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Joining Al 5052 alloy to aluminized steel sheet using cold metal transfer process

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ABSTRACT

The arc braze welding process for Al/Fe dissimilar metal joints was investigated to meet the needs for multi-material mixed structures in the automotive industry. In this study, the Al 5052 alloy was joined to hot-dip aluminized steel sheets using low-heat-input cold metal transfer (CMT) arc welding. Four kinds of filler wires (Al 4043, 4047, 5356, 5183) were examined in the dissimilar metal joint. Using aluminized steel sheets, although the wettability was relatively poor compared with galvanized steel, a lower intermetallic compound (IMC) layer thickness was observed between the dissimilar metals, which resulted in a higher joint strength. The Si content in the filler metal restricted the growth of IMC layer, namely, the growth of the trapezoidal Fe_2Al_5 IMC layer into the steel base metal. When AlMg filler wires were used, a thinner IMC layer was observed, but a relatively low tensile shear strength was measured due to micro cracks and porosities formed along the interface between braze welds and steel sheet. The joint strength of the combination of Al 5052/aluminized steel/AlMg filler wire was equal or higher than that of the heat-affected zone in the Al 5052 alloy. The integrity of the Al 5052/aluminized steel/AlMg filler dissimilar metal joint was guaranteed using both a high-speed tensile test and salt spray corrosion test.

1. Introduction

The use of ultra-high strength steel and non-ferrous alloys has remarkably increased in the automotive industry to meet global regulations for crashworthiness and CO_2 emissions. Among ultra-high strength steels, boron-alloyed steel, which is known as hot-press-forming steel, has recently received attention due to its fully martensitic microstructure with a tensile strength over 1.5 GPa after hot-press forming. Moreover, nonferrous light metal alloys including Al alloys have been increasingly applied in automotive industry due to their excellent specific strength. With increased use of ultra-high strength steel and Al alloys, multi-material mixed structures are inevitable for car body structures; however, joining dissimilar materials is a serious concern in welding research.

Steel and Al alloys have poor mutual weldability because of their differing melting points, electrical resistivity, thermal conductivity, and thermal expansion coefficients. Moreover, a brittle Al–Fe intermetallic compound (IMC) layer is formed at the interface, lowering the joining strength. Galvanic corrosion caused by the differing electrode potentials of the materials is also an unresolved problem.

As summarized by Imayaki [1], solid-state welding such as friction welding, explosive welding, and hot press welding have been applied in Al/Fe dissimilar metal joining since the 1960s rather than fusion welding. However, during the last two decades, fusion welding has been extensively investigated, and resistance spot welding, mechanical joining, adhesive bonding, friction stir welding, and laser brazing processes have been proposed for dissimilar metal joining in automotive industry [2].

Among fusion welding processes, laser welding was investigated in early fusion welding studies because formation of Al–Fe IMC is accelerated by heat exposure and time [3]. Autogenous "braze welding" [4,5], laser pressure welding [6–9] in which pressure was simultaneously applied with laser irradiation, and filler-metal-added braze welding [10–16] have been considered. In these studies, only the Al alloy was melted, while the steel remained unmelted. Note that the term "braze welding" has not been standardized, and this process is commonly referred to as "brazing." In this study, this process will be called braze welding because the authors believe it more properly describes this process than brazing [1,13,17].

Compared with laser welding, arc welding has an economic advantage, but arc welding requires more heat input to the weld

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joint. Recently, with the rapid progress in the low-heat-input arc welding process, cold metal transfer (CMT), waveform controlled cold arc, AC pulse arc, and pulsed double electrode arc welding processes have been developed for thin sheet welding, and their application to Al/Fe dissimilar metal joining has been studied. In most cases, galvanized steel was considered as the steel base material [18–25,26] because the Zn-coating layer prevents oxidation of the steel plate before welding. Otherwise, the oxide layer disturbs the wetting of the filler metal on the steel sheet. The Zn-coating layer can be spontaneously pushed out of the braze weld joint during the braze welding process because of the low melting point of Zn and arc pressure [4].

More recently, non-coated steel [27] and aluminized steel [17,28,29] were adopted for dissimilar metal joining rather than galvanized steel. The fluxless joining process is almost impossible for non-coated steel due to insufficient wetting, as explained above. However, aluminized steel can be a good alternative for galvanized steel in dissimilar metal joining. Although a thicker IMC layer was observed for joined Al/aluminized steel compared with that of joined Al/galvanized steel, higher joint strength has been reported in the previous studies [28,29]. Nevertheless, aluminized steel has received less attention than galvanized steel in the automotive industry, and the arc welding processes for Al/aluminized steel have not been sufficiently investigated. In this study, the CMT arc joining of Al 5052/aluminized steel was investigated using various filler metals, and the joining characteristics were compared with that for Al 5052/galvanized steel. The metallurgical and mechanical characteristics of the dissimilar metal joint were examined.

2. Preparation of braze welding specimen

In this study, the base materials were Al 5052 alloy with a thickness of 1.0 mm and a hot-dip aluminized (Al-coated) steel sheet with a thickness of 1.2 mm. For comparison, a hot-dip galvanized (GI) steel sheet with a thickness of 1.2 mm was also selected. Both AlSi alloy (Al 4043 and Al 4047) and AlMg alloy (Al 5356 and Al 5183) wires with a diameter of 1.2 mm were used as filler metals. The nominal chemical compositions for the base materials and filler wires are given in Tables 1–3, respectively.

The coating layer of the aluminized steel sheet is composed of an AlSi layer and an $Fe_x(AlSi)_y$ layer; the total thickness of the two layers averages about 30 μm, as shown in Fig. 1(a). The $Fe_x(AlSi)_y$ layer with an average thickness of 3 μm is an IMC layer formed during the hot-dip aluminizing process prior to arc braze welding, whereas the AlSi layer is a metallic layer. On the other hand, the coating layer of galvanized steel sheet is composed of almost pure Zn; the coating thickness was 10–15 μm, as shown in Fig. 1(b).

Table 1
Chemical compositions of the Al base materials (wt.%).

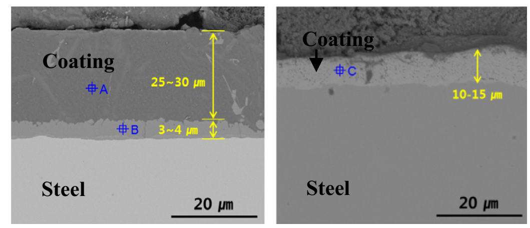
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Al5052	0.25	0.40	0.10	0.10	2.2–2.8	0.15–0.35	0.10	Bal.

Table 2
Chemical compositions of the steel base materials (wt.%, provided by the material supplier).

	C	P	S	Mn	Ti	Si	Al	Fe
Aluminized steel	0.002	0.008	0.005	0.08	0.003	–	0.005	Bal.
Galvanized steel	0.045	0.001	0.00	0.022	–	0.002	0.003	Bal.

Table 3
Chemical compositions of the filler materials (wt.%).

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Al4043	4.5–6.0	0.8	0.3	0.05	0.05	–	0.1	Bal.
Al4047	11.0–13.0	0.8	0.3	0.15	0.1	–	0.2	Bal.
Al5356	0.25	0.40	0.10	0.05–0.20	4.5–5.5	0.05–0.20	0.10	Bal.
Al5183	0.40	0.40	0.10	0.5–1.0	4.3–5.2	0.05–0.25	0.25	Bal.



(a) Aluminized steel (b) Galvanized steel

(at.%)	Al	Si	Zn	Fe
Point A	91.1-94.6	5.4-8.9		
Point B	66.9-67.9	12.1-12.6		20.0-20.9
Point C			94.3-97.8	2.2-5.7

Fig. 1. The chemical components and thickness of the coating layer by SEM-EDS for (a) aluminized steel and (b) galvanized steel.

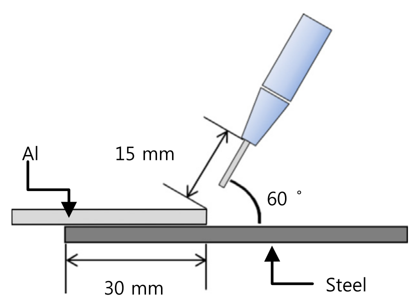


Fig. 2. Setup for braze welding.

Table 4
Arc braze welding parameters.

Steel	Filler wire	Current (A)	Voltage (V)	Welding speed (m/min)	Wire feeding speed (m/min)
Aluminized	Al4043	76	12.3	0.5	4.2
	Al4047	76	12.3	0.5	4.2
	Al5356	76	12.5	0.5	4.8
	Al5183	76	12.5	0.5	4.8
Galvanized	Al4047	76	12.3	0.5	4.2
	Al5183	76	12.5	0.5	4.8

Rectangular (150 × 120 mm) welding samples were lap-fillet welded with an overlapping length of 30 mm as shown in Fig. 2. The Al alloy sheet was placed on the steel sheet, and the filler wire was fed with an angle of 60° from the specimen. The Fronius CMT 3200 was used as the arc power source, operating in CMT mode. Similar arc process parameters (Table 4) were selected for each material combination to maintain the same heat exposure and time for each specimen. Argon shielding gas was supplied with a flow rate of 15 ℓ/min to prevent oxidation during the arc braze welding.