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Effects of zinc layer thickness on resistance spot welding of galvanized mild steel

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ABSTRACT

This study investigated the resistance spot welding (RSW) parameters for an uncoated mild steel sample and two hot-dip galvanized steel samples with different zinc layer thicknesses. Two RSW schemes were considered: a one-step scheme with no pre-heating stage and a two-step scheme comprising a pre-heating stage followed by a main welding stage. The strengths and weldabilities of the weldments were evaluated by peeling tests, cross-tension tests and weld lobe diagrams with welding currents ranging from 5 to 12 kA and welding times of 8–24 cycles. The optimal welding time was found to be 16 cycles. The weldability window shifted to a higher welding current region as the zinc layer thickness increased. Compared to the one-step RSW scheme, the two-step scheme suppressed interfacial failure and achieved a higher peeling load at a lower welding current. For a given welding current, the weldments produced using the two-step scheme had a larger nugget diameter and higher cross-tension load. Overall, the two-step RSW scheme achieved a better welding quality than the one-step scheme irrespective of the zinc layer thickness.

1. Introduction

In electrical resistance spot welding (RSW), an electric current flows through the workpiece to generate resistance heat and a force is simultaneously applied to squeeze the two components together to form a single connected part. The resistance heat depends on the applied electric current, the resistance of the workpiece materials, and the time for which the current is applied. Li et al. (2000) investigated the quality of RSW weldments using a two-stage, sliding-level experiment and found that axial misalignment, angular misalignment, poor fit up, edge welds, and electrode wear all have a significant effect on the weld size and hence the weld quality. Jou (2003) reported that the geometric and mechanical properties of the RSW welding nugget depend on the welding current, the welding time, the applied electrode force, the shape and material properties of the electrode, and the surface condition of the base metal. Tawade et al. (2004) reported that the use of an additional pre-heat current, post-heat current, or temper current improves the size and shape of the nugget in RSW galvanized steel. The weld lobe diagrams indicated that a double-pulse welding schedule enlarged the width of the welding current window and hence improved the weldability. Chan et al. (2006) showed that more extreme welding conditions may result in welding expulsion and a shorter tip life. Lin et al. (2007) reported that the three most important RSW parameters are the welding current, the welding time and the electrode force.

Galvanized steel consists of a thin sheet or strip of steel coated with a zinc layer to protect against rusting. Zinc has a low electrical resistance and a high thermal conductivity. Thus, in RSW processing, the resistance heat generation rate is low, while the heat transfer rate at the electrode-sheet and faying interfaces is high. To produce satisfactory weld nuggets, longer weld times (20–50%), higher electrode forces (10–25%) and higher welding currents (30–40%) are therefore required (Ruukki, 2009). Lubrication was another factor influencing the welding performance, Spitz et al. (2015), discovered that the surface lubrication would degrade the electrode life in RSW of hot dip galvanized steel.

The literature contains many investigations into the RSW processing parameters, e.g., the welding current and the welding time (Jou, 2003), or the welding setup (Li et al., 2000). The effects of the zinc layer thickness on the RSW parameter design are, however, still unclear. Thus, this study conducts an experimental investigation into the RSW processing conditions for an uncoated mild steel sample and two mild steel samples coated with zinc layers with different thicknesses. Two RSW schemes are investigated, namely a one-step process with no pre-

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heating stage and a two-step process consisting of a pre-heating stage followed by a main welding stage. The strengths and weldabilities of the various weldments are evaluated by peeling tests, cross-tension tests, and weld lobe diagrams. The results provide a useful insight into the RSW mechanism for galvanized steel and the welding scheme for galvanized steel components with different zinc layer thicknesses.

2. Experimental procedure

The experiments commenced by generating weld lobe diagrams with welding currents ranging from 5 to 12 kA and welding times of 8–24 cycles. Based on the weldability determined by weld lobe diagrams, one-step and two-step RSW schemes were designed for the three different specimens. Following the RSW trials, optical microscopy (OM) samples were prepared to examine the weld nugget diameter and nugget fracture features. Cross-tension tests were then performed to evaluate the weldment strength.

2.1. Preparation of welding specimens

The RSW trials were performed using mild steel as the base metal (JIS G3302, 1998). The chemical compositions of the uncoated sample and two hot-dip galvanized samples (denoted as Z-0, Z-10 and Z-20, respectively) are shown in Table 1. All three samples had a base metal thickness of 1.2 mm. The weight (per square meter) and zinc layer thickness of the three samples are shown in Table 2. The RSW welding tests were conducted using a commercial 200 kVA alternating current (AC) electrical resistance welder (NASTOA, AIT-844-3, Japan) with Cu-Cr-Zr alloy electrodes. The electrodes had dome-shaped tips with a 6-mm diameter and were cooled by a continuously circulating water flow.

2.2. Peeling tests and weld lobe diagrams

Peeling test samples were prepared with a length and width of 100 mm x 30 mm, respectively, and an overlap distance of 30 mm. The weldments were fabricated using welding currents of 5–12 kA and welding times of 8–24 cycles. The RSW spot was located in the center position of the overlapped area in every case. The peeling tests were performed using the setup shown in Fig. 1. The weldability of the samples was then evaluated by weld lobe diagrams.

A weld lobe diagram consists of two curves plotted within the space constructed by the welding current (X-axis) and the welding time (Y-axis) (Dickinson, 1981). The first curve represents the minimum acceptable nugget diameter, while the second curve depicts the onset of weld expulsion. According to the JIS Z3140 (B class) test standard for spot welds (JIS Z3140, 1987), the minimum acceptable diameter (D_{min}) of the weld nugget is equal to $4.5\sqrt{t}$, where t is the workpiece thickness. For a given sample, the weldability is specified by the zone bounded by the two curves since, in this region of the diagram, the welding current and welding time result in a weld with both a sufficient nugget diameter and a sufficient nugget penetration (Liang, 2000). The strength of spot welds varies in direct proportion to the nugget diameter. An acceptable nugget size thus represents an acceptable nugget strength (Tawade, 2004).

Table 1
Chemical composition of mild steel sheets used in welding trials (wt.%).

Sample Code	C	Si	Mn	P	S	Fe
Z-0	0.05	0.014	0.014	0.011	0.009	Bal.
Z-10	0.04	0.017	0.016	0.013	0.005	Bal.
Z-20	0.05	0.015	0.013	0.013	0.005	Bal.

Table 2
Weight (per square meter) and zinc layer thickness of three specimens.

Standard values of zinc coating weight and thickness (JIS G3302)					
Sample Code	Average		Minimum		Actual Zinc layer thickness (Single side) (μm)
	Weight (g/m^2)	Layer thickness (Double sides) (μm)	Weight (g/m^2)	Layer thickness (Double sides) (μm)	
Z-0	0	0	0	0	0
Z-10	100	14.0	85	11.9	6.9 ± 0.5
Z-20	200	28.0	170	23.8	14.1 ± 0.5

* Thickness = weight per square meter/density, Zinc density = 7.14 g/cm^3.

Fig. 1. Peeling test setup.

2.3. RSW processing parameter design

Welding trials were performed using a one-step scheme and a two-step scheme. The former scheme consisted of a single welding step (Fig. 2(a)), while the latter scheme comprised a short pre-heating stage followed by a main welding stage (Fig. 2(b)).

In accordance with the weld lobe diagram results (see Section 3.1), the welding time was set as 16 cycles in both schemes. The welding current was varied in the range of 5–12 kA in increments of 1 kA. The holding time, cooling time, electrode force and electrode contact diameter were set in accordance with (Lin, 2013). The detailed parameter settings for the three samples in the one-step and two-step RSW schemes are shown in Tables 3 and 4 respectively.

2.4. Cross-tension tests

The nugget strengths of the various RSW samples were evaluated by cross-tension tests. In accordance with the JIS Z3137 standard (JIS Z3137, 1999), test specimens were prepared with dimensions of 150 mm by 50 mm (Fig. 3). For each sample, the RSW spot was located in the center of the overlapped area. The tests were performed using a 100-kN capacity MTS 810 material testing system with a crosshead speed of 10 mm/min.