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Investigation of the parameters of the cold roll bonding (CRB) process

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ABSTRACT

In this study, commercial purity aluminum (AA1100) strips were cold roll bonded at ambient temperature. As the main factors, the effects of different amounts of reduction in thickness, initial thickness, rolling speed, and rolling direction on bond strength were evaluated by the peeling test. Also, the effects of pre- and post-rolling annealing treatments were investigated. It was found that higher reductions, lower initial thickness, and rolling speed were the important factors involved in improving bond strength. Also, annealing treatment before and/or after the CRB process increased bond strength, while the effect of pre-rolling annealing was more pronounced. Furthermore, bond strength decreased by increasing the angle of CRB process with respect to the rolling direction of as-received strips. Finally, optical and scanning electron microscopes were used to evaluate the surface conditions of the peeled surfaces.

1. Introduction

Aluminum alloys are commonly used in heat exchangers in the automotive industry for their interesting combination of such properties as low density, satisfactory mechanical properties, good thermal conductivity, and relatively good corrosion resistance [1]. It is well known that 46% of aluminum alloys used for various applications comes in sheets and plates [2]. Among the alloy technologies, the cold roll bonding (CRB) process for producing sheets has witnessed rapid growth and development in recent years due to its unique service performance features [3–7]. In comparison with other methods, CRB is simple and can be easily automated.

CRB is a solid phase welding process, in which bonding is established by joint plastic deformation of the metals to be bonded. Bonding is obtained when surface expansion causes the surfaces of virgin metal to be exposed and when pressure reaches a value large enough to extrude the virgin material through the cracks of the fractured layer, resulting in the establishment of contact and bonding between opposing virgin surfaces [7–9].

Many studies have been carried out on the parameters governing the bonding mechanism in order to understand its complex nature so that the conditions of the process have nowadays been well defined. It has been reported that the roll bonding of metals is affected by various factors such as reduction in thickness during rolling [10–12], bonding temperature [7], and annealing treatment [13].

Recent applications of CRB to a range of materials prompted the present study to investigate the effects of process parameters on bonding quality. This paper will, therefore, report our findings concerning the effects of process parameters on bonding, including reduction in thickness during rolling, annealing treatment before (pre-rolling annealing) or after (post-rolling annealing) bonding, initial thickness of strips, rolling direction, and rolling speed. Efforts will also be made to provide a brief description of bonding mechanisms.

2. Experimental procedure

2.1. Materials

Commercial purity aluminum strips (AA1100) with the specifications given in Table 1 were used in this study. Strips 150 mm long, 30 mm wide, and of varying thicknesses (0.5, 1, and 1.5 mm) were cut from a cold rolled sheet, parallel to the original rolling direction, in order to investigate the effect of initial thickness on bond strength. Additionally, some strips were cut parallel to the transverse rolling direction to determine the effect of rolling direction on bond strength.

2.2. Surface preparation

To produce a satisfactory metallurgical bond by roll bonding, it is essential to remove contamination layers on the surfaces of the metals to be joined. These layers are composed of oxides, adsorbed ions, greases, moisture, and dust particles. A number of authors have stated that the best method of surface preparation is degreasing followed by scratch brushing with a rotating steel brush [3]. The

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Table 1
Specifications of the commercial purity aluminum.

Material	Chemical composition (wt.%)	Temperature	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Hardness (HV)
Al 1100	99.11Al, 0.17Si, 0.49Fe, 0.12Cu, 0.02Mn, 0.09 others	As-received	186.4	169.1	6.02	57
		Annealed	92.5	47.3	29.2	22

preparation processes used here included degreasing in an acetone bath followed by scratch brushing of the surfaces with a stainless steel circumferential brush made of wires 0.26 mm in diameter. To maintain consistency among samples, scratch brushing was carried out to generate evenly distributed scratches. It is important to avoid touching the clean surface because grease or oil by hand contamination on the faying surfaces may impair the formation of a strong joint. Welding should take place as soon as practical after degreasing and scratch brushing to avoid interference with bonding from oxidation.

2.3. Cold roll bonding (CRB) process

After surface preparation, the handling of strips was performed carefully to avoid renewed contamination. Less than 120 s was allowed as the interval between surface preparation and rolling in an attempt to avoid the formation of a thick and continuous oxide layer on the bond surfaces of the strips. Then, the two metal strips to be joined were positioned with the two prepared intimate surfaces against each other. CRB 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 (speeds of 6 and 10 m/min were also used for investigation of the effect of rolling speed on bond strength). The schematic illustration of CRB is presented in Fig. 1. The high reduction generates a great amount of heat and creates virgin surfaces on the materials being bonded. For these samples, a series of rolling experiments were carried out using the rolling reductions between 20 and 90%. Also, in order to investigate the influence of annealing treatment on the bond strength, some of the samples were annealed at 643 K for 2 h before or after the CRB process.

2.4. Peeling test

The bond strengths of the strips were evaluated using the peeling test procedure according to ASTM-D1876-01 as shown schematically in Fig. 2. The peel tests were performed using a Houndsfield H50KS tensile testing machine with a 50 kg load cell and a crosshead speed of 20 mm/min. In these tests, the breakings off forces were measured as shown in Fig. 3 and the average peel strength was determined using the following equation [14]:

$$\text{Average peel strength} = \frac{\text{Average load (N)}}{\text{Bond width (mm)}} \tag{1}$$

After peeling, the fracture surfaces of the samples were examined by PHILIPS XL30 scanning electron microscopy (SEM) and optical microscopy (OM).

3. Results

3.1. Effect of reduction

The results of the peeling tests for the samples were obtained for different reductions after one pass rolling had been accomplished. Fig. 4 presents the effect of reduction on the peeling force of Al strips at ambient temperature. It is obvious that the peeling force is enhanced with increasing reduction. The results also indicate that, for low thickness reductions, the performed bonding was not strong but for high reductions, the bonds created were so strong that the specimens broke in the base metal. Also, the threshold deformation (R_t) for producing the bond between Al/Al strips was about

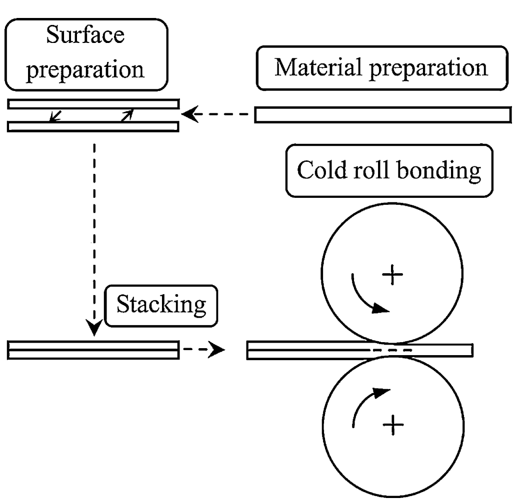

Fig. 1. Schematic illustration of the principle of cold roll bonding (CRB).

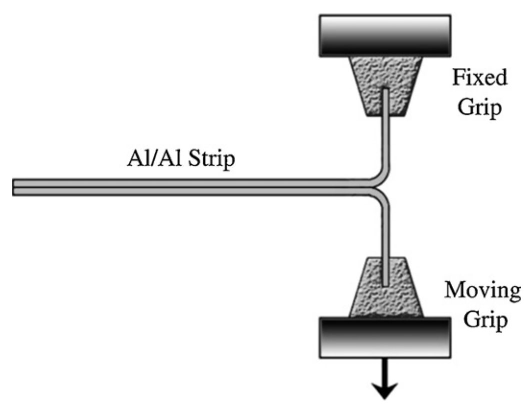

Fig. 2. Schematic illustration of peeling test.

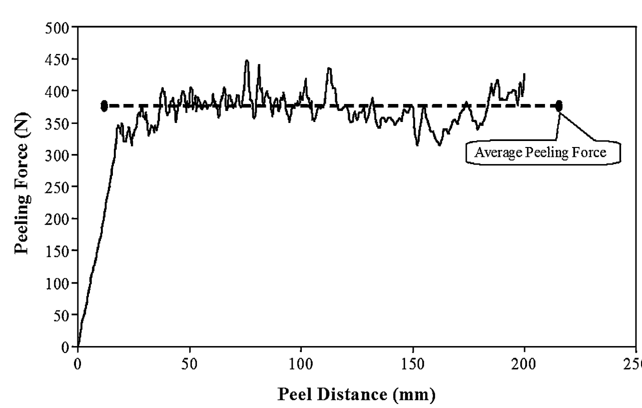

Fig. 3. Typical plot of peeling force versus peel distance.