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A direct adhesion of metal-polymer-metal sandwich composites by warm roll bonding

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ABSTRACT

Metal-polymer sandwich composites have been rapidly replacing metallic materials in aerospace and automobile industries. Their desirable mechanical properties including excellent fatigue and impact strength, as well as damage tolerance, are accomplished without sacrificing the benefit of lightweight. In this study, a three-layer metal-polymer-metal sandwich composite was fabricated using a direct adhesion warm roll bonding (WRB) technique without the use of an adhesive agent. Samples were made at various thickness reductions (40%, 50%, 60%, and 75%), and their mechanical properties were compared with the monolithic metallic sheet by performing a small punch test. The results showed significant improvements in the specific strengths of the sandwich composites compared with the monolithic material by 26%, 20%, and 39% at the thickness reductions of 50%, 60%, and 75%, respectively. The specific fracture energy of the sandwich composites at thickness reductions of 60% and 75% was higher than the monolithic material by 7% and 20%, respectively. The results showed that the direct adhesion WRB is a promising technique to fabricate a lightweight, metal-polymer sandwich composite panel.

1. Introduction

Structural weight reduction is one of the main design objectives in automotive engineering. Various concepts have been proposed to reduce the weight of modern passenger cars. Among them, application of sandwich composites, which consists of two metal skin sheets and a low density core material, offers advantages for weight reduction (Harris, 1991). Compared with monolithic metallic sheets, metal-polymer-metal sandwich sheets offer a significantly lower density, and better sound vibration and damping characteristics (Huang and Leu, 1995). Furthermore, these composites have the advantage of good surface finish and bending rigidity properties (Chao et al., 1994). Due to their favorable properties, laminated metal-polymer-metal sheets have been considered as a potential candidate for replacing monolithic sheet structures used in vehicle body panels, and indeed have been implemented by several automotive manufacturers to reduce cabin noise (Ruokolainen and Sigler, 2008).

Various manufacturing techniques have been used to produce metal-polymer-metal sandwich composites such as heat pressing (Kim et al., 2003), direct injection molding (Ramani and Moriarty, 1998), overmolding (Joachim Gähde et al., 1992), and roll bonding (Carrado. et al., 2010). Among these processes, roll bonding offers advantages of continuous production and cost reduction when compared with other techniques. Several studies were carried out to investigate the use of roll bonding to manufacture metal-polymer-metal sandwich composites (Palkowski and Lange, 2005). In roll bonding, metal-polymer-metal sandwich composites can be fabricated either by using a glue agent (indirect adhesion) or without using a glue agent (direct adhesion) to bond the laminates (Grujicic, 2014). Carrado et al. (2010) produced steel-polypropylene-steel sandwich composites using the roll bonding technique and employed a glue agent between the composite layers. Harhash et al. (2014) investigated the formability of steel-polymer sandwich composites and found them to be very comparable to mono-materials in terms of the savings realized by the lightweight of the composite. In contrast to the indirect adhesion, Mousa and Kim (2015a) introduced a direct adhesion technique by using a warm roll bonding (WRB) process to produce aluminum-polyurethane-aluminum sandwich composites. They investigated the adhesion strength of the layers and found that the dominant bonding mechanism was mechanical interlocking (Mousa and Kim, 2015b).

In this study, aluminum (AL1100)-polyurethane (PU)-aluminum (AL1100) sandwich composites were fabricated

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Table 1
Specification of AL1100 strip and PU sheet.

Material	Chemical composition (wt.%)	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (%)	Density (g/cm^3)
AL1100	99.61 Al, 0.11 Si, 0.55 Fe, 0.11 Cu, and 0.07 others	85	33	30	2.7
Material	Shore durometer (ASTM, 2000)	Compression set (ASTM, 2000)	Ultimate tensile strength (ASTM, 2006)		Density (g/cm^3)
PU	60 A (medium hard)	30% Max	21 MPa		0.85

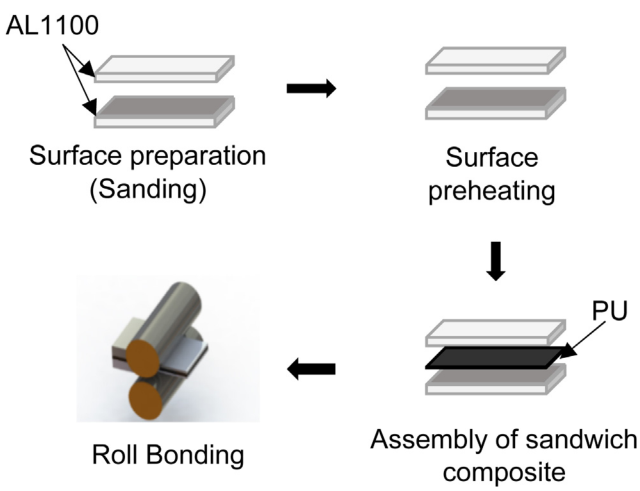

Fig. 1. A schematic illustration of warm roll bonding.

using the direct adhesion WRB technique to investigate the specific strength. A prior study by Mousa and Kim (2015b) showed reasonable bonding strengths for the metal-polymer composites fabricated by the direct adhesion WRB. The small punch test (SPT) was employed to characterize the mechanical properties of the sandwich composites, including ultimate load, specific load, average stiffness, and specific fracture energy, at various thickness reductions. Fracture analysis was conducted to evaluate the fracture behavior of the composite panels.

2. Experimental procedure

2.1. Material preparation

The sandwich composites consist of two strips of commercially pure aluminum (AL1100) for the skin with initial dimensions of 70 mm × 20 mm × 0.5 mm, and a polyurethane (PU) sheet at the core with initial dimensions of 60 mm × 20 mm × 0.8 mm. The specifications of AL1100 strips and PU sheets are summarized in Table 1. The procedure for specimen preparation is illustrated Fig. 1. It is critical to clean the surfaces and remove any contamination before rolling to produce a satisfactory bond. The procedure used for all sample preparation was first to degrease the surface in ethanol, followed by sanding the surface with 50 grit sandpaper to generate a fresh surface with a surface roughness value of 5.6 μm to facilitate the bonding (Mousa and Kim, 2015b). It is important that bonding takes place as soon as possible after degreasing, sanding, and heating to avoid excessive oxidation, which will increase over time. The preheating of the AL1100 strips was accomplished by placing the panels in a furnace for 15 min at 200 °C. Then each sample was assembled by inserting a PU sheet between the two AL1100 strips. The samples were joined using a rolling mill with a roll diameter of 65 mm, at a rolling speed of 30 rpm, which was the optimum rolling speed needed to produce a robust bond for the given materials and conditions according to our previous study (Mousa and Kim, 2015a). Experiments were analyzed at various thickness reductions of 40%, 50%, 66%, and 75%.

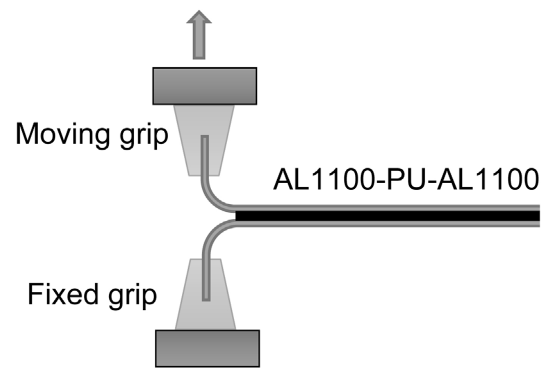

Fig. 2. Schematic illustration of the peel test.

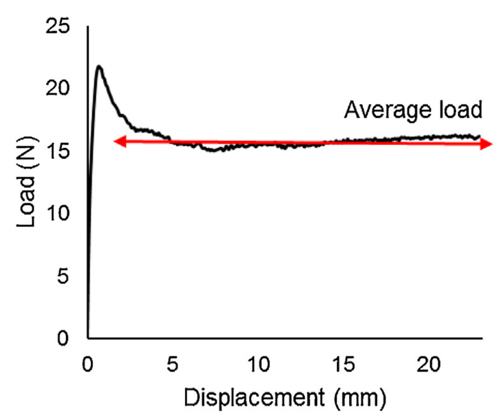

Fig. 3. The load versus displacement curve of a peel test.

2.2. Peel test

The adhesion between the core and the metal sheets was investigated by a T (180°) peel testing according to DIN53282 using the setup shown in Fig. 2. The peel test was performed using a universal testing machine (TestResources Inc.) with a crosshead speed of 20 mm/min. A typical force response from the peel test is shown in Fig. 3 where the average load is noted. The average peel strength can be calculated by:

$$Average\ peel\,strength = \frac{average\,load\,(N)}{bond\,width\,(mm)} \tag{1}$$

2.3. Small punch test (SPT)

The SPT was used to analyze the mechanical performance of the sandwich composites since the samples were not large enough for a full size bulge test. A number of mechanical properties can be measured from the SPT including ultimate load, average stiffness