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Influence of different zinc coatings on laser brazing of galvanized steel

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ABSTRACT

The use of hot-dip galvanized steel sheets as base material for laser brazing led to the formation of spatter and a wavy appearance of the seam. High-speed imaging revealed that spatter formation occurs mainly close to the seam edges. Thermography of the brazing process showed that the type of zinc coating affects the resulting temperature distribution and thereby changes the conditions for the zinc evaporation. Higher temperatures were observed at the seam edges on electro galvanized and phosphated substrates. The cross sections and the process analysis indicate that the zinc evaporation on electro galvanized substrates takes place prior to the wetting with the molten filler material. On the other hand a merely partial evaporation of the zinc coating and the accumulation of zinc at the seam edges takes place during the brazing of hot-dip galvanized substrates. The formation of spatter is caused by the zinc dissolution and the subsequent evaporation of the zinc rich alloy at the seam edges. The optical properties of the base material are considered to be a crucial factor for the temperature distribution and the resulting zinc evaporation. Brazing trials on hot-dip galvanized and phosphated substrates, which show a reflectance similar to electro galvanized and phosphated specimens, confirm this assumption, as no spatter formation at the seam edge was observed.

1. Introduction

Laser brazing of zinc-coated steel is an established application for joining exposed parts of the body in white. The seams are located in the visible area, requiring surface and seam characteristics of high quality. Imperfections such as spatter, blow holes or a wavy seam surface are not tolerated. In the automotive production, process velocities reach up to six meters per minute and the seams are not reworked before painting. It remains a challenge to achieve the required seam quality for steel sheets with various types of zinc coatings.

Gatzen et al. (2014a) stated that the influence of zinc coatings on the laser brazing process is known to be a crucial factor for the process dynamics and the wetting of the steel substrate with liquid filler metal. As regards the wetting of aluminum on galvanized steel, Gatzen et al. (2014b) observed that a zinc coating on the steel substrate is required to obtain wetting of an aluminum-silicon braze metal droplet. The wetting process is enhanced by the reactive propagation of the aluminum on the liquid zinc interface.

Koltsov et al. (2010) observed similar effects in wetting experiments with liquid CuSi3 braze droplets which were heated to a temperature of 1400 °C and dropped on zinc-coated steel substrates at room temperature. After the initial contact a short stage of non-reactive wetting, lasting about 10–30 ms, was observed. Thereafter the dissolution of the zinc coating led to an enhanced wetting process and thus to better wetting results on zinc-coated steel compared to bare steel. Higher spreading rates were measured on hot-dip galvanized substrates relative to electro galvanized substrates with the same coating thickness. Furthermore, the initial stage of non-reactive wetting was shorter on hot-dip galvanized substrates. On the basis of brazing and wetting experiments Bailly et al. (2009) concluded that hot-dip galvanized steel sheets offer the best conditions for laser brazing.

In contrast to these findings, first brazing experiments with parts made of hot-dip galvanized steel showed a severe limitation of the process window, due to different kinds of seam imper-

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Table 1
List of used zinc-coated substrates.

Substrate	Type of Coating	Phosphate [g/m^2]	Specimen thickness [mm]	Measured coating thickness [μm]	Average coating thickness [μm]
DC06 ZE75/75 BPO	Electro galvanized	0.4	0.78	5–11	7.5
DX57 Z100 MCO	Hot-dip galvanized	–	0.75	6–11	8.0
DX57 Z100 MCO +P	Hot-dip galvanized	0.4	0.75	6–11	8.0

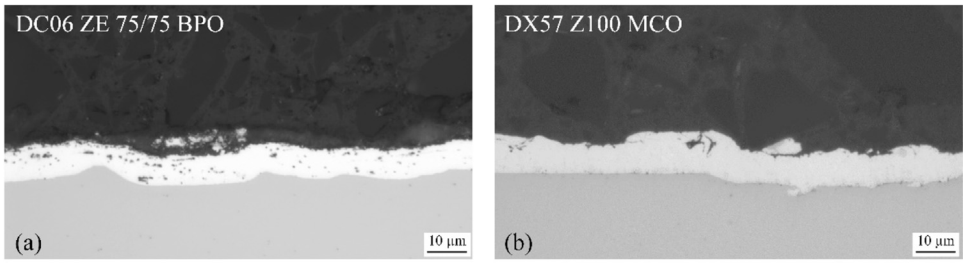

Fig. 1. Cross sections of zinc coatings (a) DC06 ZE75/75 BPO; (b) DX 57 Z100 MCO.

fections; spatter, melt expulsions and wavy seam surfaces were frequently observed.

Kimura et al. (2006) investigated the causes for seam imperfections and stated that spatter and blowholes originate as a result of zinc evaporation and the elusion of zinc vapor through the liquid filler metal. Schmidt et al. (2008) pointed out that this phenomenon is a well-known issue in welding zinc-coated steel. The set of a mechanical gap between the joined sheets enables the lateral degassing of the vapor and is an established method to reduce the spatter formation. Roos and Schmidt (2014) observed a distinct influence of the type of zinc coating on the spatter formation during laser welding. The different process characteristics of hot-dip galvanized zinc coatings compared to a foil of pure zinc were attributed to the physical properties of the zinc-iron-alloy, which is present on hot-dip galvanized substrates. Higher evaporation temperatures of the iron-zinc-alloy result from the higher iron content. This increases the spatter formation, as the temperature gap between zinc evaporation and the melting of the steel substrate is reduced.

Grimm (2012) reported that the formation of pores and blowholes during laser brazing is initially caused by a wetting instability, which leads to the formation of a one-sided indentation in the melt. This indentation drifts towards the center of the seam and remains as a pore after solidification. Such seam irregularities were largely caused by an asymmetric temperature profile in the process zone, resulting from a misalignment of the wire and the laser spot. Heitmanek et al. (2014) observed that the wetting of the zinc-coated steel takes place in an oscillating process. This wetting cycle was identified as an initial cause for wetting instabilities and pore formation. Ungers et al. (2010) identified pores, joint disruptions and surface irregularities as notable seam imperfections. It is stated that seam imperfections are caused by an external trigger event, which disturbs the melt pool dynamics, e.g. an unsteady rate of wire feed and brazing speed. In further studies Ungers et al. (2013) analyzed that potential trigger events can originate from all parts of the equipment in use. In order to stabilize the process a monitoring and control system was developed which measures the brazing velocity and controls the laser power and the wire feeding rate.

Research has shown that joint imperfections at laser-brazed joints result from process instabilities of different origins. The findings concerning the formation of pores and seam disruptions have been verified by various research groups. In contrast, a detailed description of the phenomena leading to the formation of spatter is not yet available. Different types of zinc coatings are thought to play a role in laser brazing, but have not yet been analyzed as an influencing variable for the formation of seam imperfections.

It is the aim of this study to characterize the effect of different types of zinc coatings on the laser brazing process and to describe the phenomena which lead to the formation of spatter. To gain a more detailed understanding of the process dynamics, a separate examination of the evaporation characteristics of different coating types was performed. To investigate the process stability and the attainable seam quality, laser brazing was applied on three different types of zinc-coated steel grades, two of them commonly used for the body in white. Particular attention is paid to the effect of the different types of zinc coatings on the process dynamics and the formation of spatter.

2. Experimental procedure

2.1. Materials

Specimens with three different zinc coatings were used. All coatings feature the best surface quality according to DIN EN 10346, which is a pre-condition to applying a uniform high-class paint finish. Nonetheless local variations of the zinc layer thickness were found. The average coating thickness is given in Table 1. Typical cross sections for the different coating types are given in Fig. 1.

Electro galvanized steel sheets are usually phosphated before forming and joining processes are executed. Accordingly, phosphated substrates were used for the brazing experiments. Contrary to this, hot-dip galvanized steel sheets are processed without a phosphate coating. To investigate the influence of the additional phosphate layer, plates of hot-dip galvanized steel were phosphatized. The additional phosphate layer changed the optical appearance of the hot-dip galvanized substrates from shiny metallic to a matte appearance, similar to the electro galvanized and phosphated substrates. The diffuse reflectance of the different substrates was measured with a PerkinElmer Lambda 900 spectrometer using an Ulbricht sphere. The reflectance of the different materials is given in Fig. 2.

For all experiments a massive CuSi3 wire according to DIN 1733 with a diameter of 1.6 mm was used. According to the manufacturer the melting interval of the filler metal is 965–1035 °C. Thus the processing temperature is distinctly higher than the boiling point of pure zinc, which is reached at 907 °C. The chemical composition of the wire was determined by optical emission spectroscopy and is given in Table 2.