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The effects of oxide film and annealing treatment on the bond strength of Al–Cu strips in cold roll bonding process

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A B S T R A C T

In this study the influence of Al_2O_3 coating and post-rolling annealing on the bond strength of dissimilar Al–Cu strips was investigated. For this purpose different degrees of thickness of Al_2O_3 film on Al strips were coated using anodizing process. Anodized aluminum and copper strips were then cold-rolled at different reduction levels. To investigate the effect of annealing treatment on bond strength after cold rolling, selected strips were annealed. Peeling test was used to investigate the effect of ceramic-based oxide film on bonding strength of Al–Cu strips. It was found that bond strength was improved after applying higher reductions and was decreased dramatically by providing oxide film. However, by increasing the thickness of oxide film up to a certain value (20 μm), bond strength was increased after which it was decreased. A decrease in bond strength was observed by post-rolling annealing.

1. Introduction

Layered alloys and composites composed of similar and dissimilar layers have attracted significant interest in recent years. Metal matrix composites (MMCs) were developed due to their unique mechanical properties such as light weight and high elastic modulus. Although different methods are used to manufacture these composites, Cold Roll Bonding (CRB) has proved to be more efficient and economical in recent years, as compared to other processes.

CRB is a solid phase welding process in which bonding is created by joint plastic deformation of the metals to be bonded [1]. The metal must be deformed by rolling pressure to establish bonding. The deformation breaks the hard surface layers on the metal. By applying rollers pressure, material is extruded through the cracks present in the fractured films causing bonding the surfaces together. The solid state joining technique in the CRB can be applied to a large number of materials with identical attributes and widely varying mechanical and metallurgical properties. To date, this method has been widely used for producing similar and dissimilar layered composites including Al [2,3], steel [4], Cu [5], Al–Ti [6], Al–Mg [7], Al–Zn [8], Al–steel [9,10], Ag–Cu [11], Cu–Nb [12], and Ti–Ni [13]. In the case of Al–Cu dissimilar strips, it was found that the formation of intermetallic compounds between layers had an important effect on bond strength [14–18]. In recent study, the effects of different degrees of thickness of nickel (provided by electroplating on Cu strips) and also post-rolling annealing on the bond strength of Al–Cu strips were investigated [19]. It was reported that the nickel coating could cause a significant decrease in the bond strength of Al–Cu layered strips. However, increasing the thickness of coating could enhance the bond strength of the strips.

The bond strength of strips is affected by various factors such as the reduction in thickness during rolling, rolling temperature, annealing treatment before and after CRB, initial thickness, rolling direction, rolling speed, and particles including reinforced particles from micrometer to nanometer scales [1]. This research aims to produce Al–Cu–Al_2O_3 composite using anodizing process and accumulative roll bonding. Therefore, for the first step, it focuses on optimizing different parameters affecting on the bond quality of Al–Cu strips in the presence of Al_2O_3 film. For this purpose, the effect of different Al_2O_3 coating thicknesses, reduction and also the effect of post-rolling annealing on bond quality of Al–Cu strips in CRB process was evaluated.

2. Materials and experimental procedure

2.1. Material and surface preparation

In this study, materials included commercially pure Al and Cu strips with the specifications given in Table 1 were used. Strips of dimensions 100 (L) × 25 (W) × 0.5 (T) mm were cut parallel to the original rolling direction from cold rolled Al and Cu sheets. Al and Cu sheets were annealed at 643 K and 753 K for 2 h, respectively followed by air cooling to room temperature. Cu strips were

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Table 1
Chemical composition of used Al and Cu strips (wt%).

Al	Si	Fe	Mn	Ni (ppm)	Zn	Sn (ppm)	Cu	Ti	Sb	V
99.65	0.043	0.245	0.150	64	0.000	4.7	0.000	0.019	0.012	0.010
Cu	Si (ppm)	Fe	Mn (ppm)	Ni (ppm)	Zn (ppm)	Sn	Cr (ppm)	Al	Pb (ppm)	S (ppm)
99.86	30	0.060	34	84	20	0.017	20	0.021	73	34

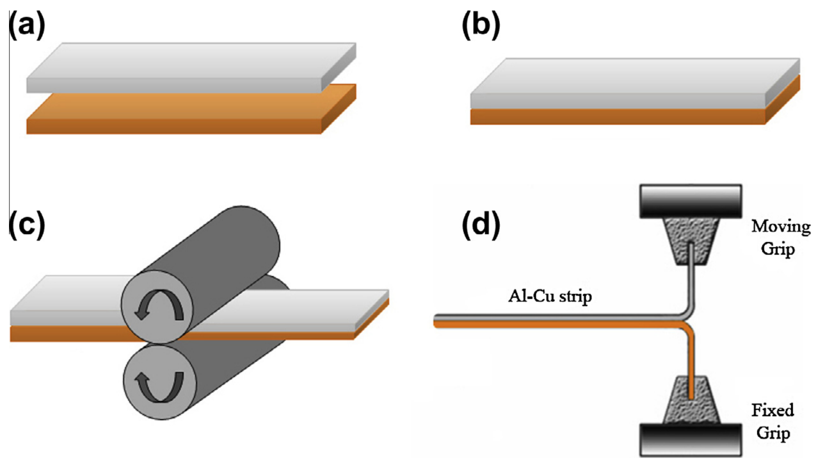

Fig. 1. Schematic illustration of cold roll bonding process for Al–Cu dissimilar and peeling test, (a) surface preparation, (b) stacking of two strips, (c) cold roll bonding and (d) peeling test.

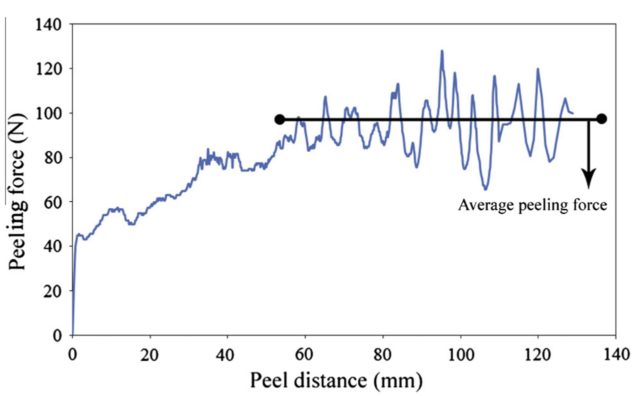

Fig. 2. Typical plot of peeling force versus peel distance.

de-greased with acetone to remove the surface contamination. Contamination layers composing oxides, adsorbed ions (ions of sulphur, phosphor and oxygen), greases, moisture and dust

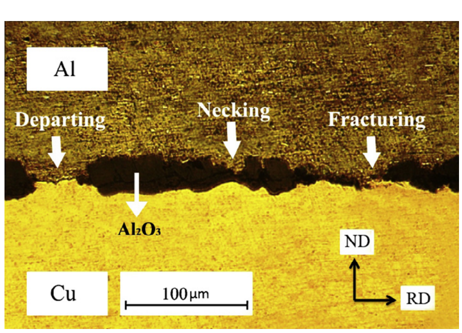

Fig. 3. Optical micrograph in longitudinal section (RD-ND) of Al–Cu with 32 μm oxide film coating after cold roll bonding subjected to 60% total reduction.

particles can impair the formation of a strong joint during cold rolling. Preparation process was followed by scratch brushing on one side of the Cu strip surfaces parallel to rolling direction using a stainless steel circumferential brush made of wires 0.25 mm in diameter. Handling of anodized Al and also scratch-brushed Cu strips after preparation and stacking was performed carefully to avoid renewed contaminations. In the present investigation, the time between surface preparation and rolling was kept less than 120 s.

2.2. Anodizing

In order to investigate the effect of oxide film on bond quality, Al_2O_3 was coated on the Al strips by anodizing process. Al strips after annealing were cleaned in NaOH. Strips were anodized in 15 wt.% sulfuric acid under an applied voltage of 15 V. In order to obtain 4 different oxide thickness, strips were held in electrolyte for different soaking times (5, 15, 30 and 60 min). To ensure a constant and homogeneous temperature (i.e. 283 K) throughout the solution, forced convection was provided by electrolyte stirring. The thickness of the alumina layers was determined using standard metallographic procedures with 20 measurements for each sample. This measurement was carried out for 5, 15, 30 and 60 min anodizing times, being 4 ± 0.5, 10 ± 0.3, 20 ± 0.2 and 32 ± 0.3 μm, respectively.

2.3. Cold roll bonding and peeling test

After surface preparation the two layers i.e. one anodized Al and one scratched brushed Cu layer were fixed by steel wire at both ends and then cold roll bonded. Cold roll bonding experiments were carried out with no lubricant using a laboratory rolling mill with a loading capacity of 20 tons. The roll diameter was 125 mm and the rolling speed was 2 m/min. The schematic illustration of this dissimilar CRB is illustrated in Fig. 1a–c. In order to study the effect of reduction on bond strength, anodized Al–Cu strips were cold-rolled for different reductions. Also, to investigate