Lasers in Manufacturing Conference 2019

Laser brazing of zinc-aluminum-magnesium coated steel – influence of the joint geometry

S. Wachsmuth[a*], S. Nothdurft[b], W. Reimann[a], B. Tigges[a], J. Hermsdorf[b], L. Overmeyer[b]

[a]*Volkswagen AG, Berliner Ring 2, 38440 Wolfsburg, Germany*
[b]*Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany*

Abstract

Laser brazing of zinc coated steel is a widely spread technique in car body manufacturing. For visible joints at the outer surface a double flanged joint geometry is common. However, the influence of the outer bending radius of the joint geometry is rarely discussed. Furthermore, the influence of zinc aluminum magnesium coatings (ZM) on the laser brazing process has not been reported so far. The properties of laser brazed joints on electrogalvanized (EG) and ZM coatings show deviant properties. In particular, the dimensions of the smallest wetted length, which is a widely used synonymously for the smallest seam thickness in micro-sections, are comparatively lower. Exemplary, the average smallest wetted lengths at a bending radius of 1.6 mm reach values of 0.64 mm on EG coated material and 0.49 mm on ZM coated steel respectively. Depending on the smallest wetted length the tensile strength is reduced as well. In the case described above, values of the tensile strength differ from 228 kN/mm on EG coatings to 187 kN/mm on ZM coatings. Hence, the brazed seam's thickness is identified as a crucial factor for the strength of a brazed joint. On ZM coatings, the properties of the joints improve to 0.57 mm smallest wetted lengths and 216 kN/mm tensile strength by increasing the outer bending radius. Thus, the connection between the outer bending radius, the smallest seam thickness and the mechanical properties are demonstrated. In general the brazeability of EG coated material is superior to ZM coated material. While increasing outer bending radii improve the properties of brazed joints on ZM material, properties of joints on EG coated material worsen.

Keywords: laser brazing; joining radius; electrogalvanized steel zinc-aluminum-magnesium coated steel

* Corresponding author. Tel.: +49-511-798-0.
E-mail address: steffen.wachsmuth@volkswagen.de

1. Introduction

Laser brazing with copper based filler wire is a standard application in the manufacturing process for visible parts of the body in white, such as roof to side panel joints or bifid hatchbacks, because of its superior surface quality. Since the exposed parts are in a customer's direct view and directly exposed to environmental conditions, corrosion resistance is an important property. One component of the corrosion protection concept in the automotive industry is the use of zinc coated steel. In the European market electrogalvanized (EG) and hot-dip-galvanized (GI) zinc coatings are common. Exemplary for a large number of studies Le Bozec et al., 2013, Diler et al., 2014 and Volovitch et al., 2011 reported the resistance against corrosion of comparatively newly developed ternary zinc-aluminum-magnesium (ZM) coatings is superior to EG and GI coatings. Thus, the use of ZM coated steels enables an advanced corrosion resistance.

The current design of bifid hatchbacks is characterized by double flanged joints with an offset in height between the joining partners. The outer bending radius of the lower joining partner is directly exposed to the laser brazing process. Hence, the variation of the bending radius is expected to affect the laser brazing process.

The influence of zinc coatings on the laser brazing process has been investigated by several authors. Heyn, 2003 compared the brazeability of both zinc coatings to uncoated steel. The results show the best surface quality for uncoated material followed by EG and GI coatings shifting from a smooth and even surface over a uniformly v-flaked surface to a non-uniform, wavy braze surface. Kimura et al. 2006, assumed zinc vapor of GI coatings as a source of pore formation inside of the brazed joint. Furthermore, Reimann et al., 2017 stated that the laser brazing process is closely connected to the absorption and reflectance behavior of the laser radiation depending on the type of zinc coating. In comparison to EG coatings, GI coatings show a higher reflectance of the laser radiation hindering the evaporation of the zinc coating prior to the wetting process. As a result, zinc evaporation takes place leading to spatter formation.

The minimum thickness of a brazed seam is considered to be a crucial factor for the strength of a laser brazed joint. A widely used synonym for the smallest seam thickness is the smallest wetted length as introduced by Kimura et al., 2006. The target failure mode for tensile strength tests is the occurrence of a base material rupture. Kimura et al., 2006 observed the first appearance of base metal rupture at minimum wetted lengths of approximately 0.8 mm for GI coated steel sheets with a thickness of 0.8 mm. Heitmanek, 2015 defines a smallest wetted length of 80 percent of the thinnest joint partner as sufficient.

So far the influence of ZM coatings on the laser brazing process has not yet been reported. In addition, the bending radius of the double flanged joint geometry is considered to be a further influencing factor for the laser brazing process. Accordingly, results and information on the brazed seam appearance, the smallest wetted lengths and the tensile strength for both factors are lacking.

2. Experimental

2.1. Materials

According to VDA 239-100 the utilized steels are specified as CR5-EG29/29-E-P and CR5-ZM40/40-E with a thickness of 0.75 mm respectively. Both materials offer the highest surface quality for exposed parts. The average coating thicknesses were measured to be 6.2 μm for EG coated material and 7.3 μm for ZM coated material. In addition the EG coated material is pre-phosphated. SEM images of micro-sections of the coatings are shown in figure 1. The chemical composition of the coatings is listed in Table 1.

Table 1. Chemical composition of the utilized zinc coatings

Material	Al [m%]	Mg [m%]	Zn [m%]
CR5-EG29/29-E-P	-	-	100
CR5-ZM40/40-E	1.6	1.6	96.8

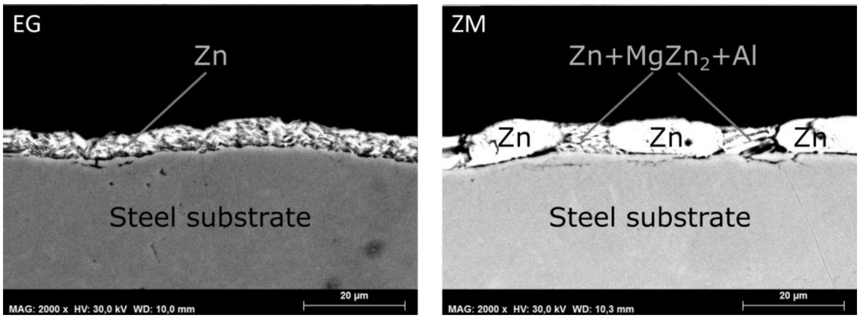

Fig. 1. Cross sections of EG and ZM coatings: a) CR5-EG29/29-E-P; b) CR5-ZM40/40-E

As common in automotive industry, a CuSi3Mn filler metal with a diameter of 1.2 mm was used for brazing experiments. According to the supplier's data sheet the wire consists of approximately 95.7 % copper, 2.9 % silicon, 0.9 % manganese and maximum 0.5 % further alloy elements. The melting interval of the filler wire ranges from 965 °C to 1035 °C.

2.2. Experimental setup

The laser brazing experiments were performed with an IPG YLS-5000-BR fiber laser at a wavelength of 1070 nm. The laser source was connected to Scansonic ALO3 brazing optics with a magnification ratio of 1:5.2 via a process fiber with a diameter of 400 µm. The approximate spot diameter was 2.4 mm, which correlates with twice the size of the filler wire. The laser beam power distribution was a top hat shaped profile at a power adjustment of 2.5 kW for EG coated and 2.75 kW for ZM coated steel. The laser power outputs for both coatings were optimized to achieve a high quality surface determined by pre-investigations. An Abicor Binzel Master Feeder-System MFS V2 fed the filler wire into the processing zone. The brazing optics and the filler wire feeding unit were manipulated by a Kuka KR210 R3100 ultra robot. The travel speed of the robot and the filler wire feeding unit were set to 55 mm/s respectively.

The sample material was cut into 190 mm x 95 mm pieces and edge bended to L-shaped specimens. The samples were positioned in a clamping device. An offset in height between both sample halves was chosen to 4.0 mm in order to obtain process conditions similar to those in the series production of bifid hatchbacks. The bending radius of the lower sample half varied from 1.6 mm to 2.6 mm in 0.2 mm increments. The outer radii of the upper halves were set to 2.5 mm. An overview of the experimental setup is shown in figure 2.

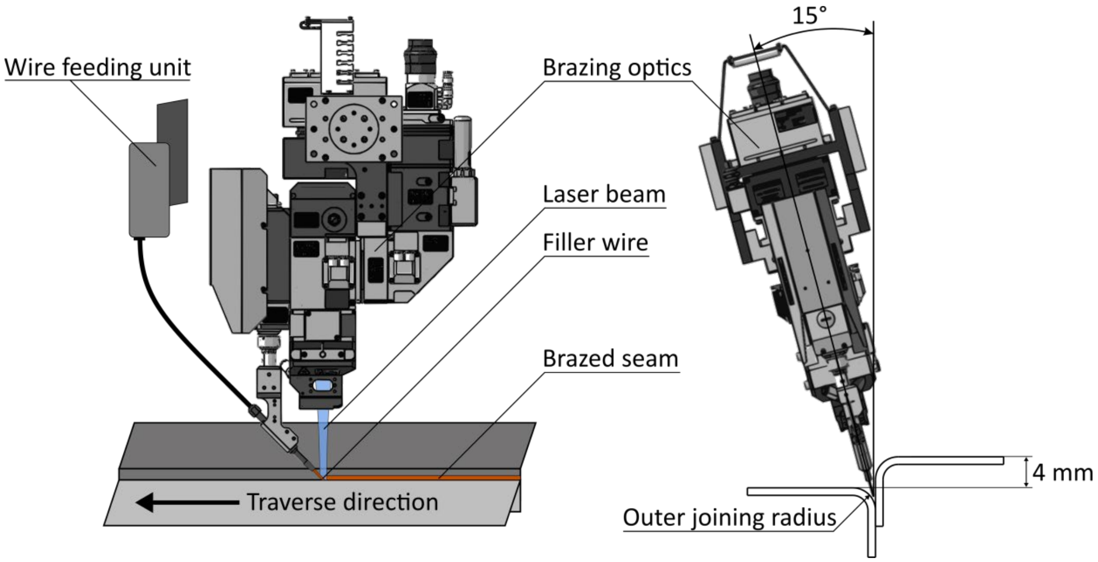

Fig. 2. Schematic experimental setup

In order to determine the properties of the joints, the brazed samples were evaluated on the basis of three main criteria. The first criterion is the appearance of the seams, which is evaluated by visual inspection. The focus of the visual inspection was set on the detection of superficial imperfections such as pores, cracks, spatters or a flaked brazed seam. Secondly, by assessing several micro-sections, the minimum wetted length was identified. Because of the different joint geometries, two distances were measured for joints with ZM coating and three distances were measured for EG coated material respectively, as illustrated in figure 3. The minimum distance of a, b and c was considered as the minimum wetted length. Thirdly, the mechanical properties were obtained by tensile tests performed with numerous samples. The traverse speed was chosen to be 10 mm/min. The free clamping length was set to 80 mm. At least five brazed samples were evaluated for each of the three criteria.

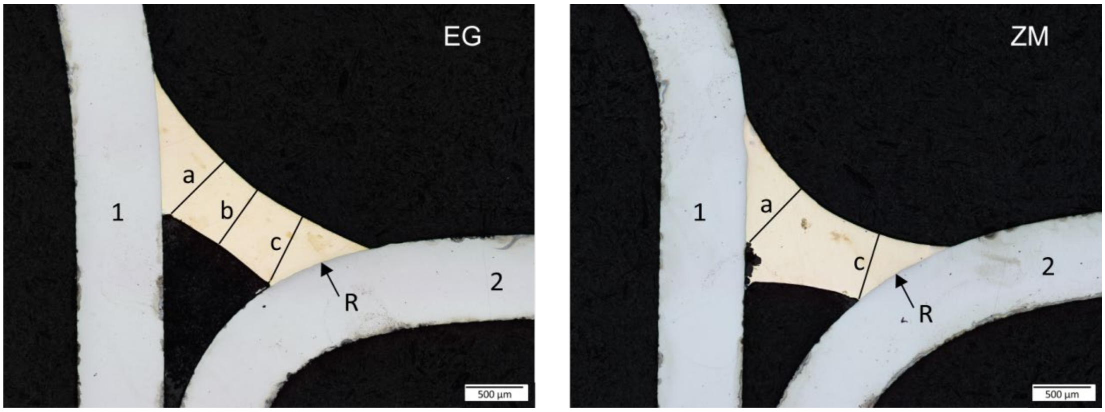

Fig. 3. Micro-sections of laser brazed joints on EG and ZM coated steel: 1 - upper joining partner; 2 - lower joining partner; R - outer joining radius; minimum of a,b,c – minimum wetted length.

3. Results

The visual inspection of the brazed samples shows no effect of the joint geometry on the formation of superficial imperfections for EG coated material. Independent of the outer brazing radii all EG samples show a uniform and smooth braze surface. Neither pores, spatters, cracks nor other surface imperfections can be detected. The surface investigations of the joints manufactured with ZM coatings show similar results compared to those made with EG material. Again, a dependency of the outer brazing radius on the surface quality cannot be seen. Instead an influence of the coating on the surface appearance of the joint can be identified over all ZM coated samples. Though no severe imperfections of the surface are observed, the surface of the braze shows a slightly pronounced wavy appearance. To illustrate the difference between the braze appearance pictures of an EG coated and a ZM coated sample with an outer radius of 2.6 mm are displayed in figure 4.

The analysis of the micro-sections demonstrates the influence of both, the type of coating and the joint geometry. Joints manufactured with EG coated material exhibit two joining partners, which are continuously and smoothly wetted with filler material, independent of the outer radii. With an increase of the brazing radius a progressively pronounced formation of a notch in the filler material next to the lower joining partner is observed. Thus, for radii up to 2.0 mm the smallest wetted length is located in the center of the seam. At larger radii the position of the smallest wetted length is determined by the notch close to the lower joining partner. In addition, the length of the smallest seam thickness decreases from 0.64 mm to 0.53 mm at outer radii of 1.6 mm and 2.6 mm respectively.

In comparison, the micro-sections taken from samples made with ZM coatings show a differently developed joint. Independent of the outer radii a characteristic, downwardly opened cavity in the filler material, which is located close to the upper joining partner, can be found. In general a larger amount of the filler material is located close to the upper joining partner. Thus, the smallest seam thickness is situated directly next to the lower joining partner. By increasing the outer radius of the lower joining partner the distribution of the filler material becomes more uniform, resulting in an increasing smallest wetted length. According to this, the smallest seam thickness rises from 0.49 mm to 0.57 mm. In figure 5 micro-sections of joints on EG and ZM coated material are compared to each other to illustrate the influence of the joint geometry and the type of coating. In addition, the course of the smallest seam thickness in dependence of the outer joining radii and the different coatings are shown in figure 6 (a). The values of the smallest wetted lengths of seams made with EG coated steel at radii smaller than 2.0 mm are superior to the highest values achieved with ZM coating. Thus, EG coatings appear to be advantageous for the laser brazing process.

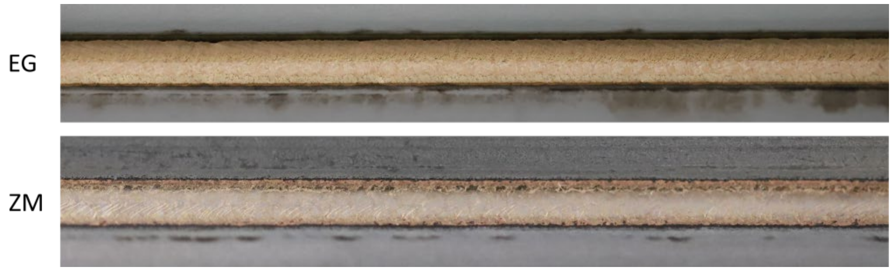

Fig. 4. Exemplary surface appearance of laser brazed joints on EG and ZM coated steel at outer joining radii of 2.6 mm

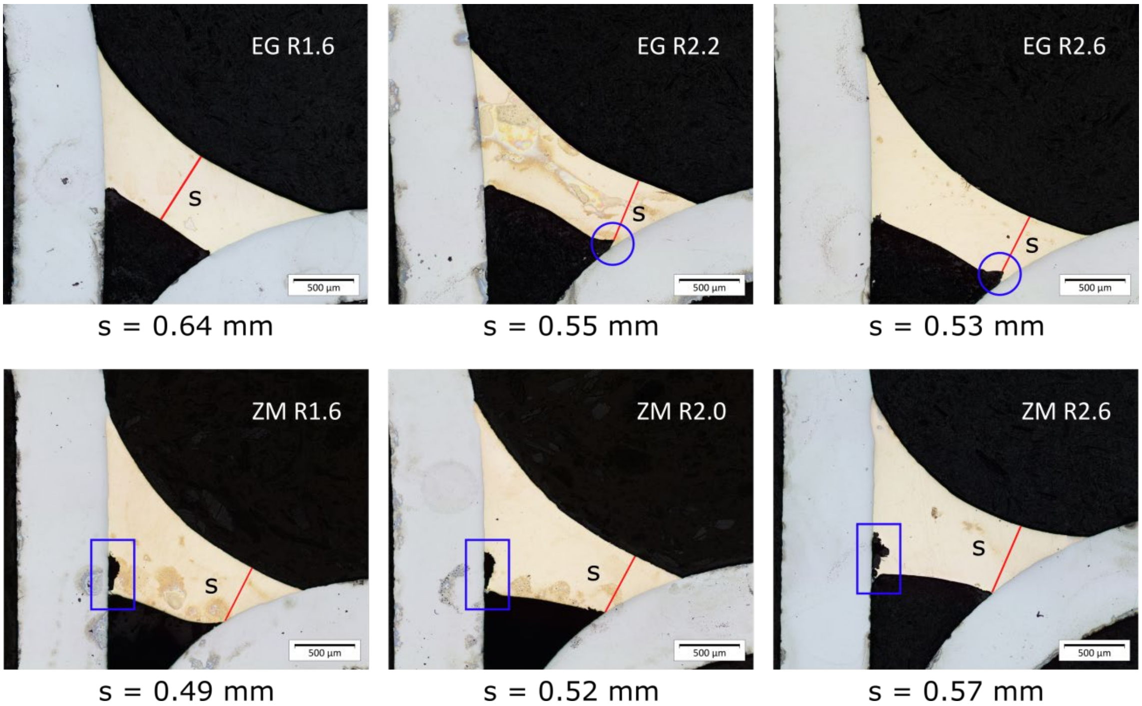

Fig. 5. Representative micro-sections of brazed joints on EG and ZM coatings. Red lines indicate the position of the smallest wetted lengths in the micro-section. The average smallest wetted length of the respective bending radii is listed below the images. Blue circles highlight the formation of notches on EG coated material. Blue rectangles show the characteristic open cavities of joints on ZM coatings.

The dependency of the tensile strength from the coatings and the joining radius are illustrated in figure 6 (b). Corresponding to the trend of the smallest seam thickness, the tensile strength of the joints decreases with an increase of the joining radius for EG coated material. The course and the values of the tensile strength of ZM coated material confirm the influence of the smallest wetted length on the tensile strength – in general lower values for ZM coated material are obtained. Another confirming aspect of the mentioned correlation is the failure mode during tensile testing. Most samples crack in areas of the smallest wetted lengths. Deviant, some EG coated samples with a radius of 1.6 mm fracture in the base material. This circumstance demonstrates a higher applicability of EG coatings on the laser brazing process.

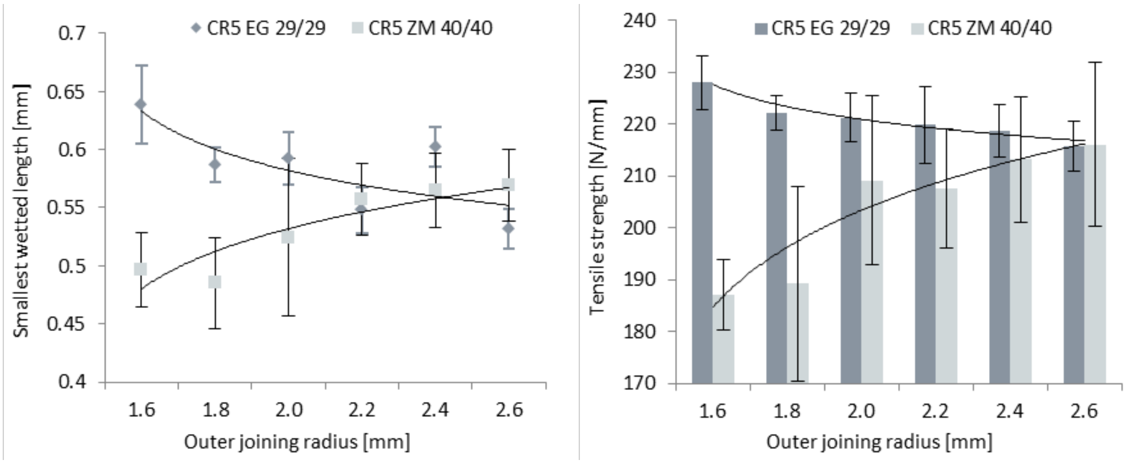

Fig. 6. (a) Smallest wetted lengths in dependency of the outer joining radius and the type of zinc coating; (b) Tensile strengths in dependency of the outer joining radius and the type of zinc coating

4. Conclusions

The study of the outer radii of double flanged joints on the laser brazing process of EG and ZM coated steel shows an influence of the bending radius on the wetted length and thus the tensile strength. While the increase of the outer joining radius results in the reduction of the smallest seam thickness and thus reduced tensile strengths for EG coated steel, the radius of joints made with ZM coated material change oppositely. Consequently, the joint geometry is identified as an important factor on the laser brazing process. Additionally the study gives first insight into the influence of ZM coated steels on the laser brazing process.

In comparison to brazed joints on EG coated material a slightly lower quality of the joint appearance, distinct lower seam thicknesses and associated reduced tensile strengths characterize joints made with ZM coated steel. For these reasons, the laser brazing process applicability of EG coatings is superior to ZM coatings. Due to the properties of the ZM coating and the observed wetting behavior, laser brazing of this material is a demanding application. With respect to the superior corrosion resistance of the coating, the process development for a laser brazing process is a challenging task.

References

Diler, E., Rouvellou, B., Rioual, S., Lescop, B., Nguyen Vien, G., Thierry, D., 2014. Characterization of corrosion products of Zn and Zn–Mg–Al coated steel in a marine atmosphere, in "*Corrosion Science 87*" G.T. Burstein,Editor. Elsevier Ltd., Cambridge, p. 111–117. DOI: 10.1016/j.corsci.2014.06.017.

Heitmanek, M., 2015. Reduzierung von Nahtimperfektionen beim Laserstrahlhartlöten. Dissertation. Technische Universität Dresden, Dresden.

Heyn, H., 2003. Laserstrahllöten von verzinkten Stählen - Einfluss der Oberflächenbeschichtung. EALA - European Automotive Laser Applications. Bad Nauheim, April 2003.

Kimura, S., Takemura, S., Mizutani, M., Katayama, S., 2006. Laser brazing phenomena of galvanized steel and pit formation mechanism, in ICALEO® 2006: 25th International Congress on Laser Materials Processing and Laser Microfabrication. Scottsdale, Arizona, USA, p. 528.

Le Bozec, D. T., Rohwerder, M., Kovacs, A., Peltola, A., Luckender, G., Luxem, L., Marchiaro, G., 2013. Advanced zinc-based hot dip coatings for the automotive application. European Commision, publisher, Brussels (EUR 26323 EN).

Reimann, W. H., Pfriem, S., Hammer, T., Päthe, D., Ungers, M., Dilger, K., 2017. Influence of different zinc coatings on laser brazing of galvanized steel, in: Journal of Materials Processing Technology 239, p. 75–82. DOI: 10.1016/j.jmatprotec.2016.08.004.

Volovitch, P., Vu, T. N., Allély, C., Abdel Aal, A., Ogle, K., 2011. Understanding corrosion via corrosion product characterization. Role of alloying elements in improving the corrosion resistance of Zn–Al–Mg coatings on steel, in *"Corrosion Science 53 (8)"*, p. 2437–2445. DOI: 10.1016/j.corsci.2011.03.016.