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The Preparation and Characterization of Cu/AA6061 multi-layer Composte produced by Accumulated Roll Bonding

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Abstract. The present study focuses on the preparation and characterization of Cu/AA6061 multi-layer composite materials produced by accumulated roll bonding (ARB). The bonding between metallic layers and the microstructure of samples was characterized by optical and scanning electron microscopy and tensile testing which were used to characterize the mechanical properties. After four ARB cycles, the interface only displays a little bit, showing that the good contact between layers were formed and the mechanical properties were improved. The both materials have a fine microstructure with grain sizes decreased with increasing cycles of ARB.

1. Introduction

Light alloys and light metals have low density and high strength-to-weight ratios. They are generally characterized by low toxicity in comparison to other heavy metals, but beryllium is an exception. Lightweight materials include aluminum, magnesium, titanium, and beryllium alloys. A composite material [1,2] is a combination of two or more materials that leads to better properties than an individual component. In this combination, each material retains its original chemical, physical and mechanical properties [3]. Two components of the composite material are reinforcements and matrices. The main advantage of lightweight composite materials is their rigidity, durability and high fatigue performance, combining with low density, which allows weight reduction during use compared to other bulk materials.

Knowing that large distortions at low temperatures can lead to significant changes in the microstructure of metallic materials [4-6] and metal matrix mixtures (MMC) [7-9]. Based on this particle transformation effect, bulk nanostructured materials are treated with some intense plastic deformation methods (SPD), such as channel angular pressing (ECAP), high-tension torsion, cumulative roll bonding, rolling equal angle, grooved rolling, equal pressing multi-channel angle, etc., was developed [10-14]. In different SPD methods, the accumulated roll bonding (ARB) is defined as a sheet metal forming process, in which a large plastic deformation is applied to a bulk process in order to make an ultra-fine grained materials. Accumulated rolling techniques are part of the development of conventional rolling methods to improve the mechanical properties of materials. It was developed by Saito and Tsuji [15-18], this technique involves the steps of: (1) cleaning the contact surfaces of two metal plates, (2) rolling two metal plates, (3) cutting adhesive metal sheets into two halves, (4) cleaning the surface and (5) continuing rolling them. This process is repeated according to the requirements of the product.

One cycle in the ARB technique and is repeated several times by the following procedure; cutting - cleaning the surface - stacking - rolling adhesive to achieve superfine structure and bond the desired layers shown in Figure 1. In the ARB technique, it is possible to use the same or different layers of

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materials. Recently, a number of studies on ARB techniques of different materials have been published [19-23].
In this paper, the study focuses on the preparation of Cu/AA6061 multi-layer composite materials as well as characterization of their microstructure and mechanical properties after having accumulated roll bonding.

2. Experimental work

Accumulated roll bonding was used to study the grain refinement potential. A detail study on microstructure, interfacial bonding and mechanical properties of Cu/AA6061 laminated composite deformed by this SPD technique was carried out. The experimental work was succeeded with processing a combination of two dissimilar materials: an aluminum alloy AA6061 (Al-Mg-Zn) and a commercial pure Cu (99.9 %). The initial thickness of each material was 2 mm. The ARB samples are cut perpendicularly to the original rolling direction. Two pieces of the original samples were erased by acetone. The samples were then stacked and heated in a furnace at 350 °C for 10 minutes and then rolled with a thickness of about 50 % reduced under non-lubricant conditions.
The microstructure evolution and interfacial bonding studies were carried out by using optical and scanning electron microscopy. Specimen preparation was done by mechanical grinding; polishing and etching with mixture of distilled water (100 ml), Hydrochloric acid (25 ml), Ferric chloride (5 grams) for copper and 0.5 % hydrofluoric acid for aluminum. Uniaxial tensile provide a precise estimation of mechanical properties. All the tensile tests have been carried out on the 809 Axial/Torsional Test System.

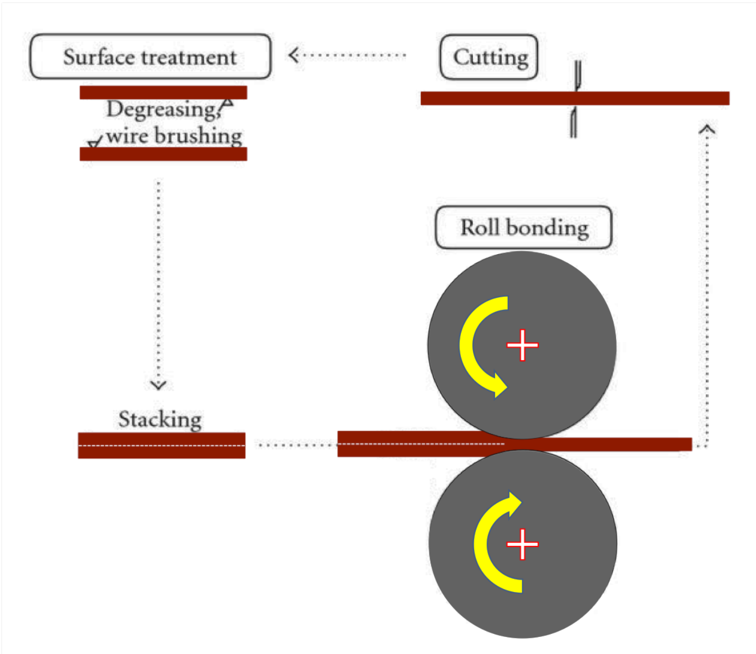

Figure 1. One cycle in the ARB technique. [13]

3. Results and Discussion

To process Cu/AA6061 multi-layer composite materials with stable, the ARB cross section processed strips is controlled as shown in Figure 1. To successfully process a large deformation, uniform and reduce residual stress in the rolling process, both Cu and AA6061 are heat treatment between ARB cycles.
The interface which is after the first cycle (Figure 2a) visible more the interface of after 3 ARB cycles (Figure 2c). After 4 ARB cycles (Figure 2d), the interface only displays a little bit, showing that the good contact between layers are formed. In this case, only a few unbound parts are seen in the sample.

Obviously, the next roll is enough to improve the alignment of the introduced interfaces in a previous cycle. The multi-layer of Cu/AA6061 combination are successfully processed according to the ARB process. By increasing the number of ARB cycles, the reinforcement layers in the aluminum matrix increase. The bonding between the reinforcement layers and the matrix layers are formed when the rolling force is applied on the sample. This causes the sample to undergo the severe plastic deformation process. In addition, the difference in mechanical properties, especially the hardness between the two materials, has created the appearance of the fracture of aluminum in the interlayer. The extrusion of the copper through the fractures into aluminum also occurs simultaneously. This creates the formation of bonding and coalescence in the interlayer.

When the samples are annealed between ARB cycles at 350 °C, residual stress has not been completely eliminated, but micro-cracks can significantly be reduced through the recovery process. Figure 3 and 4 shows that the grains are stretched in the rolling direction and reduced in size from the first ARB cycle to the fourth cycles. The microstructural analysis reveals that during further deformation small equiaxed grains appear. After four ARB cycles, the mean grain size reduced from (40 – 50) µm to (10 – 15) µm. The grain sizes in aluminum alloy are smaller than copper.

Base on the scanning electron microscopy (SEM) images of the grain structure of samples in the initial state and after 2, 4 ARB cycles, what can be easily seen is the change of the microstructure in the two materials. The grains are elongated along the rolling direction.

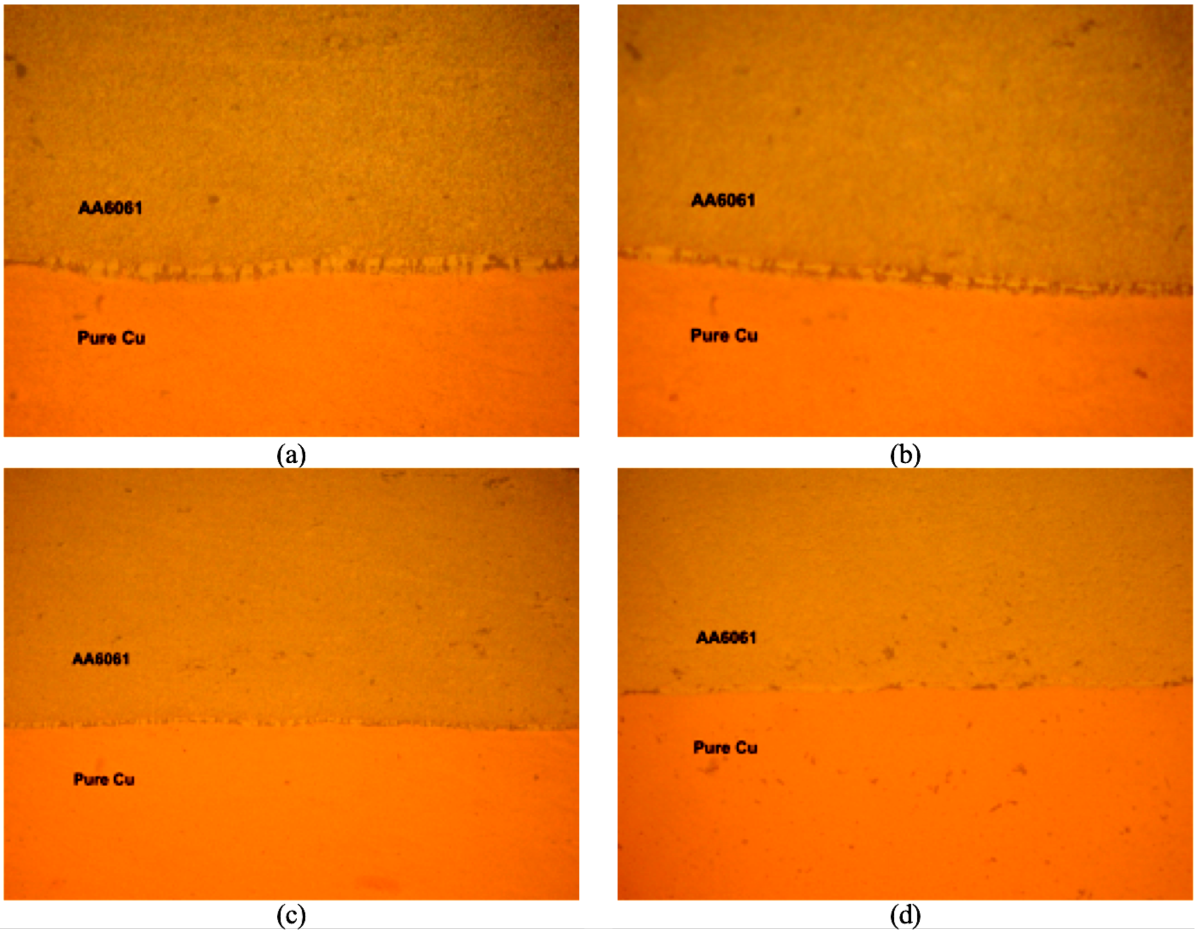

Figure 2. The micrographs (×500) of the bonding between the various layers of one (a), two (b), three (c) and four (d) ARB cycles

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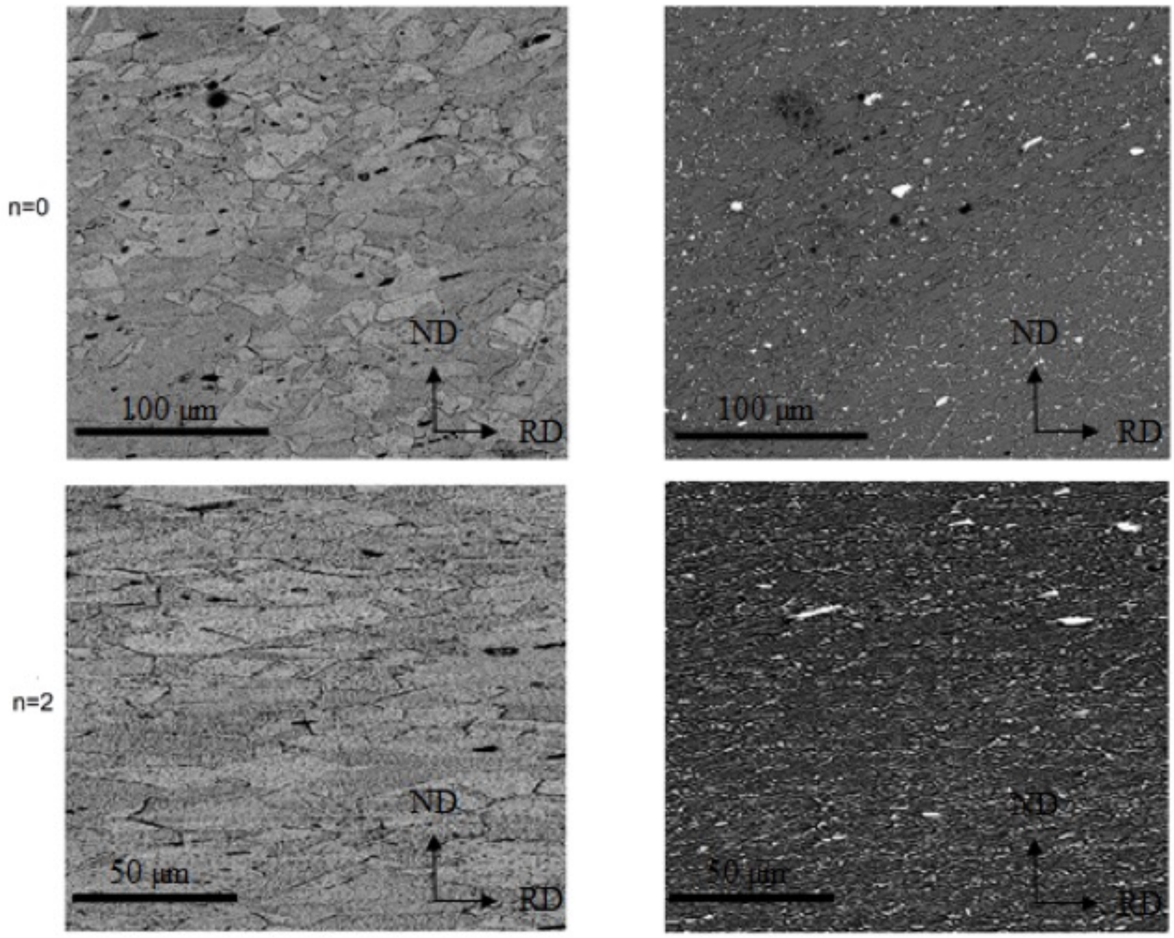
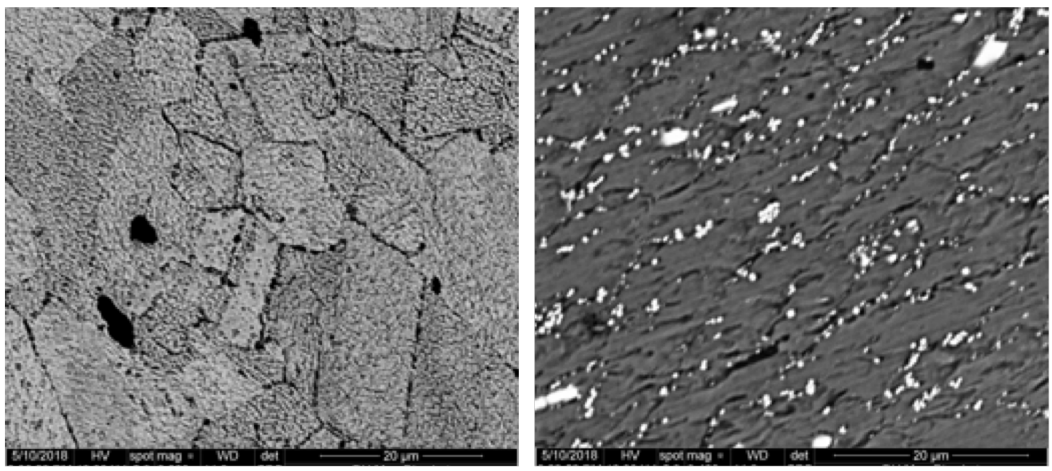


Figure 3. The scanning electron microscopy of pure Cu (left) and AA6061 (right) in befor and after 2 ARB cycles



(a) (b)

Figure 4. The scanning electron microscopy of pure Cu (a) and AA6061 (b) after 4 ARB cycles

The stress increased from 197 (Cu) and 233 (AA6061) to 247 MPa (4 cycles), so the stress of the after 4 ARB cycles is higher than initial single copper and aluminum alloy. On the other hand, the elongation value greatly increased from 33 % (AA6061) and 42 % (pure Cu) to more 70 % in the after 4 cycles of ARB (Figure 5). This can be explained as follows: with deformed aluminum alloys and copper, in addition to the movement of the deflection within each grains, the role of grain boundaries is not significant due to coarse grains. However, post-deformed aluminum and copper alloys with ARBs, have finer and finer grains with a higher angle of the coarse grains, hindering the movement of the stronger deflection, leading to a more durable material limit. The outstanding advantage of the durable increasing mechanism by making fine grained is to increase all indicators.

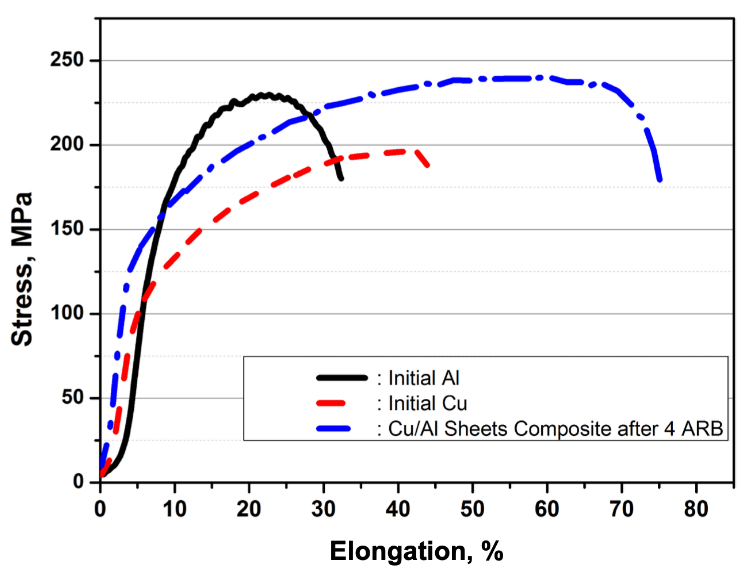


Figure 5. The stress – elongation of the initial copper and aluminum alloy and the Cu/AA6061 multi-layer composite materials after 4 ARB cycles.

In addition, the multi-layer composite materials can promote the advantages of each material separately. In this case, it is the combination of aluminum alloy strength and pure copper ductility. It can be seen that the uniform rolling of both aluminum alloy and copper in the rolling process is ensured by recovering them by heat treatment between ARB cycles. It is a typical phenomenon in SPD materials.

4. Conclusions

To maintain the stability of the layer in ARB composites of Cu/AA6061 multi-layer during processing. The weaknesses such as rolling speeds and intermediate annealing temperatures have been found to be effective because they prevent microscopic crack formation in Cu/AA6061 multi-layer composite materials.
By increasing the layer in the ARB process, the interface of the previous layer is improved. After four cycles, both materials have microscopic structure with reduced grain sizes.
Tensile strength increased moderately but the elongation increased significantly after ARB. This shows that when combining a variety of materials and increasing the number of layers by ARB technique, ductility has increased significantly.

Acknowledgments

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