Materials Letters 222 (2018) 122–125

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/mlblue

Effect of strain on mechanical and microstructural properties of Al/Cu claddings during caliber-rolling

Jongbeom Lee [a,*], Jeongmin Park [a,b], Haguk Jeong [a]

[a] Advanced Process and Materials R&D Group, Korea Institute of Industrial Technology, Incheon City 21999, Republic of Korea
[b] Department of Advanced Materials Science and Engineering, Inha University, Incheon City 22212, Republic of Korea

ARTICLE INFO

Article history:
Received 6 March 2018
Received in revised form 28 March 2018
Accepted 29 March 2018
Available online 31 March 2018

Keywords:
Structural
Metallic composites
Grain boundaries
Microstructure
Recrystallization

ABSTRACT

Al/Cu claddings were fabricated by caliber-rolling process at 298 K and their mechanical and microstructural properties were evaluated. The Vickers hardness (VH) value of the Al layer in the claddings increase with increasing strain, however, it decreased when the strain was over 0.48. For Cu layer, the VH value rose with strain. The grain size of the Al layer in the cladding decreased with increasing strain and then the grain size increased with a strain of over 0.48. In the case of Cu layer, the grain size increased with increasing strain of the cladding. The relationship between hardness and grain size follows the Hall-Petch equation. During, dynamic recovery is pronounced in the Cu layer, however, grain growth only take place in the Al layer. The evolution of texture is due to a difference in stacking fault energy (SFE) between Cu and Al. The Al layer, with a low SFE, exhibits stronger texture than the Cu layer because of different deformation mechanisms.

1. Introduction

Metallic composites have received much attention recently because they have improved material properties when compared to pure metals [1–3]. In the case of Al/Cu claddings, the material is almost half the weight of pure copper and its cost is 30% less. At the same time, the electrical and thermal properties of Al/Cu claddings are better than those of pure Al. Base on these advantages, the Al/Cu claddings have been used to fabricate products such as armored cables, TV yoke coils and busbars. Several processes have been used to fabricate bimetal claddings, including extrusion [4], drawing [5], roll forming [6], and explosive welding [7]. The caliber rolling process is a process of interest due to its capability of grain refinement and its relative ease of processing. However, very few studies have been reported on the caliber rolling process for manufacturing bimetal materials. Furthermore, microstructural and textural studies of bimatal materials are rare.

In this study, Al/Cu claddings were fabricated by caliber rolling process at 298 K with a rolling speed of 2.8 m/min. Mechanical properties and microstructural change in the Al and Cu layer of the claddings were investigated as a function of strain, using Vickers hardness (VH) and electron backscatter diffraction (EBSD) analysis.

* Corresponding author.
E-mail address: ljb01@kitech.re.kr (J. Lee).

https://doi.org/10.1016/j.matlet.2018.03.193

2. Material and methods

A commercial extruded Al6061 rod, 14 mm in diameter and 200 mm in length was used as the core and a Cu tube (Cu-99% wt), 18 mm in diameter, and 2 mm in thickness was used as the sheath in this study. The Cu tube and Al bar were homogenized at 673 K for 2 h under an Ar atmosphere. The caliber rolling process was carried out at 298 K with a reduction of area (RA) per pass from 8 to 12%, which is equivalent to a strain of about 0.1 as shown in Fig. 1(a). The caliber rolling speed was 2.8 m/min without lubricant and the claddings were rolled without annealing. Caliber-rolled specimens were cut parallel to the rolling direction (RD) with a size of 3 mm for mechanical and microstructural evaluation.

Vickers hardness (VH) measurement was used to investigate mechanical properties of the cladding specimens, as shown in Fig. 1(b). The VH test was carried out using 0.4 Kg weight after each. Electron backscatter diffraction (EBSD) was used to observe the microstructure and crystalline texture. EBSD measurements were conducted using a FEG SEM equipped with a TSL EBSD system. EBSD maps were acquired using a spatial step size of 0.1 μm and a size of 150 μm × 150 μm.

3. Results and discussion

Fig. 1(c–e') shows inverse pole figure (IPF) maps from the Al (c–e) and Cu (c′–e′) layers of caliber rolled samples with respect

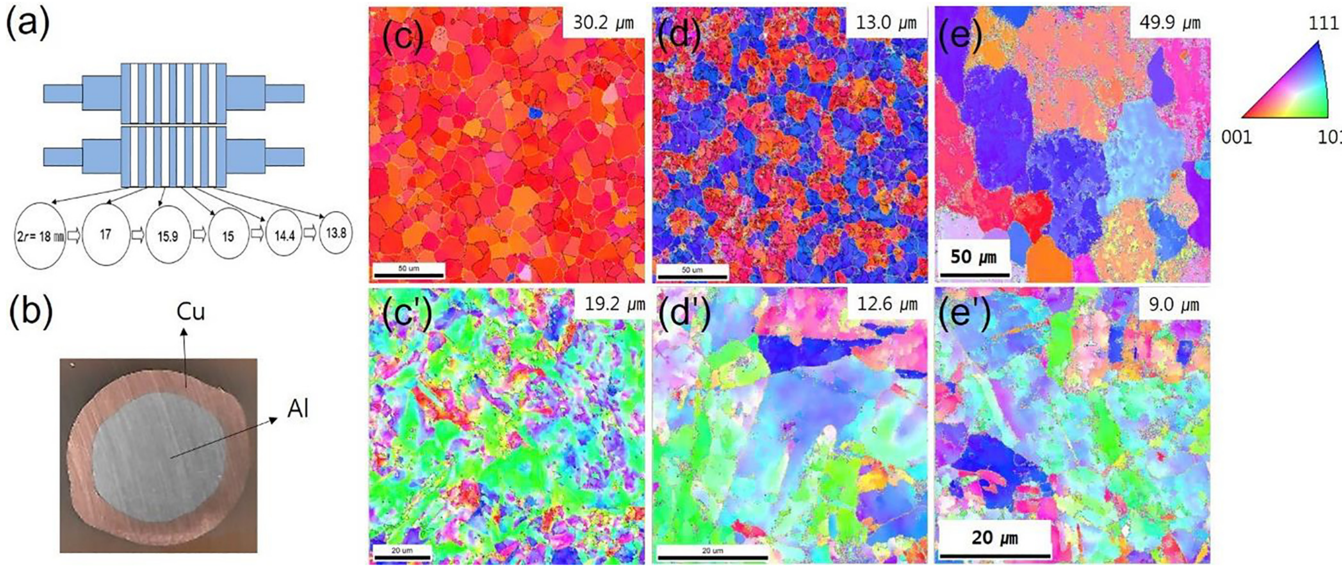

Fig. 1. Schematic of deformation process (a), and cross-section of sample caliber-rolled with strain of 0.56, and inverse pole figure (IPF) maps from Al layer (c) ε = 0, (d) ε = 0.48, (e) ε = 0.56 and Cu layer (c′) ε = 0, (d′) ε = 0.48, (e′) ε = 0.56 of caliber rolled samples.

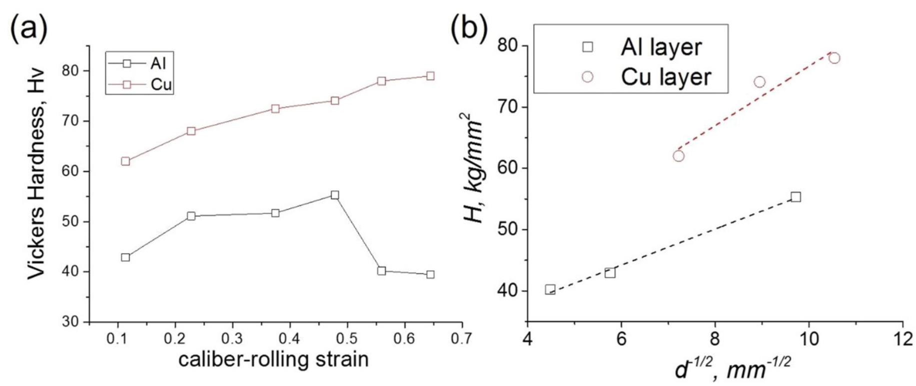

Fig. 2. (a) Variation of Vickers hardness (VH) in the Al and Cu layers of Al/Cu claddings with strain and (b) relationship between hardness and grain size.

to the rolling direction. Each point is depicted with a color according to the crystal orientation. The right upper figure of each picture indicates the average grain size. As can be seen in Fig. 1(c)–(e), the mean grain size of the Al layers decreases as a function of increasing Al/Cu cladding strain, however, it increases when the Al/Cu cladding is strained by more than 0.48. For the Cu layer of Al/Cu claddings, the mean grain size decreases with an increase in strain. Concerning the change of grain size, in this study both grain refinement and grain growth occur in the Al layer, while in the Cu layer only grain refinement take place. Interestingly, the rate of grain refinement and grain growth in the Al layer of the Al/Cu cladding is larger than that of the Cu layer, when comparing the microstructure of the Al and Cu layers at the same strain. The heat generated is different between the Al and Cu layers of Al/Cu cladding during caliber rolling deformation. The amount of heat is determined by deformation and by characteristics of materials. Eq. (1) expresses the relation between heat and deformation [8].

$$\Delta \mathrm{T} = \frac{\eta}{\rho C_v} \int_0^{\varepsilon_e} \sigma d\varepsilon \tag{1}$$

where ΔTis generated heat, $\varepsilon_e$is the equivalent strain, $\sigma$is yield stress, $\rho$is material density and $C_v$is specific heat. The value of $\eta$is 1 when all the work is used to heat the sample without any heat loss. According to Eq. (1), Al materials can generate more heat than Cu materials for the same equivalent strain because the value of material density multiplied by specific heat is lower in Al than Cu. According to a report by R. Kapoor [8], Al 6061 materials have a larger value of deformation-induced temperature than pure Cu materials. A temperature rise in Al materials could increase the rate of grain refinement and grain growth.

Fig. 2(a) shows the variation of Vickers hardness (VH) in the Al and Cu layers of Al/Cu claddings with strain. As can be seen in the graph, the VH value of Al layer and Cu layer increase with increasing strain, however, the VH value of the Al layer decreases when the strain is over 0.48. As a result of the grain growth as shown in Fig. 1(e), the microhardness value decreases for the sample caliber-rolled with strain of 0.56. When the VH values change in the Al and Cu layers during caliber-rolling deformation, it could be related to the change in mean grain size in the Al and Cu layers as seen in Fig. 1. Attempts have been made to correlate the hardness of a materials with its flow stress [9]. Hall [10] proposed that the dependence of hardness on grain size follow directly from the Hall-Petch [11–12] relation between flow stress,σ_ε, and grain size, d, (2), thus the hardness-grain size relation is described by (3)

$$\sigma_\varepsilon = \sigma_{0\varepsilon} + K_\varepsilon d^{-1/2} \tag{2}$$