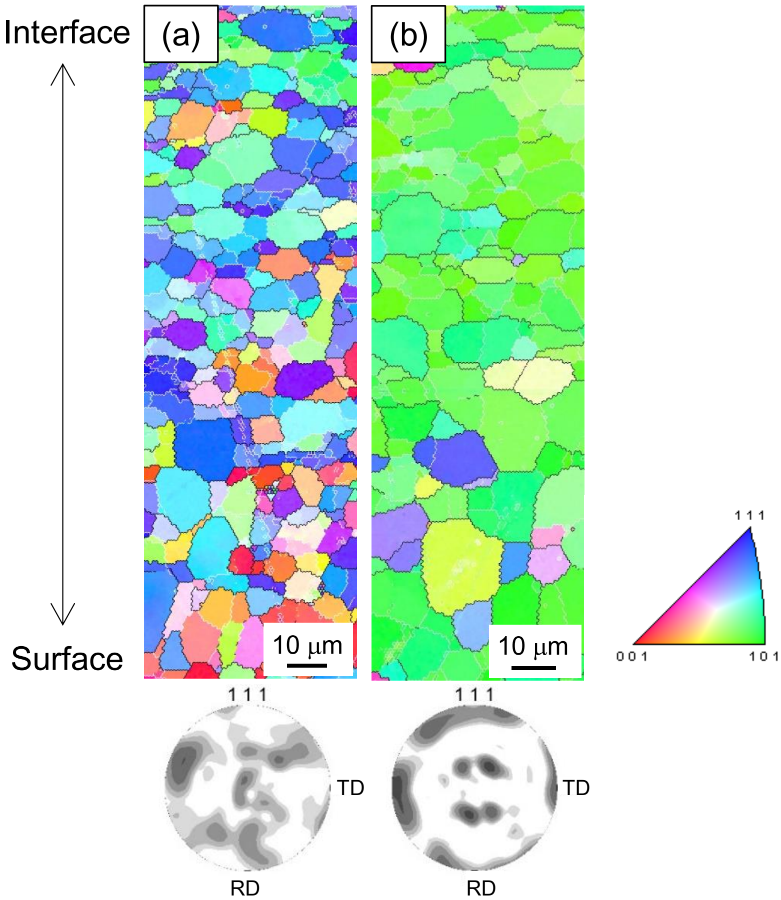

Figure 1. Crystal orientation evolution during the tensile test at a temperature of 573 K and at a strain rate of 1.0×10^{-3} s^{-1}. Figures (a) and (b) show the microstructures at strains of 12 and 50%, respectively. The black and white boundary lines represent high (more than 15°) and low (2° to 14°) angle grain boundaries. TD and RD indicate the tensile and forging directions, respectively.

At the elongation of 12% (Figure 1 (a)), the Al exhibits the fiber texture of [111], which is known as a tensile texture of fcc. However, after the elongation of 50% (Figure 1 (b)), the brass-type texture was observed and it remained until fracture. The brass-type texture typically appears in rolled alloys. Pure Al generally does not show the brass-type texture because of its high stacking fault energy (Takahashi, Hashimoto, & Murakami, 1973). The present brass-type texture should originate from effects of the Mg alloy substrate. The reason why the brass-type texture appeared in the present Al part is discussed in detail in the next section.

Development of Brass-Type Texture

Figure 2 depicts the various constraints models of the so-called "relaxed Taylor model" that indicates the deformed shapes of an originally-cubic grain with different shear (Hirsch & Lucke, 1988). Three principle shears are considered in the relaxed Taylor model. Figure 3 illustrates four types of calculated textures (Hirsch & Lucke, 1988). RD in Figure 3 is specified as R in Figure 2, and it is different from the direction indicated in Figure 1. The pole figures of the specimens after the elongations of more than 50% (such as Figure 1 (b)) were similar to the calculated ones with the constraints BS (Figure 3 (c)) or BSC (Figure 3 (d)). This comparison implies that the Mg alloy substrate may induce the constraint BS or BSC during the deformation of Al part. In the next section, the relation in the constraint, the texture and the deformation behavior of the Al part is discussed.

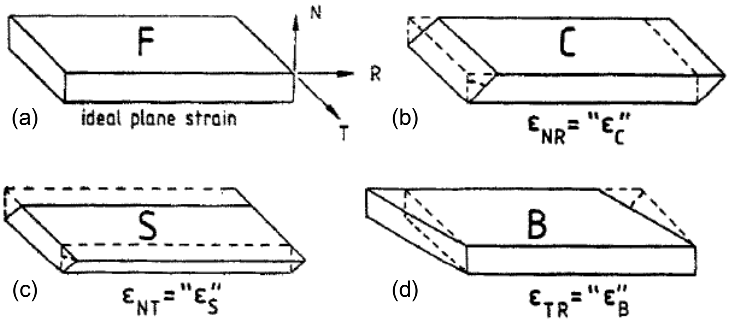

Figure 2. Deformed shapes of an originally-cubic grain (a) under full constraints, and with relaxed constraints conditions with free shears of (b) ε_{NR}, (c) ε_{NT} and (d) ε_{TR} (Reprinted from Hirsch and Lucke, 1988. License No. 4266361036982, License date: Jan 12, 2018, with permission from Elsevier).

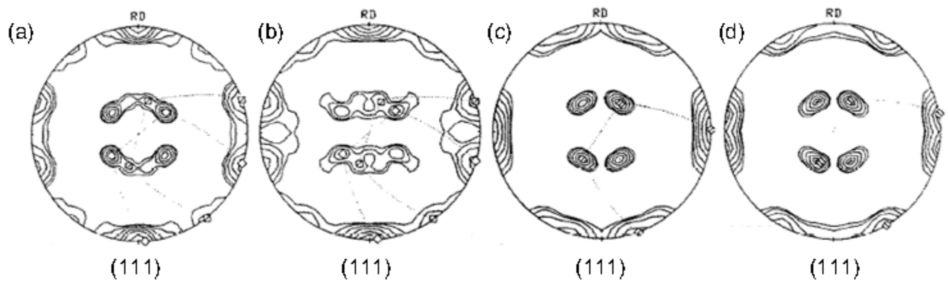

Figure 3. (111) pole figures of calculated fcc rolling textures with the constraints (F, C, S and B) shown in Figure 2. Figures (a), (b), (c) and (d) are results of constraint B, complex constraint of B and C (constraint BC), complex constraint of B and S (constraint BS) and complex constraint of B, S and C (constraint BSC), respectively (Hirsch & Lucke, 1988) (Reprinted from Hirsch and Lucke, 1988. License No. 4266361036982, License date: Jan 12, 2018, with permission from Elsevier).

Texture Development of the Al Part

In the authors' previous study, it has been demonstrated that the Al coating layer and the Mg alloy substrate were bonded without debonding (Tokunaga et al., 2014). The mechanism of the large elongation of the Al part on the Mg alloy substrate has been considered to be due to the suppression of necking of the Al by the uniform deformation of the Mg alloy substrate.

The mechanism of necking suppression of a less ductile layer in a clad sheet which consists of combination of ductile and less ductile layers has been reported as below (Yanagimoto, Oya, Kawanishi, Tiesler, & Koseki, 2010). When necking is initiated in the less ductile layer, its local elongation tends to become larger than that of the ductile layer due to a stress concentration. However, the total elongation of the both layers should be equal. Thus, in the reported work, it has been considered that the necking initiation arises additional elongation inside the ductile layer to compensate the increased elongation. On the other hand, additional compression has been considered to be arisen in the less ductile layer in the necking part for making the total elongation equal to that of the ductile layer. This compression suppresses the growth of the necking. Therefore, it can be considered that the necking of the less ductile layer in the clad sheet is suppressed and the less ductile layer can be elongated over its original elongation.

In the case of the present study, the suppression of the necking of the Al part in the clad sheet can be considered as follows. When necking is initiated in the Al part, additional elongation and compression could be arisen in the Mg alloy and the Al, respectively. The additional compression suppresses the necking initiation of the Al part. However, a shear should have arisen in the present Al part instead of a pure compression because the Al was constrained by the Mg alloy substrate in the Al/Mg interface side but the surface side was free. As a consequence, it can be considered that the shear leads to the deformation of the Al part as the constraint model of BS or BSC, which leads to the brass-type texture.

CONCLUSIONS

Deformation behavior of the Al part in the Al/Mg/Al clad sheet during the tensile deformation has been investigated with a focus placed on evolution of microstructure and crystallographic orientation. The texture of the Al part changed from the fiber-type to the brass-type texture during the superplastic elongation. It was considered that the texture change in the Al part was due to the shear and the compression which were arisen from the constraint by the Mg alloy substrate.

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