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Mechanical properties and microstructure evolutions of multilayered Al–Cu composites produced by accumulative roll bonding process and subsequent annealing

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ABSTRACT

In this investigation different thicknesses of Cu and Al strips were accumulative roll bonded (ARBed) to form five dissimilar multilayered Al–Cu composites. Also, to investigate the effect of annealing on the mechanical properties, selected ARBed composites were annealed at three different temperatures (300, 400 and 500 °C) for four different periods (10, 30, 60 and 360 min). Different microstructural characterizations were conducted on the produced composites. The results demonstrated that by increasing the amount of Cu in the composites, tensile strength improved while elongation deteriorated. By increasing the annealing time and temperature, the tensile strength of the composites was remarkably decreased, after which it was increased while the elongation was increased rapidly and then decreased. This behavior was considered to be due to the restoration of the work-hardened metallic layers as well as formation of intermetallic compounds during annealing process. Corresponding fracture surfaces also revealed a brittle fracture in most of the annealed composites.

1. Introduction

Metal Matrix Composites (MMCs) have received attention due to their specific properties such as high strength and lightweight as compared to bulk materials [1] and can be considered as enhancement of lightweight materials such as Al alloys [2,3]. The MMCs are interesting materials for many applications such as automobile and aerospace industries [4]. There are numerous methods to produce MMCs such as squeeze or stir casting, spray forming and powder metallurgy techniques. In the casting method which is widely used for producing MMCs, non-homogenous distribution of the reinforcement as well as sinking or floating behavior of reinforcement in the melt can deteriorate the composite properties [5].

The disadvantages of the aforementioned techniques led to inventing a novel method of producing MMCs, so-called Accumulative Roll Bonding (ARB), which was first introduced by Saito et al. [6]. The advantages of ARB technique such as simplicity, cheap manufacturing, capability of mass production and industrialization resulted in receiving great attention in recent decades. Besides, ARB is one type of severe plastic deformation in which bulk ultra-fine grains (UFG) metallic material can be produced [7].

To date, ARB method has been widely used for producing similar and dissimilar layered composites. In a recent study [8] for instance, an Al layer underwent anodizing process to obtain alumina layers which were used as reinforcement particles in the Al matrix. In the case of dissimilar layered composites a great number of studies were performed including Al–Ti [9], Al–Mg [10], Al–Zn [11], Ag–Cu [12], Cu–Nb [13], Ti–Ni [14], and Al–Ni [15]. It was generally found that during the ARB process of dissimilar layered metals, due to intrinsic differences in mechanical properties, instabilities (necking and fracturing) took place in one of the layers. This was mainly considered due to the different strain hardening behavior of the layers, e.g. Al versus Ti or Ni. In this regard, Eizadjou et al. [16] produced Al–Cu composite using ARB process. They found that during the ARB process, Cu layer having higher strain rate hardening fractured and distributed homogeneously through the Al matrix resulting in improved tensile strength. However, they did not consider the effect of other parameters (such as amounts of Cu and Al as well as effect of annealing) which could have an influence on the mechanical properties of the Al–Cu composite.

The overall aim of the current research is then to produce Al–Cu–Al_2O_3 composite using anodizing and ARB processes. For the first step, different parameters to achieve the best condition for Al_2O_3 coatings and reductions during cold roll bonding were

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optimized [17]. For the present study as the second step, the effect of different amounts of Al and Cu in composite (by altering the thickness of initial metallic layers) and also the effect of subsequent annealing treatment on mechanical properties of Al–Cu composites were investigated.

2. Materials and experimental procedure

2.1. Materials and surface preparation

In this study, materials including commercially pure Al and Cu strips with the specifications given in Table 1 were employed. The Cu and Al strips (200 mm long, 50 mm wide) were cut parallel to the original rolling direction from cold rolled initial strips. In order to achieve composites with different amounts of Cu and Al, different thicknesses of Al and Cu (150, 300, 500 and 1000 μm) were used. The Al and Cu strips were firstly annealed at 370 °C and 480 °C for 1 h, respectively, followed by air cooling to room temperature. Strips were then de-greased with acetone to remove the surface contaminations. Contaminated layers including oxides, adsorbed ions (ions of sulfur, phosphor and oxygen), greases, moisture and dust particles could impair the formation of a strong joint during cold rolling. Preparation process was followed by scratch brushing on the side of the surfaces at peripheral speed of 2000 rpm at least for 60 s. The brushing was performed parallel to rolling direction using a stainless steel circumferential brush made of wires 0.25 mm in diameter. Handling of Al and Cu strips after preparation and stacking was made carefully to avoid renewed contamination, followed by immediate cold roll bonding process. In the present investigation, the time between surface preparation and rolling was kept less than 120 s.

2.2. ARB process

This process is schematically drawn in Fig. 1 which consists of two steps. In the first step, the Al strip was laid between two Cu strips and fastened at both ends using steel wires. Accordingly, the above mentioned couple was roll-bonded to 50% reduction. In the second step, the roll-bonded strips were cut in half, then the two intimate Cu surfaces were scratch-brushed, stacked on each other and fastened at both ends to be roll-bonded at a given reduction value equal to 50%. The latter step was repeated up to 8 cycles. The alignment of the strip edges prior to rolling had to be strictly considered. The ARB process in this study was carried out with no lubrication, using a laboratory rolling mill with 125 mm of rollers diameters and a rolling speed of 2 m/min and a loading capacity of 20 t. To produce the composites with 23%, 37.5%, 50%, 62.5% and 77% amounts of Cu (the Cu percentages are in volume basis), Al strips with thicknesses of 1000, 1000, 1000, 600 and 300 μm were laid between two Cu strips with thicknesses of 150, 300, 500, 500 and 500 μm, respectively. In order to investigate the effect of annealing on mechanical properties of composites, selected composites were annealed in three different temperatures (300 °C, 400 °C and 500 °C) at four different periods (10, 30, 60 and 360 min).

2.3. Microstructure studies and mechanical properties

The microstructures of composite strips were investigated using optical microscopy (OM) parallel to rolling direction on RD–ND plane. Also, fractured surface of composites were studied by Scanning Electron Microscopy (SEM). The tensile test specimens were wire cut from the ARBed strips according to the ASTM E8M standard along the rolling direction. Tests were conducted at

Table 1
Specifications of initial Al and Cu strips.

Material	Chemical composition (wt%)	Condition	Tensile strength (MPa)	Elongation (%)	Hardness (HV)
Al	99.64Al, 0.24Fe, 0.04Si, 0.02Ti and 0.06 balance	Annealed	80.1	25.0	21.4
Cu	99.86Cu, 0.06Fe, 0.02Al, 0.01Sn and 0.05 balance	Annealed	189	40.4	53.2

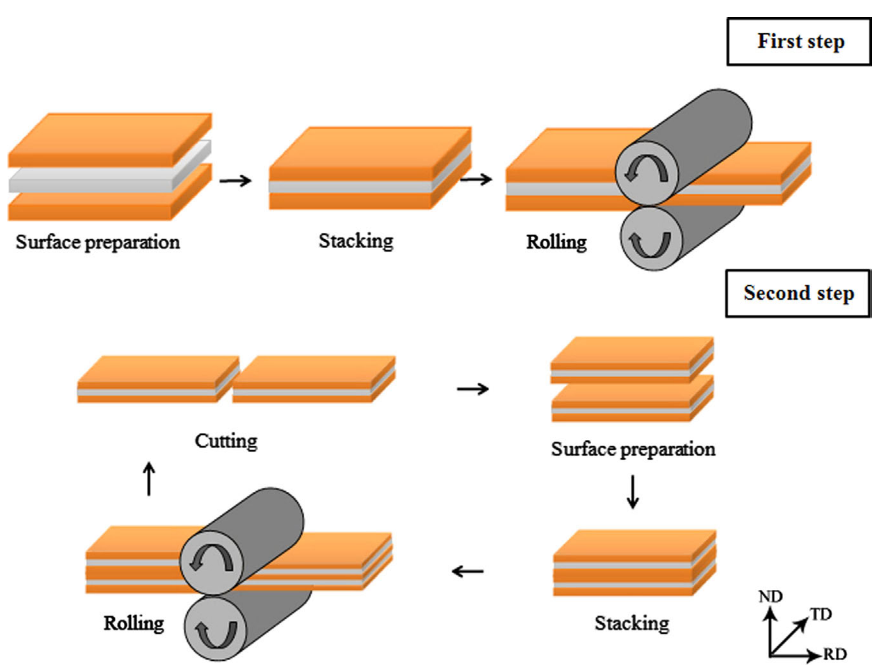

Fig. 1. Schematic illustration of the principle of the ARB process.