

Effect of Coating Thickness on Electrode Life in the Spot Welding of Galvanized Steels

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Abstract

This study examined the effect of coating thickness on electrode life and nugget strength. Uncoated and galvanized steel sheets supplied from Ereğli Iron and Steel Factories Co. (Erdemir) with similar chemical compositions having different coating weights (100, 180, and 275 g/m²) were welded using resistance spot welding under constant welding parameters. Electrode force used during spot welding operation was 7.3 kN under 6.5 kA of constant welding current and 2 s welding time. After welding operations, shearing tests were applied to selected specimens and the nugget diameters were measured. Experimental results showed that as the coating thickness increased the electrode life and the strength of the weld nugget decreased.

Key words: Galvanized steel, Spot welding, Coating thickness, Nugget, Electrode life.

Introduction

In recent years, automotive manufacturers have been using increasing amounts of galvanized steels in the automotive bodies, aiming to increase corrosion protection. Generally, for joining steel sheets that are up to 5 mm in thickness, resistance spot welding has been successfully applied (Kearns, 1982). There are approximately 3000 to 4000 spot welds in every passenger vehicle. Therefore, the cost and quality of spot welds in the manufacturing of automotive bodies is an important issue. For example, Kaminsky (1995) and Kimchi (1997) studied electrode life in spot welding of galvanized steels. Waschkies (1997) introduced a parameter on the basis of welding time, temperature, and weld diameter. Holliday et al. (1995) investigated spot welding electrode life with various electrode compositions. They continued their work on tip growth mechanism in electrodes (Holliday et al., 1996). A relationship between electrode life and content of aluminum in zinc was re-

ported by Gugel et al. (1994). Their further investigation was on the differences in welding currents and time between galvanized and uncoated steels (Gugel et al., 1995). Geometry of the electrode tip in spot welding performance was also studied (Gedeon and Eagar, 1986a, 1986b). Lane et al. (1987) reported the effect of preheating and variable current on the strength of spot welding. Harlin et al. (2003) studied the effect of applied pressure on the strength of the weld nugget and the optimum current necessary for spot welding for galvanized and uncoated steels.

The above-mentioned researchers are in agreement that galvanized steels are, in general, more difficult to weld than uncoated steels. The underlying mechanisms are not well understood. The zinc coating and changes in thickness or composition are thought to play a role. Therefore, it is important to understand the relationship between weldability and coating thickness (i.e. coating weight). However, reports on the effect of coating weight on spot weld are scarce (Howe and Kelley, 1988); in particular, coat-

ing weights above 100 g/m^2 are not examined in the literature. Thus the aim of this work was to study the relationship between electrode life and coating thickness, weld nugget diameter and its strength.

Experimental Procedure

Resistance spot welds were produced in both uncoated and hot dip Zn coated low carbon steel sheets having 1.5 mm thickness. The properties of the uncoated and hot dip Zn coated steels are listed in Table 1. Hot dip galvanized steels, supplied from Ereğli Iron and Steel Factories Co. (Erdemir), having coating weights of 100, 180, and 275 g/m^2 , were used. These are coded as UC, C100, C180, and C275 for uncoated steel, and 100, 180, and 275 g/m^2 for coated steels, respectively, unless otherwise stated. Cu-Zr electrodes having cone-shaped tips with 6 mm diameters were used in the experiments. A Digit 6500 single phase resistant spot welding machine was used. Before the tests, all sets of electrodes were aligned and dressed to ensure their parallelism. Two pieces of the steel being tested were sandwiched between the welding electrodes. The electrode force used during spot welding operations was 7.3 kN under 6.5 kA of constant welding current and 2 s welding time. Welding continued until the electrode diameter reached a minimum acceptable value of $3.5.t^{1/2}$, where t is the thickness of the steel sheet (Kearns, 1982). For the evaluation of nugget and electrode face diameters and shear strength 3 specimens were selected at every 50 weld intervals. After welding operations, shearing tests were applied to selected specimens and the nugget diameters were measured.

Shearing tests were carried out in accordance with BS 1140 using Zwick/Roel Z 100 equipment. The surfaces of both electrodes and the selected welds were studied by both scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS).

Results and Discussion

The electrode lives were evaluated as the nugget diameter versus the number of welds applied until the nugget diameter reached a minimum acceptable value of $3.5.t^{1/2}$ ($\sim 4.3 \text{ mm}$ for the present work). Electrode life was reduced proportionally with increasing number of welds for all steels used as shown in Figure 1. In general, electrodes tested on galvanized steels exhibited shorter electrode lives than those tested on uncoated steel. The diameter of the electrode increases as the electrode wears. Due to increasing electrode diameter the current density decreases. Consequently, smaller nugget diameters occur. Experimental results also showed that nugget diameter decreased as the coating thickness increased. This was attributed to wear of the electrodes due to formation of a brass layer at the tips of the electrodes since the Cu-Zr electrode alloy will tend to react with the Zn-rich coating on the steel sheet forming the Cu-Zn alloy (brass). As a result of this reaction, changes in the electrical characteristics and the hardness of the electrodes would be indispensable (Kaminski, 1995; Kimchi, 1997). For example, it was reported that current necessary for welding was higher due to the presence of Zn at the surface; thus temperature increases on the tips of the electrodes (Kaminski, 1995).

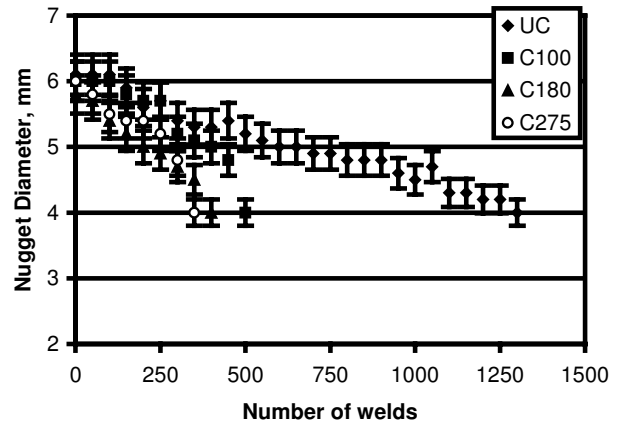


Figure 1. Nugget diameter as a function of number of welds for the steels used.

Table 1. Properties and chemical composition of the steels used.

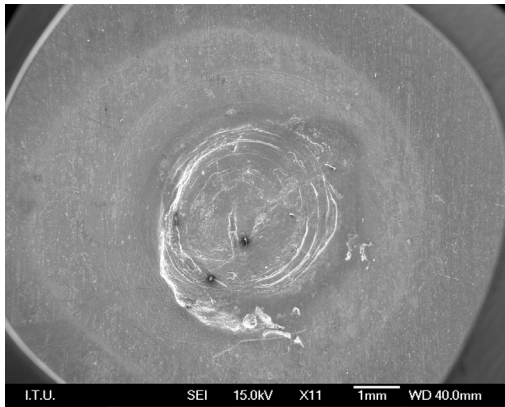
Tensile Strength (N/mm^2)	Elongation (%)	C (%)	Mn (%)	P (%, max)	S (%, max)	Si (%, max)	Al (%)
270-510	22	0.02-0.06	0.15-0.30	0.020	0.020	0.030	0.02-0.08

EDS analysis revealed the presence of copper on the weld nugget and it decreased as the number of welds increased (Table 2). This could be explained by the enrichment of the brass layer on the tip of the electrode after each successive weld. Thus reduced Cu content (i.e. increased brass layer) on the tip of the electrode would leave a reduced amount of Cu on the nugget. Cu content on the nugget surface for coated steels is similar for the first weld (see Table 2); then it is reduced as the coating thickness increased with increasing number of welds attributable to increased brass layer thickness due to Zn diffusion to the inner part of the tip of the electrodes. It is worth noting that the presence of Cu on the weld nugget was also reduced as the number of welds increased for the uncoated steels. Probably, oxidation of the electrode face takes place due to higher temperatures as the number of weld increases, leading to restricted Cu diffusion on the weld nugget surface.

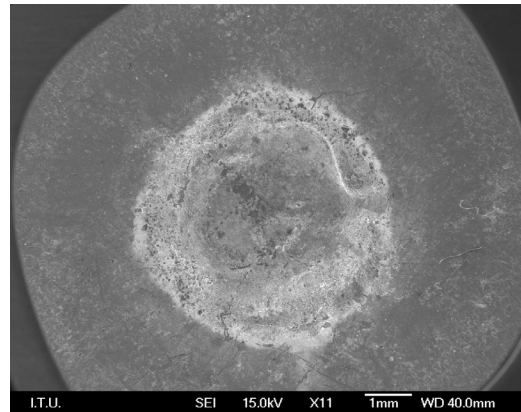
Table 2. Amount of Cu (wt.%) on the weld nugget as a function of number of weld obtained by EDS analysis.

Number of weld	UC	C100	C180	C275
1st weld	7.0	10.5	10.0	10.5
200th weld	3.0	9.0	7.0	6.5

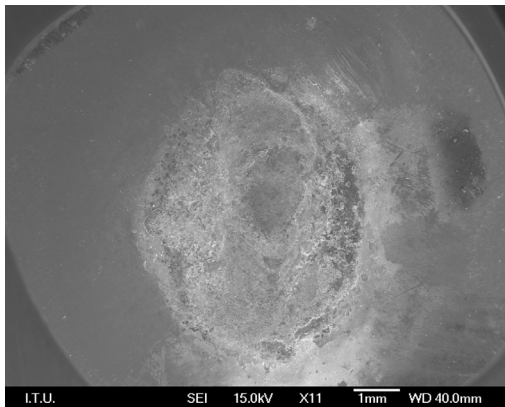
Figure 2a-d depicts surface morphology of the resulting weld on the steel surfaces after 200 welds. It is evident from Figure 2b-d that, during the formation of a resistance spot weld between 2 zinc-coated sheets, zinc at the interface between the electrode and the sheet had been molten and displaced from the weld zone, forming a zinc annulus, which had encircled the weld. This could be explained by the electrode face temperature melting the Zn coating



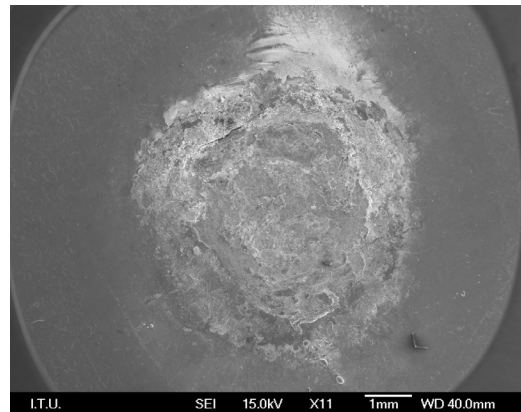
(a)



(b)



(c)



(d)

Figure 2. SEM micrograph of uncoated (a), C100 (b), C180 (c), and C275 (d) steel surfaces after 200 welds.

material and expelling the molten zone to the outer band of the electrode (Kaminski, 1995). As mentioned earlier, both brass alloying and alteration in the hardness will accelerate deformation of the electrode face, and thereby acceleration of electrode wear. Hardness measurements were carried out for the determination of electrode deformation. It was shown that the hardness of the electrode tip increased as the coating thickness increased. Obtained hardness values from UC, C100, C180, and C275 were 149, 175, 208, and 235 HV, respectively. This could be explained by the increase in the brass ratio. Evidently, the weld nugget had lost its symmetric form (Figure 2b-d), probably due to the deformed surface of the electrode tip as a result of a loss in hardness and the thermal conductivity of the contaminated electrode during welding. However, these results are not in agreement with those published by Howe and Kelley (1988), who reported that the relationship between coating thickness and electrode life was not clear. As successive welds are made, the electrode faces become pitted and slowly erode, increasing the face diameter, which ultimately reduces the current density to the point where an insufficient nugget is formed. Electrode life testing seems to indicate that the formation of brass and coating material pick-up mechanism are responsible for variations in nugget diameter and therefore electrode wear.

Figure 3 illustrates the shearing strength of the weld nugget versus number of welds. The shearing strength is reduced with an increasing number of welds applied for all steels used. This was thought to be due to the reduction in weld nugget diameter as discussed earlier. However, nugget diameter itself does not seem to be a factor in shearing strength. Taking into account C180 and C275 steels, the nugget diameters are 4.9 and 5.4 mm, respectively (see Figure 1); however, the shearing strength of C180 is higher than that of C275. Physical properties of the nugget are much more influential on the shearing strength. The occurrence of hollows in the weld interfaces of the galvanized steels was observed. Thus the area under load decreased and this would result in lower shearing strength. Furthermore, the size of hollows increased as the coating thickness increased. Probably, molten coating material residuals were entrapped in the nugget during spot welding, deteriorating the strength of the nugget. The possibility of entrapment is higher as the coating thickness increased and this phenomenon is under investigation.

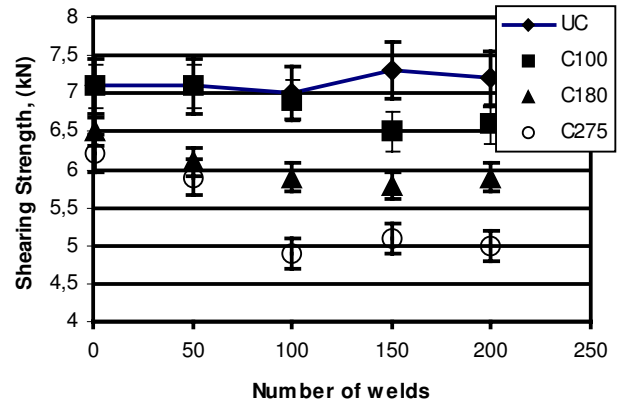


Figure 3. Shearing strength of weld nugget versus number of welds for the steels used.

Conclusions

In this study, the effect of coating thickness on the electrode life in the spot welding of galvanized steels was investigated. The results are summarized as follows:

1. Electrode life decreased with an increasing number of welds for all steels investigated. However, the electrode wear was more pronounced on galvanized steels than on uncoated steel.
2. Electrode wear increased as the coating thickness increased, which was attributed to the formation of a brass layer on the tip of the electrode.
3. Shearing strength decreased as the number of welds increased, due to the reduction in nugget diameter.

Nomenclature

UC	Uncoated
C100	Coating weight of 100 g/m ²
C180	Coating weight of 180 g/m ²
C275	Coating weight of 275 g/m ²

Acknowledgments

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