Materials Letters 236 (2019) 139–143

Contents lists available at ScienceDirect

Materials Letters

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

Texture development in the interfacial zone of Al/Cu bimetal cold roll-bonded for E-mobility

Jian Feng [a,b,*]

[a] Centre of Materials Engineering, Heilbronn University, Max-Planck-Str. 39, D-74081 Heilbronn, Germany
[b] Institute of Materials Science, TU Bergakademie Freiberg, Gustav-Zeuner-Str. 5, D-09599 Freiberg, Germany

ARTICLE INFO

Article history:
Received 20 August 2018
Received in revised form 9 October 2018
Accepted 13 October 2018
Available online 15 October 2018

Keywords:
Texture
Al/Cu bimetal
Cold roll bonding
ODF
EBSD
Crystallography

ABSTRACT

Cold roll-bonded Al/Cu bimetal has been widely used in heat sinks for main converters in E-mobility. The development of textures in the interfacial zone of cold roll-bonded Al/Cu bimetal was investigated with the help of orientation distribution function (ODF) analysis based on the FEG-SEM/EBSD technique. The present results show that the texture development of the cold-rolled Al strips can be represented by an α-fibre shift approaching the bonding interface. Cold rolling of Cu strips in the bonding zone splits Goss {1 1 0}<0 1 0> and increases the intensities of metastable T {1 1 2}<1 3 1> texture components. By approximating the bonding interface, T components dissolve and both α- and γ-fibre sharpen. The intensities of the approx. 40° <1 1 1> pair, Cu {1 1 2}<1 1 1> and RC {1 0 0}<0 1 1>, increase significantly. The strong bonding of the bimetal can be attributed to the strain-induced formation of ultrafine grains during severe plastic deformation at the bonding interface without recourse to concepts such as 'diffusion' or 'intermetallics'.

1. Introduction

Cold roll-bonded Al/Cu bimetal has been widely used in heat sinks for today's automotive electronic devices. The bimetal combines high thermal conductivity and good formability and can be well solderable to the electronic components. After cold roll bonding (CRB) the bonding of bimetal should be strong enough to survive the following process steps especially the cold extrusion. CRB is a low-temperature solid-phase welding process, which has been widely used in manufacturing large layered sheets and foils.

It has been found that during CRB two opposing surface layers of metal strips break up and underlying metal is extruded through cracks of the broken layers. Through intimate contact between contaminate free metal areas, the bonding is established [1–3]. However, there are still difficulties in explaining and modeling the exact bonding mechanism of CRB [3]. Progresses have been made in the past for understanding of interfacial structures of cold roll-bonded Al/Cu bimetal strips developed upon different annealing conditions [4,5], yet annealing is neither a sufficient nor a necessary condition for a strong bonding. The crystallographic orientation distribution of bimetal created by CRB, which is a central concept in texture analysis and anisotropy, has rarely been reported.

The aim of the work is to investigate the texture development in the interfacial zone of cold roll-bonded Al/Cu bimetal and to find out its relevance to the formation of ultrafine grains in the interfacial region and the bonding efficiency of CRB. The development of automated electron backscatter diffraction (EBSD) technique has enabled us to handle this problem by directly examining the interfacial zone of the cold roll-bonded bimetal.

2. Experimental

Commercial EN AW-1050A (Al-0.12Si-0.24Fe-0.05Cu-0.02Zn) and SE-Cu58 (Cu-0.003P) were used in the present investigation. As-received Al-strips with the dimensions 1200 × 80 × 25 mm and Cu strips 1400 × 80 × 4.5 mm were in soft-annealed conditions. The strips with brushed surface were cold-rolled without lubrication and with a maximum thickness reduction rate of 80%. These specimens with high bond shear strength (>$R_{P0.2,\ Al}$ measured according to DIN 50162 specifications) were chosen before cold extrusion and without further annealing. Crystallographic orientations of the bimetal were measured at room

* Address: Centre of Materials Engineering, Heilbronn University, Max-Planck-Str. 39, D-74081 Heilbronn, Germany.
E-mail address: jian.feng@hs-heilbronn.de

https://doi.org/10.1016/j.matlet.2018.10.079
0167-577X/© 2018 Published by Elsevier B.V.

temperature by FEG-SEM/EBSD technique and analyzed by MatLab-MTEX toolbox. The accelerating voltage for EBSD measurements was 20 kV, the step size was 40 nm, and the tolerance range of the Euler-angle measurements is 0.5–1° in these observations. The overall hit rate was ~93%. The average grain size was weighted by area fraction with the maximal misorientation angle 15°.

3. Results

Fig. 1 shows inverse pole figure (IPF) maps of the interfacial zone at the beginning of rolling. The number of large grains, which consist of numerous crystallographic packets separated by low-angle grain boundaries, decreases significantly during the one-pass rolling from left to the right. The average grain size of Cu in the vicinity of the bonding interface (~0.4 μm) is much smaller than Al (~1.2 μm), although the average prior grain size of Cu (~20.5 μm) was much larger than Al (~9.6 μm). The interfacial zone of cold roll-bonded Al/Cu bimetal has been longitudinally divided into 7 areas as shown by way of example in Fig. 1. Notably, ODF-analysis was not confined to the beginning of the rolling but rather based on limited number of EBSD maps.

Fig. 2 represents the texture development of Al-strips by approaching the bonding interface. 0° and 45° ODF sections of the Euler space show that the rotated Goss component {1 1 0}<1 1 0> with high intensities transformed to the Brass deformation component {1 1 0}<1 1 2> and further to {1 1 0}<1 1 3> component along the α-fibre. In the immediate vicinity of the bonding interface, the texture transformed back to the rotated Goss again but with a large spread of the intensity. {1 1 3}<0 3 1> texture, which is typical for grains with high grain boundary mobility with respect to the deformed matrix, was also observed along with the shifting of α-fibre.

The texture development in Cu strips is complex and distinguishing. As shown in Fig. 3, by approximating the bonding interface, the Goss component {1 1 0}<1 0 0> with high intensities climbed along the τ-fibre. The intensities of the RC {1 0 0}<0 1 1> and unstable T {1 1 2}<1 3 1> components increased notably. As deformation proceeded, the Goss component split further along θ-fibre. The intensity of the rotated Goss {1 1 0}<1 1 0> increased as well. In the immediate vicinity of the bonding interface, the Goss and T components dissolved. The intensities of the approx. 40°<1 1 1> pair, Cu {1 1 2}<1 1 1> and RC {1 0 0}<0 1 1>, increased significantly. Components of the α-fibre, Br {1 1 0}<1 1 2>, rotated Br {1 1 0}<5 5 6>, and P {1 1 0}<1 1 1> were emphasized. In the 45° ODF section, intensities of the γ-fibre can be well recognized.

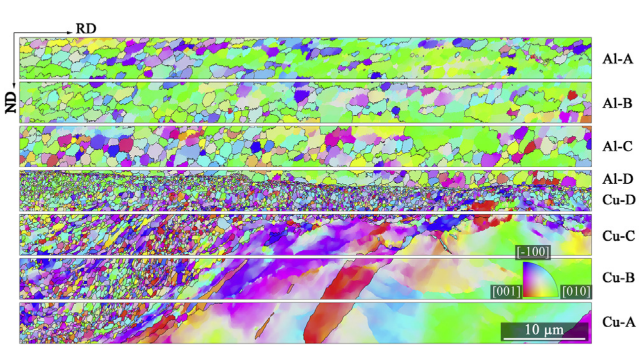

Fig. 1. Inverse pole figure (IPF) maps of the interfacial zone of cold roll-bonded Al/Cu bimetal with high bond shear strength. The solid lines indicate high-angle grain boundaries.

4. Discussion

4.1. α-fibre shift

α-fibre texture is also known as a pure-metal texture. In face-centered cubic metals of high stacking fault energy, the homogeneity along α-fibre deteriorates as rolling continues and as deformation proceeds. The presence of the rotated Goss component in cold-rolled specimens is not yet fully understood, but it was suggested to be retained from the hot rolling [6]. The shift of α-fibre components especially the Brass component could be attributed to rolling geometry and the friction [7]. The dissimilar thickness of strips leads to non-plane-strain state during CRB and results in the texture heterogeneity. The shift becomes more pronounced under conditions of high friction, which can be indirectly proved by the observations in Cu strips. The strong RC {1 0 0}<0 1 1> component developed in the immediate vicinity of the bonding interface and the γ-fibre especially the {1 1 1}<0 1 1> component indicate the cold rolling without lubricant involves strong surface shears [8].

4.2. The T component

The rise of the 45° plane-strain T {1 1 2}<1 3 1> component may indicate an extension of β-fibre beyond Y {1 1 1}<1 1 2> orientation through the T component and further towards C {0 0 1}<uvw> [9]. As observed in Al-C, pancaking may increase the intensities of the T component [10] and the T component can dissolve as the pancaking is removed by the severe plastic deformation (SPD) as shown in Fig. 3.

4.3. Formation of ultrafine grains

As shown in Fig. 4, due to SPD strain-induced formation of ultrafine (submicron) grains of both Al and Cu strips was observed at the bonding interface, which can be related to the mechanism of CRB without recourse to concepts such as 'diffusion' or 'intermetallics'. Wright et al. [1] have proposed the relationship between the cold bonding efficiency η and the rolling deformation

$$\eta = \frac{S_B}{S_M} = H\left[1 - \frac{(1-R_f)^2}{(1-R_t)^2}\right] \tag{1}$$

where S_B is the strength of the cold bonding, S_M is the strength of the matrix, R_f is the final reduction at the end of cold rolling, R_t is reduction at threshold deformation, and H is an empirical hardening factor. In this approach, the bonding area A is given by

$$A = 1 - \frac{(1-R_f)}{(1-R_t)} \tag{2}$$

By combing Eq. (1) and Eq. (2), we get

$$\eta = H\left[1 - (1-A)^2\right] \tag{3}$$

i.e. η increases monotonously with an increase in A. The ideal shear deformation textures of face-centered cubic metals can be approximated by the RC components and γ-fibre [11], which compare to the observations in Cu-D. The shear deformation textures especially γ-fibre can improve the Lankford values and facilitate the grain refinement [11]. The formation of ultrafine grains during SPD can greatly increase A, and, therefore, improve the bonding efficiency.

5. Summary

In this work, ODF analysis with inverse pole figure maps was used to account for the formation of ultrafine grains in the interfa-