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Effect of Aluminum-Copper Foils Interlayer on Failure Modes and Mechanical Properties of Galvanize Steel Sheets Joints Using Resistance Spot Welding

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Abstract

The purpose of this article is to investigate the influence of commercial pure (0.04 mm thick) AL-foil and commercial pure (0.1 mm) Cu-foil at the interface of lap-joint on the characteristics of welds galvanized AISil 005 steel after welding through the tensile-shear testing. It was discovered that raising the welding current increases the size of the fusion zone. Due to the low current of spot-welding, the welds failed in an interfacial manner. Increasing the welding current results in adequate weld size and encourages the failure mechanism of double pullout with enhanced mechanical characteristics. Nonetheless, a further increase in welding current resulted in metal ejection and a modification of the failure mechanism with diminished mechanical qualities. The size of the fusion zone was determined to be the most influential factor in determining the mechanical characteristics of AISil 005 spot welds. The use of an AL interlayer boosts the galvanized AISI 1005 steel's mechanical characteristics and weldability. Cu interlayer addition diminishes the mechanical properties and weldability of galvanized AISI 1005 steel because it causes steel solidification cracking.

Keywords: Resistance spot welding; AISI 1005 steel, Failure mode, mechanical properties; Al , Cu ..

1. Introduction

Due to its tremendous efficiency in manufacturing relatively thin steel sheets, resistance spot welding (R.S.W) is the primary technique for assembling vehicle bodies. RS W is the simplest, quickest, and most manageable method for steels. Consequently, the automobile sector employs R.S.W at numerous welding spots, or (2000-5000 spot welds in each car-body structure) [1,2]. Due to their superior corrosion resistance, galvanized steel sheets have found widespread usage in industries such as the automotive and shipbuilding sectors. However, it is still quite difficult to weld steels in lap-joints arrangement. Due to the low boiling temperature of Zn (906°C) relative to the melting point of steels (about 1500°C), highly pressured zinc vapor is produced at the interface of the sheets to be jointed, presenting a difficulty for the weldability of galvanized steel sheets. The highly compressed Zn vapor ejects the molten metal from the molten pool and causes various flaws in the weld, including spatter and porosity[3,4 J. The addition of Fe oxides to the lapped-surface area[5], the addition of oxygen to the inert shielding gas atmosphere around the spot[6] have been studied as methods to lower the Zn vapor pressure.

This study seeks to determine the effect of commercially pure (0.04)111111 thick AL-foil and commercially pure (O. l)mm Cu-foil at the interface of lap-joint on the properties of galvanized AISil005 steel welds after welding, as illustrated in Figure 1.

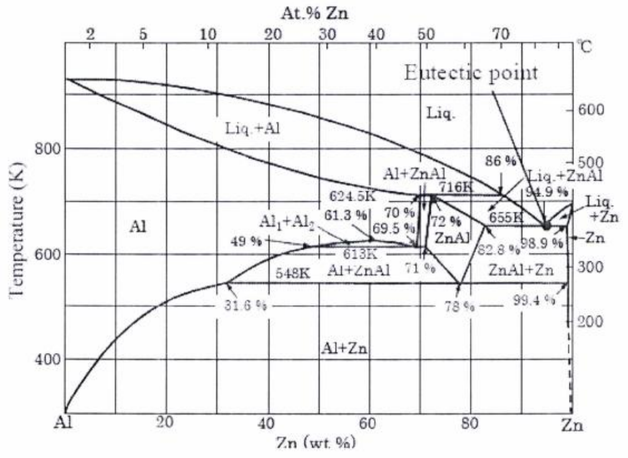


Fig.(1) Al-Zn binary phase diagram [7]

The aluminum-zinc phase diagram [7] (shown in Figure (1)). Whereas the melting temperature of Al and Zn are both 660°C, the aluminum-zinc combination experiences a low-temperature eutectic reaction at 382°C eutectic point. The findings demonstrated that the aluminum-zinc eutectic reaction is successful at reducing zinc vapor pressure. Alternatively, as illustrated in Figure (2), [7], the action and hence pressure of vapor of the zinc at the interface might be decreased by reacting the zinc with copper to generate brass alloys.

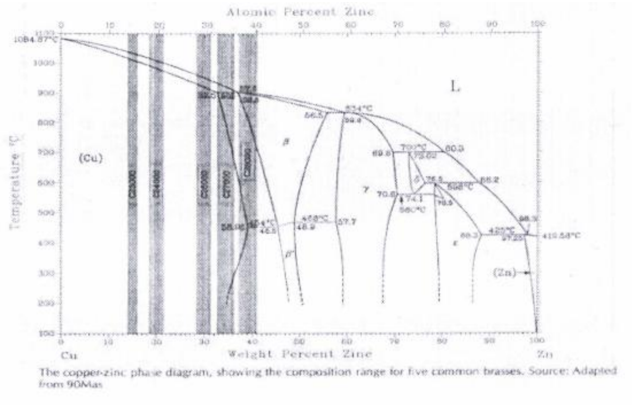


Fig. (2) Cu-Zn binary phase diagram [7]

In shear stress testing, two types of failure mechanisms are often observed: "interfacial fractures" and "complete button pullout." The weld miscarries in between the two plates in the interfacial fracture, leaving part of the weld nugget in one plate and another part in the other plate. Fracture then arises in the base metal or in the heat affected zone in the entire button withdrawal. As demonstrated in Figure (3), [8], the weld-nugget has totally drawn off one of the sheets in this failure scenario, but the weld remains intact.

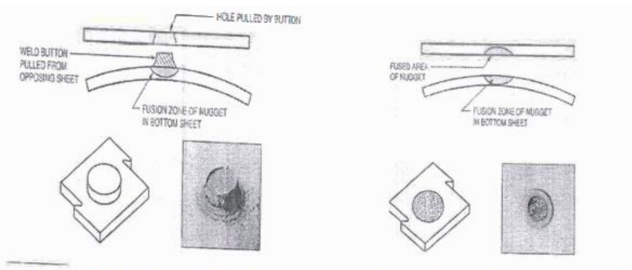


Fig (3): Button Pull Fracture and Interfacial Fracture [8]

2. Experimental procedure

The basic metals were galvanized steel sheets (AISI 1005). The sheet thickness of the base metals was 1mm, and the zinc content was 45 gm/ni 2 each side. The chemical compositions and tensile characteristics of AISI 1005 base metals are shown in Tables (1) and (2) [4]. Figure (4) shows a 120 K.V.A AC-pedestal resistance spotwelding equipment working at 50 Hz, it is computer-controlled via a programmable logic-controller (P.L.C). A 45-degree shortened cone resistance welding-manufecturing alliance (RWMA) electrode with an 8-mm face diameter was used for spot-welding processes. Welding current has been gradually raised from 6 to 12 kA in 1 KA steps. Squeeze, welding, electrode dwell time while current was turned off, and electrode force were held at 45, 15, 10, and 4.5 KN. The quasi-static tensile-shear test samples were manufactured in accordance with the American Welding Society (A.W.S) D8.1 M standard [8]. Tensile and shear tests were conducted out at a head speed of 2mm/min. Peak load was used to characterize the mechanical behavior of the welded samples (P max). Observing the weld fracture surfaces revealed the failure mechanisms.

Welded samples have been prepared for metallographic observation using standard metallography technique. The microstructures of the joints were examined using an optical microscopy. For steel microstructural metallography, Nital (100 ml C2H50H, 2 ml HN03) reagents were utilized. The spot welds' fusion zone size was measured using a digital caliper.

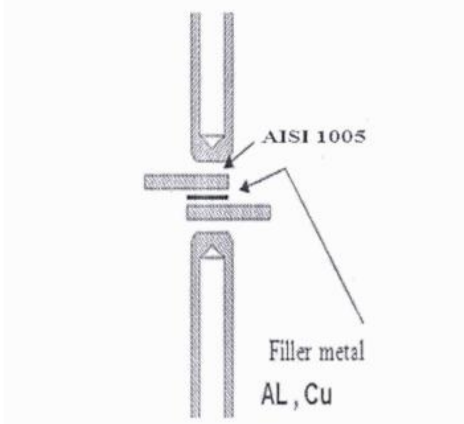


Fig (4): Typical setups for welding

Table (1) Tensile properties of AISI 1005

Properties of Low Carbon Steel	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation%
Practical	290	170	45
Nominal (Standard) AISI 1005	314 Max	165-200	43-55

Table(2) The chemical compositions of AISI 1005

Element Low carbon steel	C %	Mn %	Cr %	Ni %	Si %	Mo %	Fe %
Practical	0.055	0.22	0.015	-	0.01	-	Remain
Nominal (Standard) AISI 1005	0.06 Max.	0.3 Max.	0-02	-	0.05 Max.	-	Remain

3- Results and Discussions 3. 1. Effect of Al and Cu foil on mechanical properties

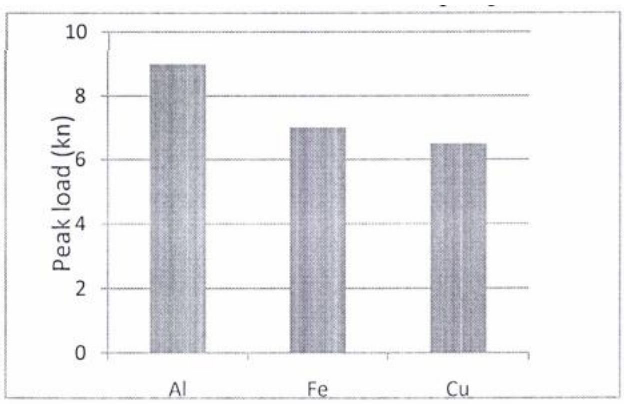


Fig. 5.Results of shear testing RSW lap welds 1-mm-thick AlSI1005 galvani zed steel sheets, with and without Al and Cu fo il inserted between sheets.

Following mechanical testing, sample investigation revealed that the strength enhancement was caused directly by Al foil, as shown in Figure (5). Because of the better thermal contact between lapped plates offered by the existence of the interfacial-aluminum layer, there is no substantial porosity at the fusion zone, a general improvement in weld diffusion, as illustrated in figure (6). Obviously, the presence of Al in the welding route can result in such disintegration into the molten steel and of the finished weld. As an alloying element in steel, aluminum has acknowledged metallurgical effects. Above and beyond the modest quantities utilized for de-oxidation, its most well-known routine was as a carbide deposition inhibitor to enhance the retained-austenitte in strong transformation induced-plasticity steels[9]. In this matter, it is also known that Al at or over 1.5% by weight may inhibit complete austenitization, resulting in delta ferrite retention[9]. Aluminum is thought to have no influence on transformation performance or resulting attributes below that level [10]. The minimal quantities of Al required to inhibit Zn vapor evolution, on the other hand, were thought improbable to be troublesome, and this hypothesis has been substantially validated in development investigations to far. Copper might diminish interfacial zinc activity by forming a molten brass alloy; nevertheless, its real efficacy should be minimal since its melting point of 1083 °C is elevated, exceeding the boiling degree of Zn. Copper is also a troublesome addition since it causes steel solidification cracking [11], as seen in figure (7).

Fig (6): Fusion zone microstructure of AISI1005 with Al foil .

Fig (7): Fusion zone microstructure of AISI1005 with Cu foil

3. 2. Effect of welding current

The most essential element in determining the mechanical properties of R.S.Ws is the fusion-zone size (FZ). The greater the size of FZ, the greater the strength. The size of the fusion zone is determined by the heat that produced during the process, which is regulated by the welding variables. In general, the larger the fusion-zone size, the greater the heat input to the welding zone (greater welding current, longer welding duration, lesser electrode force). Welding settings may have a significant impact on weld nugget growth and fusion-zone size microstructure. After testing, fusion-zone sizes were measured on the samples using a digital caliper. Figure 8 depicts the variance in FZ diameters as a function of welding-current. As noticed, the fusion-zone size rises relative to the welding-current, excepting of greater currents (greater than 8 KA), that exhibit a drop in fusion-zone owing to throwing out, as seen in figure (9).

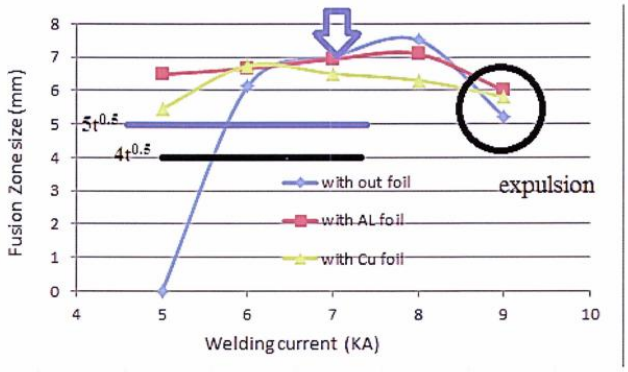


Fig. 8 Effect of welding current on the fusion zone size

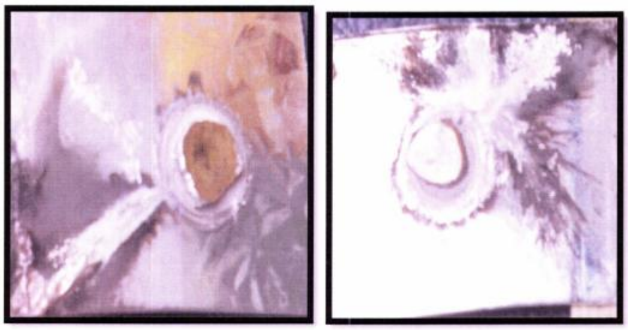


Fig. 9 Expulsion traces at the faying interface of a steel weld

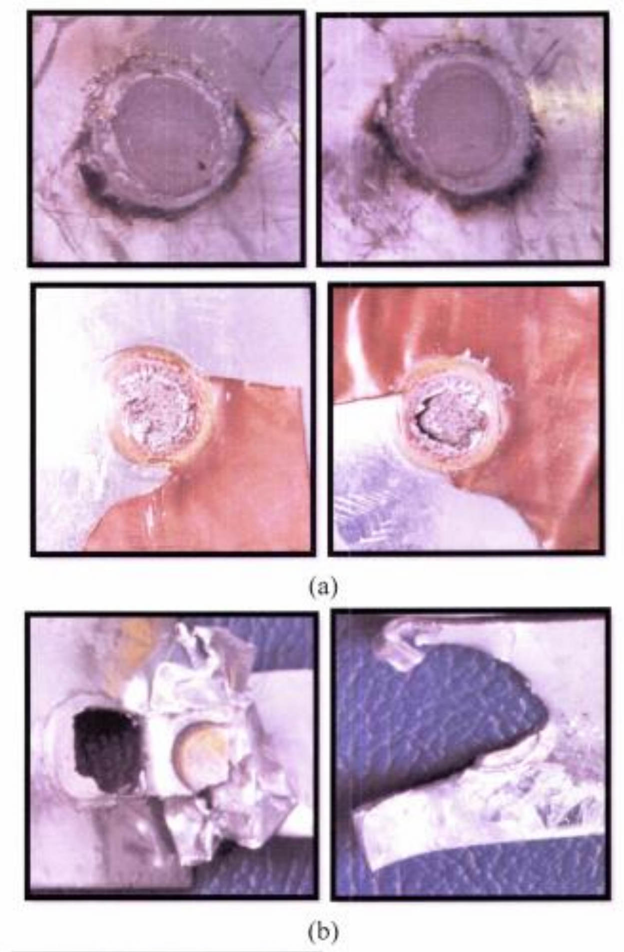
3. 3. Effect of welding-current on failure

Spot welded specimens are subjected to a variety of loading conditions over their service life like torsion and shear stresses, strength, compression, and bending. However, in this study, the tensile-shear test is regarded the reference line for the mode of failure since the R.S.W has a larger potential to be in interfacial mode at this loading circumstance than other tests such as peeling test and cross tension (12). As a result, the failure-mode during tensile/shear tests is a conventional method for spot weld quality monitoring. R.S.Ws that failed in the retreat mode when the tensile-shear testis in progress, should fail in addition mode throughout the cross section, and chisel tests. During tensile/shear testing of AISI 1005 spot welds, three distinct failure mechanisms were identified (Figure l0 (a-c)). (as shown in Figure l0a), when the applied current was between (5-7) KA, interfacial failure was the most common failure mechanism, with spot welds failing across the weld nugget centerline (Figure l0-a). Spot welds failed by a couple of failure mode (one in both sheets) when the welding current was in the 8 KA range, as illustrated in Figure (10) b. Spot weld with ejection failure mode, as illustrated in Figure (10) b, c, and d. The fusion zone size is widely proven to be the major element regulating the failure mode. Above a critical fusion zone, the failure mode is inevitable (13-14). Figure 10a shows the crucial fusion zone size. Figure 8 shows the minimum fusion zone size necessary to achieve pullout failure mode. It is useful to compare the practically obtained minimum fusion zone size necessary to achieve PF mode to current industry norms for weld pool sizes. A minimum pool size for a particular sheet thickness has been prescribed by several industry standards: The Equation is used in WS-

ANSI-AISI (8) weld button sizing to guarantee that the weld size is big enough to handle the necessary load (2)

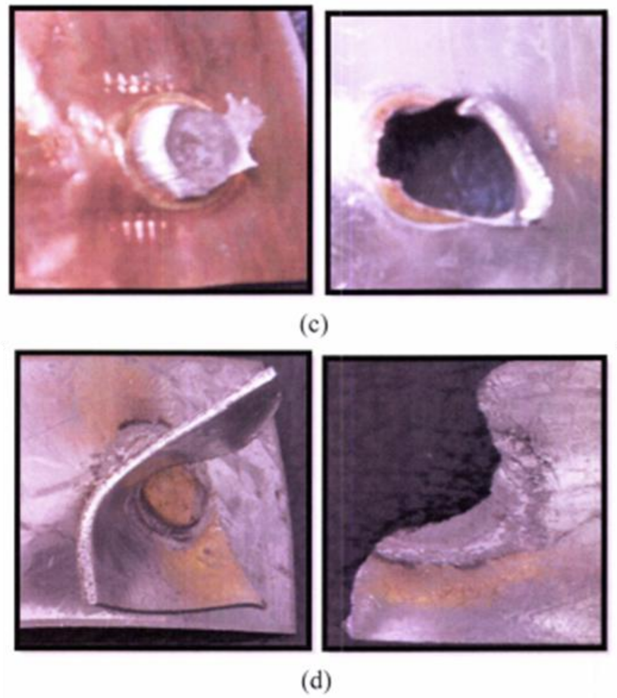
$$D=4t^{0.5} \quad (2)$$

Where D is the weld nugget size and t is the sheet thickness in millimeters. (ii) The required weld size is specified by the equation (3) $D=4t^{0.5}$ in Japanese-JIS Z3140 (15) and German DVS-2923 (16) standards. Figure 8 shows that weld sizing conditions of $4t^{0.5}$ and $5t^{0.5}$ are insufficient to produce PF mode welds under tensile-shear loading. Indeed, for the sake of simplicity, metallurgical factors are overlooked in this manufacturing criterion. As a result, new weld quality criteria for resistance-spot welded steels are required. To more accurately forecast and assess the spot weld failure mechanism, metallurgical features of welds should be examined..



(a)

(b)



(c)

(d)

Fig. 10 Failure modes observed during tensile/shear testing of spot-welded AISI 1005

4-Conclusions

1 - The AL interlayer improves the mechanical and weldability qualities of galvanized AISI 1005 steel.

2- Cu interlayer decreases the mechanical characteristics and weldability of galvanized AISI 1005 steel by promoting steel solidification cracking.

3- Weld nugget size standards of 4tand $5t^{0.5}$ are insufficient to achieve AISI 1005 resistance spot weld-pullout failure modes during tensile/shear testing. This necessitates the development of a new weld size criteria in AISI 1005 steel resistance spot welds.

4- The size of the fusion zone was shown to be an important factor in limiting the peak load of AISI 1005welds.

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