Journal of Materials Processing Technology 216 (2015) 339–347

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Surface lubrication influence on electrode degradation during resistance spot welding of hot dip galvanized steel sheets

M. Spitz[a,*], M. Fleischanderl[b], R. Sierlinger[b], M. Reischauer[b], F. Perndorfer[b], G. Fafilek[c]

[a] CEST Kompetenzzentrum fuer elektrochemische Oberflaechentechnologie GmbH, Viktor Kaplan Strasse 2, 2700 Wiener Neustadt, Austria
[b] voestalpine Stahl GmbH, TKE, Forschung und Entwicklung, voestalpine-Strasse 3, 4020 Linz, Austria
[c] Institute of Chemical Technologies and Analytics, University of Technology Vienna, Getreidemarkt 9, 1060 Wien, Austria

ARTICLE INFO

Article history:
Received 18 September 2013
Received in revised form 8 September 2014
Accepted 10 September 2014
Available online 21 September 2014

Keywords:
Resistance spot welding
Surface lubrication
Hot dip galvanized steel sheet
Electrode degradation
Welding electrode
Wear

ABSTRACT

The material uptake mechanism of a resistance spot welding electrode is presented for two selected surface conditions of hot-dip galvanized steel sheets, i.e., lubricated and non-lubricated. The evolution of material deposition varies according to the different surface states. Spot welding of lubricated sheet results in a more uniform and reduced alloyed material uptake that deposits on the welding electrode cap. Accordingly, the low deposition of material on the electrode surface enhances the weldability of hot-dip galvanized steel sheets. A reproducible current flow and a stable energy input is thus ensured along the electrode cap surface during resistance spot welding. Furthermore, lubrication leads to a considerably reduced sticking of welding electrodes.

1. Introduction

Joining hot-dip galvanized steel sheets by means of resistance spot welding is today's industrial standard. Especially when manufacturing automobile assemblies, resistance spot welding is still, aside from laser welding and adhesive bonding, the leading joining process. Surface lubrication is a common method to protect steel sheet from corrosion during transportation. With consideration to the increasing demand for metallically coated steel sheet surfaces, not only corrosion protection but also stability during further processing is highly important. Specific surface-lubrication systems support the forming processes prior to the joining of all components. Improved resistance spot welding process stability is noticed by most users in the case of lubricated hot-dip galvanized steel sheets as opposed to non-lubricated ones. Lubrication mainly improves welding electrode life but also reduces sticking of the electrode on the surface. However, differences can be observed among different lubricants. To our knowledge, there is no detailed information concerning the influence of lubrication on the resistance of spot welding of hot-dip galvanized steel sheets. A discussion on the influence of lubrication on resistance spot welding of aluminum alloys can be found in Han et al. (2010) for different wax systems, and in Rashid et al. (2007) for lubrication-induced oxidation minimization. Both works aim at determining electrode life and not on the determination of an electrode degradation mechanism explicitly. Distinct benefits of different specific surface lubrications were observed in both works.

Diffusion of elements from steel sheet surfaces changes the welding electrode cap surface with respect to electrical and mechanical properties. It is known that zinc substantially influences welding electrode performance. Parker et al. (1998) showed that zinc diffusion leads to a pronounced transformation of the electrode surface composition, i.e., to an evolution of different brass alloys of varying zinc concentrations. This change in material property of different zones of varying alloy composition with different zinc contents leads to a failure of the welding electrode due to the limited nugget size. This is mainly caused by a softening of the electrode cap material. Dupuy (1999) observed that the type of zinc coating on the steel (i.e., galvanized, galvannealed or electrogalvanized material) is of considerable importance. Zinc, which is in the coating of hot-dip galvanized steel sheets, only rarely reacts with the steel substrate. This leads to an increased amount of free zinc available during the welding process. On the other hand, galvannealed surfaces that consist of a zinc–iron alloy do not contain any free zinc. The welding electrode therefore reacts differently to

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* Corresponding author.
E-mail address: michael.spitz@voestalpine.com (M. Spitz).

http://dx.doi.org/10.1016/j.jmatprotec.2014.09.011
0924-0136/

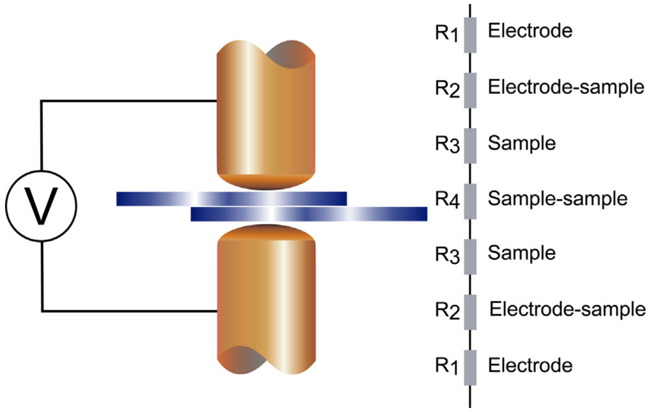

Fig. 1. Schematic illustration of resistances. Voltage drop is recorded from electrode to electrode.

these two types of chemical compositions (zinc or zinc–iron alloy) in the coating surface during resistance welding.

The objective of this work was a detailed characterization of the material-uptake phenomena exhibited by welding electrodes for two predefined surface states of hot-dip galvanized steel sheets: lubricated and non-lubricated. Previous electrode-life tests have shown that welding characteristics differ according to the type of lubricant used. Proper selection of the lubricant is of significant importance to optimized weldability, for example, with respect to the resistance spot welding of hot-dip galvanized steel sheet with a zinc or zinc–aluminum–magnesium coating. Detailed knowledge of the mechanisms of how lubrications affect the resistance spot welding of hot-dip galvanized steel sheets is fundamental to process optimization.

Analytical characterization of welding electrode imprints as well as welding electrode surface caps for an increasing energy input was done using, for example, energy dispersive X-ray spectroscopy element mapping. This procedure demonstrated the main differences that arose between lubricated and non-lubricated hot-dip galvanized steel sheet surfaces. Dynamic conduction resistance curves could be correlated to the electrode cap material uptake during the resistance spot welding process. Analysis of the evolving welding fume revealed the major difference between the two selected surface states during resistance spot welding. Lubrication permits material removal from the electrode-sample interface during the welding process. Fewer and differently distributed deposits remain on the electrode cap surface, in particular zinc. Furthermore, reduced sticking of welding electrodes could be attributed to the influence of lubrication.

A model for electrode material uptake is presented, which schematically illustrates the different deposition mechanisms of material from the welded surface onto the welding electrode for lubricated and non-lubricated hot-dip galvanized steel sheet surfaces.

2. Experimental

Resistance spot welding experiments were performed on a standard 50 Hz pedestal-type welding set-up. Dynamic conduction resistance and energy values were calculated from the recorded welding current and voltage. Voltage drop was determined across the total stack of resistances from electrode to electrode (Fig. 1), and the welding current was evaluated using a Rogowski coil.

Rogowski and Steinhaus (1912) first presented major current data recording results by means of the voltage that is induced in an electrical conductor perpendicularly oriented to the current path. This voltage is based on the magnetic field accompanying the welding current. A material-dependent welding force and the welding time were selected according to standard technical regulations. Welding electrodes (i.e., type D, d_1 = 16 mm, d_2 = 5.5 mm, $\alpha = 31^\circ$, domed) were dip-dressed prior to each experiment, which provided a defined reproducibility of starting conditions. The surface state of the welding electrode was checked electrically. This was done by recording the conduction resistance of bare welding electrodes without a steel sheet sample for a welding current of 3.0 kA. A change in the electrode cap surface by the penetrating current could be neglected according to the low current and low contact resistance of the electrode-electrode interface. With this approach, changes in the surface condition could be monitored prior to the experiment such as an oxidation of electrode caps or a change in dip-dressing procedure.

Experiments were performed on the same base material, i.e., hot-dip galvanized mild steel (voestalpine, DX54D, steel sheet thickness = 0.98 mm zinc layer thickness = Z100 corresponding to 7 μm on each coated face) to prevent an influence caused by the steel substrate. This influence is well known for resistance spot welding due to the strong dependence of welding parameters on steel grade and thickness. Additional cleaning of the sample surfaces ensured comparable starting conditions for each experiment. This comprised an alkaline rinsing bath and, if welded in the lubricated state, precisely defined re-lubrication conditions. Chemical cleaning was controlled by contact time and rinsing concentration to ensure an unchanged Al_2O_3 layer on top of the hot-dip galvanized coating. Maaß and Peißker (2008) directly correlated this native layer on hot-dip galvanized coatings to the aluminum content in the zinc bath, i.e., 0.2 wt% in this case. Surface lubrication was applied on the steel sheet surface by means of a laboratory coating, i.e., Multidraw® PL61 a deep-drawing lubricant. The thickness of this layer was defined at 1 g/m^2 although the amount of lubrication on the surface was not relevant for the final welding results. In order to limit surface oxidation, welding experiments were performed within 30 min after the cleaning process.

Conducted experiments were subdivided into energy-dependent, standard-welding and welding-fume experiments.

1 Energy dependent experiment:

The aim was the detailed determination of material uptake of the welding electrode from the sample surface during resistance spot welding. The time/energy-dependent evolution of the electrode-substrate interaction was analyzed in two ways: In one set of experiments, a series of spots was welded on a pair of galvanized steel sheets with a stepwise increase of the welding current (2.0 kA up to 8.9 kA) for a defined number of welding times (11 periods, until a predefined energy input for the last spot was reached as measured by the size of the welding nugget). In the other set of experiments, the welding current was fixed and the number of current periods was increased for each welded spot (from a single half wave to 11 periods) until the predefined energy input was reached as outlined above. For each series, one steel sheet sample was welded for each set of parameters (i.e., 40 mm × 60 mm). Naturally, each imprint on the sample surface could be analyzed for each energy input, whereas the electrode cap surfaces were analyzed after the last spot of a series.[1] The energy entry was calculated from Eq. (1).

$$\Delta Q = R \cdot I^2 \cdot \Delta t \tag{1}$$

R denotes the calculated dynamic conduction resistance; I the measured current; t the welding time; and Q the energy input, respectively. Current and voltage values were integrated from

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[1] No significant change in welding electrode cap material uptake during energy-entry increase could be observed from prior conducted experiments