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Advantages of three-focal fiber technology in laser brazing of galvanized steel

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Abstract

Application of laser as a prominent high quality tool for brazing is growing more and more. Today, this technology innovates new possibilities of highly precise and fast joining process which was not possible with the traditional methods. In automotive industry, car bodies are mostly made of galvanized steel. Because of the zinc coating, conventional laser brazing methods using monofocal beam face joining challenges. Normally, edges of the seam are neither rectilinear nor well defined. As a result, the seam surface will not be smooth and splashes or pores can be observed around the joint. A new brazing technology based on three-focal fiber is studied and produced by IPG Laser GmbH to introduce a practical solution to all so far mentioned problems. The aim of this publication is to prove the validity and advantages of three-focal fiber technology for brazing of galvanized steel. Optimal process parameters to approach a very high quality and clean brazing results are defined. Brazed joints are evaluated by microsections and microscope analysis.

Keywords: Laser joining; fiber laser; optics; zinc; three-focal; galvanized steel

1. Introduction

Laser brazing technology has become a common method currently in the car-body manufacturing industry. Short process times and one sided access to the joining zone can be addressed as the benefits of

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this technology. Consequently, it results in good adaptability and a highly appropriate connection from the viewpoint of weight reduction and costs in series production. In recent times, significant number of researches has been carried out on the laser joining of materials containing a brazing energy source with a filler metal [Schubert et al., 1997; Dharmendra et al., 2011]. Zinc-coated steel sheets are the usual materials in automotive industry used for brazing with a copper based filler wire [Schwartz, 2003]. In brazing process, the filler material and zinc-coated steel sheets are joined together. Strength, fabricability, and reasonable cost are the noticeable characteristics of the steel that make it a highly leading material used in automotive industry. Most steel sheets used in car-body are now zinc-coated in order to provide enhanced production stamping performance, corrosion resistance and product endurance. The mixture of laser brazing and advanced high-strength zinc-coated steels could lead to outstanding production improvements. But reaching this potential needs reliable and stable management of the zinc vapor that is problematic. The zinc coating has a major influence on the quality and especially on the visual appearance of the joint. Selectively de-coated material grants steady conditions and therefor high reproducibility. Throughout laser brazing, corrosion-resisting zinc coatings on the surface of the steel sheets, neighboring to the molten seam pool, will boil [TZENG, 1999; Li et al., 2007]. The reason is that zinc has a considerably low boiling point of 906 °C. During the brazing process, a highly pressured zinc vapor is formed. This vapor expels violently the liquid filler material and large amounts of it can be spattered and blown away [Dasgupta and Mazumder, 2000; Kurobe et al., 2005]. Challenges in laser brazing of zinc-coated steel are:

- Constriction of the process window and decrease of the process stability and reproducibility
- Splash, micro splash and smoke residues
- Bonding defects and pores
- Either the brazed seam surface is rough or there is imperfections

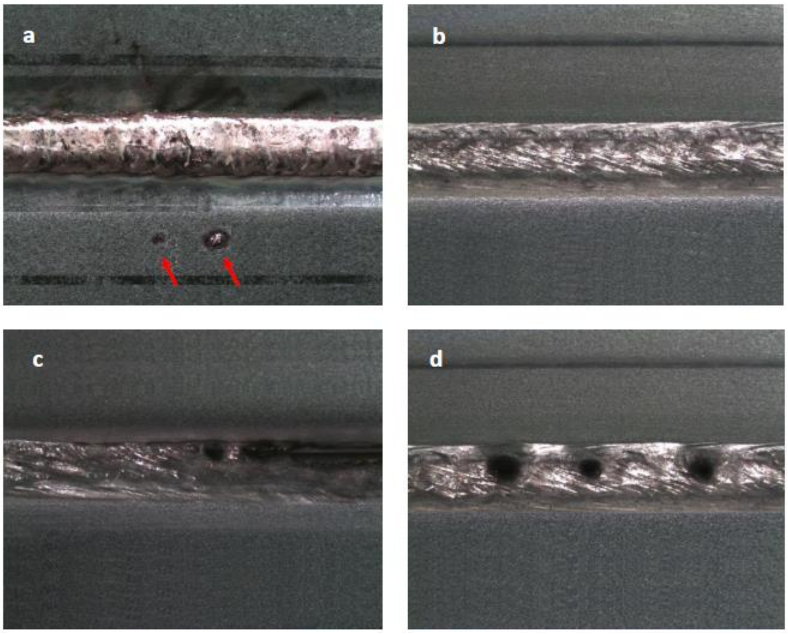

Fig. 1. (a) Smoke residues and splash of filler metal; (b) Scaly and rough surface; (c) Bonding defects between filler and base metals; (d) Pores in the joint

Because of the so far mentioned problems, mechanical performance of the brazed joint will be intensely reduced. Hence, some further steps must be taken for brazing process with the aim of zinc vapor suppression. Inappropriately as a disadvantage, the manufacturing process will get more complex and productivity will decrease [YANG et al., 2014]. A large number of mechanical procedures to zinc vapor management and numerous chemical or physical methods of suppressing vapor discharge have been already studied. They include solutions such as adding another ingredient to the brazing environment in order to absorb, dissolve, or react with the zinc to get rid of it. Until now, such methods have usually shown unproductive results and mostly undesirable destructive side effects. [Li et al., 2007] Various solutions for overcoming this problem have been so far investigated. For instance, the removal of the zinc coating can be realized by laser irradiation [Williams et al., 1993; Hamaya et al., 2002]. Another suggested option involves enlarging the seam cross section to enable the escape of zinc vapors. Two focal spots can realize this effect [Xie, 2002; Forrest and Lu, 2004; Fabbro et al. 2006].

The three-focal fiber approach of IPG in body shell makes it possible to realize the integration of the zinc coating removal in the brazing process. In this technology, brazing is conducted including three laser beams. Two leading side beams ablate the zinc coating from the steel surface and the following main beam melts the filler wire to create the joint. Figure 2 shows three beams emitted from a three-focal fiber while irradiating the filler wire and base metal in brazing process. It illustrates the removal of the zinc layer by two leading beams from the surface of galvanized steel sheets. Generation of a well-defined removal line by two leading beams is realized. The following main beam melts the filler wire to produce the braze seam. The appearance of the joint will be completely smooth in ideal form. It makes a noticeable increase in the process velocity that is very important in series production.

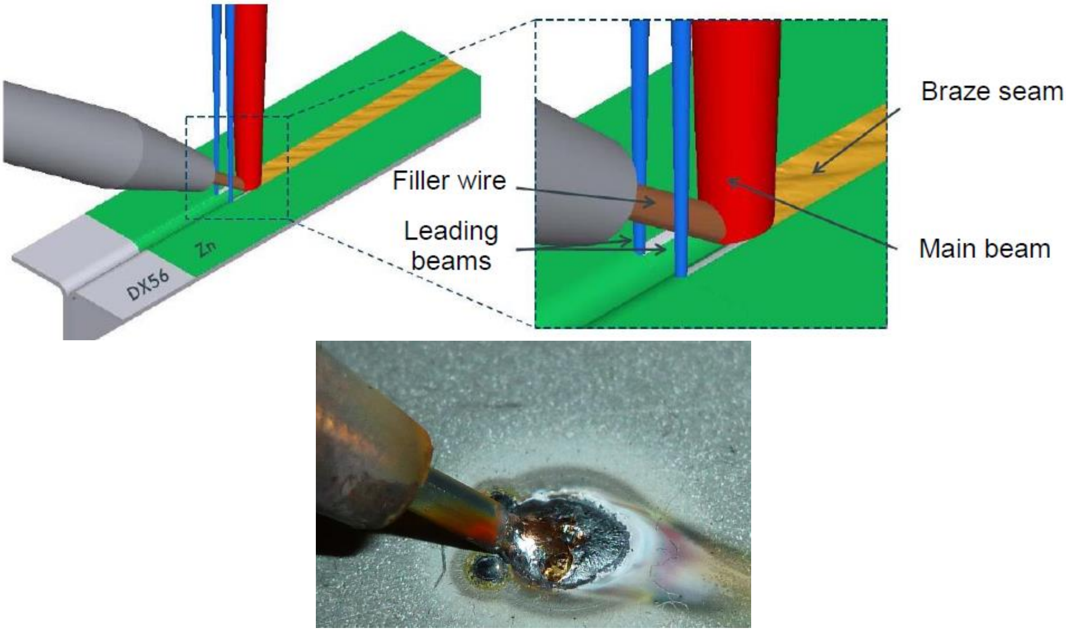

Fig. 2. Brazing process with three laser beams

Figure 3 shows how three beams can be achieved on surface of the material. By imaging the three fibers ends through the optical focusing setup, three foci are implemented.

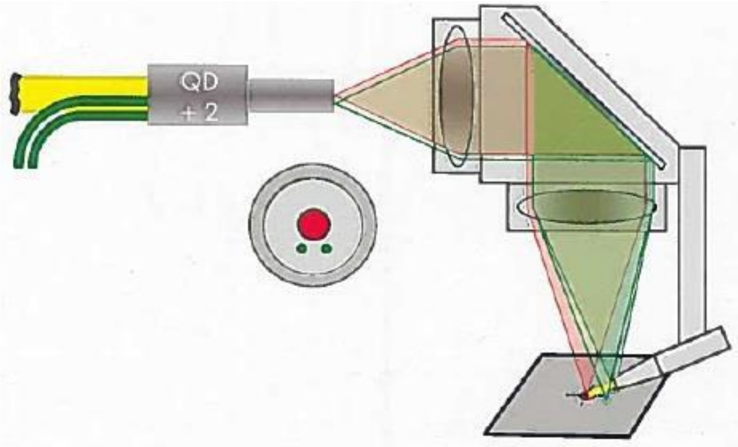

Fig. 3. Imaging optical setup and three-focal fiber end

2. Experimental setup

Laser source in this investigation is an IPG fiber laser "YLS-6000" with 1070 nm wavelength in CW mode. It delivers power up to 6 kW. The triple-core fiber is connected to the laser source and brazing optics as sketched in Figure 4. The main spot is guided with a fiber with 425 µm or 600 µm diameter. The twin spots were guided with fibers with 50 µm or 100 µm diameter. Laser powers of all three spots are adjustable. The Scansonic ALO3 brazing optic used in this experiment has a magnification ratio of 5.2. Thus, spots have diameter of about 5.2 times larger than the fibers cores. The brazing optic was installed on a Kuka six-axis robot. The filler metal used for brazing of galvanized steel is SG-CuSi3 with a diameter of 1.2 mm and 1.6 mm. Fiber and filler wire diameters should match together. A 2:1 ratio of laser spot size on workpiece to wire diameter is typically used in laser brazing.

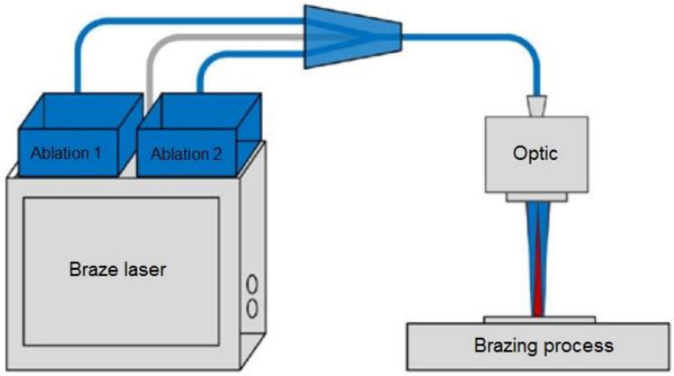

Fig. 4. Principle of operation

3. Results

Brazing is conducted with and without the twin ablation spots in order to realize the benefit of the technology. Large number of brazing are carried out in order to optimize the process and find the most appropriate parameters to accomplish high quality processing. Upon laser parameters, the ALO3 parameters have to be set exactly and also robot must be programed with a high accuracy. By varying the parameters and repeating the brazing, process is optimized and effect of zinc ablation and use of assist gas is examined. Process is conducted on reverse flange joint made of hot-dip galvanized steel DX56 Z100. This type of joint is used for deck lids of car-bodies. The resulting brazed seam looks very good and reveals neither pores nor splashes. Seam surfaces and microsections of each sample are shown in Figure 5. Surfaces of the brazed seam are mostly smooth with rectilinear bonding boundary on the edges. By use of argon as process gas for brazing, the surface of the seam looks brighter and cleaner. The 40 cm long brazed seams are free of failures such as pores or splashes and joints have a very high optical quality. Seam is thick enough and its shape is optimal.

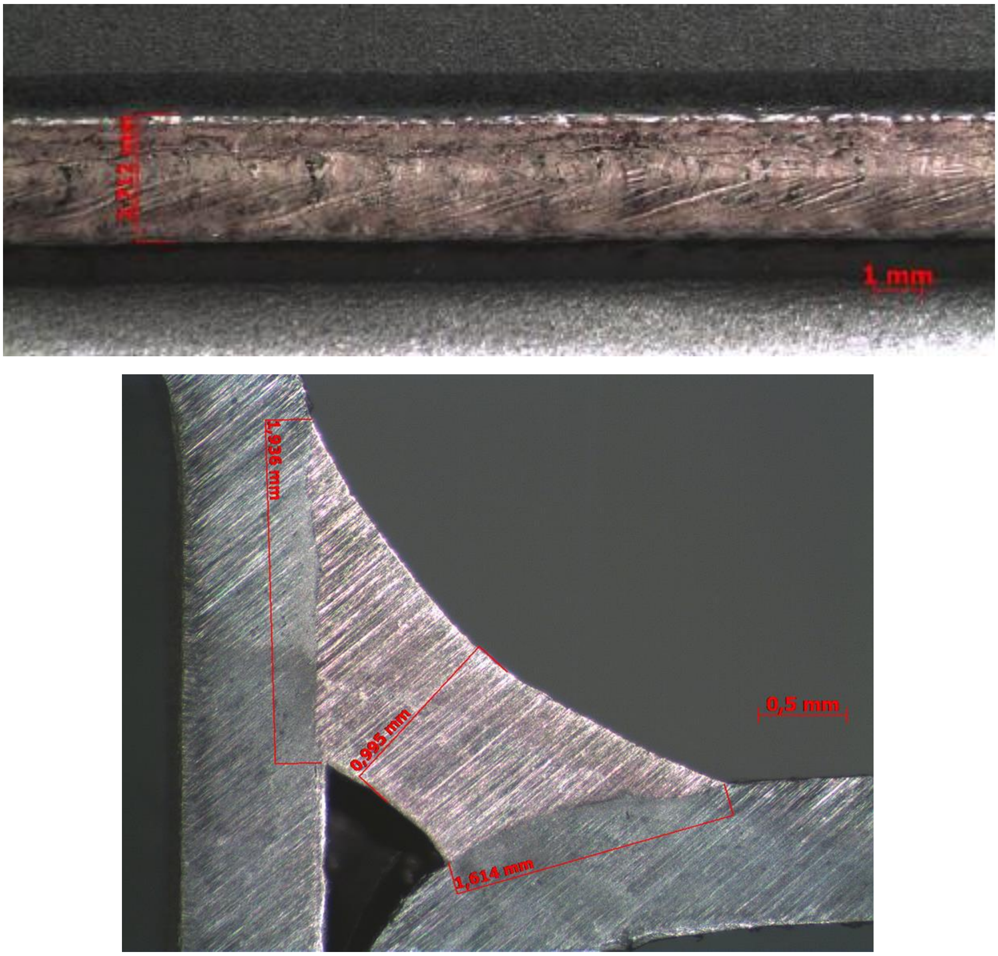

Fig. 5. (a) Seam surface; (b) Microsection of brazed samples with the three-focal fiber technology

By turning off the twin spots and brazing via monofocal process, an obvious difference is visible. The obvious difference is shown in Figure 6. Bonding problems are obvious on the edges along the brazed seam. Seam does not have rectilinear edges on both sides anymore. Consequently, the surface of the seam is not smooth. The effect of using process gas can be realized by comparing the figures in large scale. Surface of the seam which is brazed under gas flow looks much cleaner. But use of gas did not improve the seam quality and the bonding problems on the edges. Microsection of the sample in figure 6 shows that there is pore on right side between seam and base metal. Shape of the joint is not optimal with different thicknesses on each side.

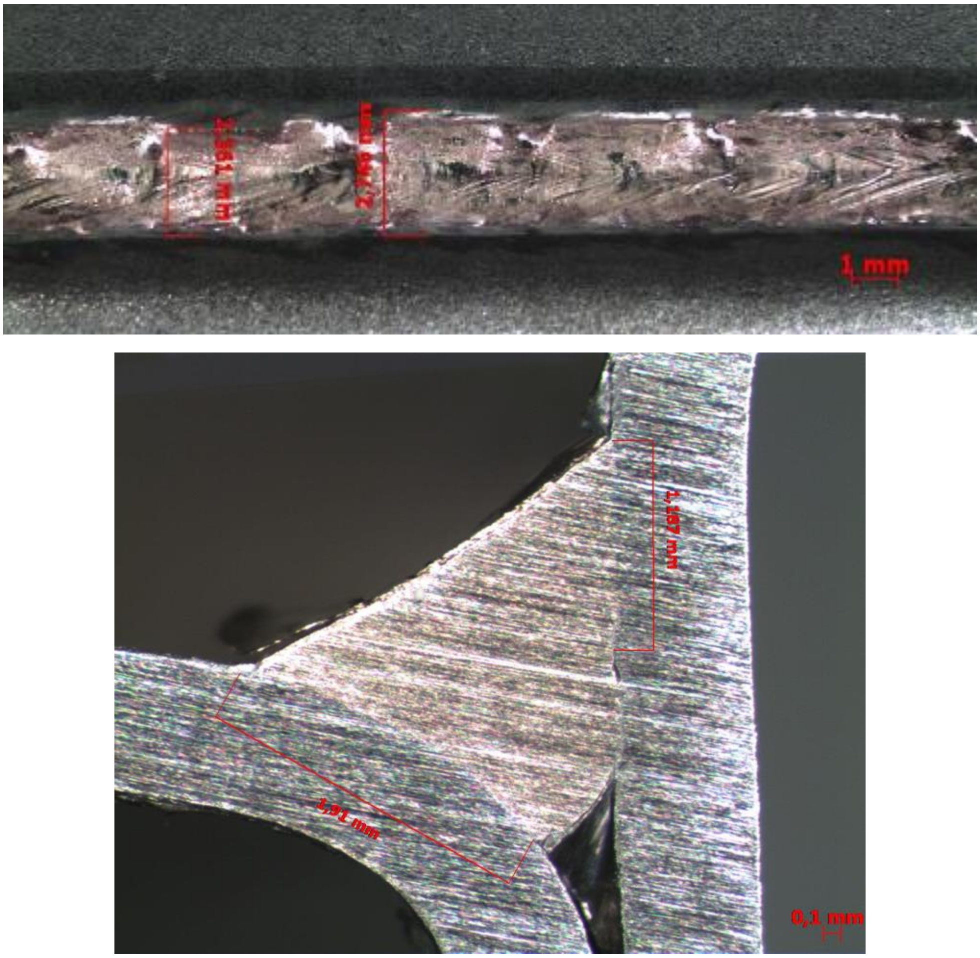

Fig. 6. (a) Seam surfaces; (b) Microsection of brazed samples with mono-focal technology and optimized parameters.

Parallel and exactly next to the trifocal brazed seam, a black track (FeOx) is sometimes apparent. Steel surface has different wetting property as the zinc coating and thus enables a rectilinear connection along the edges. The filler metal must completely cover the zinc ablated track in order to avoid any corrosion in future. An off-center alignment of the optical axis to the filler wire leads to the shift of the ablation spots. It can be corrected by readjustment of ALO3. The favorite shape of the brazed seam is shown in the Figure 7. The minimum acceptable thickness of the brazed seam is 0.8 × base metal thickness in automotive industry. Because this technology will be used in series production in industry, time is a very important factor upon the high quality. The process should last as short as possible. Thus, it should be possible to achieve a high quality by the highest possible robot speed and smallest possible laser power.

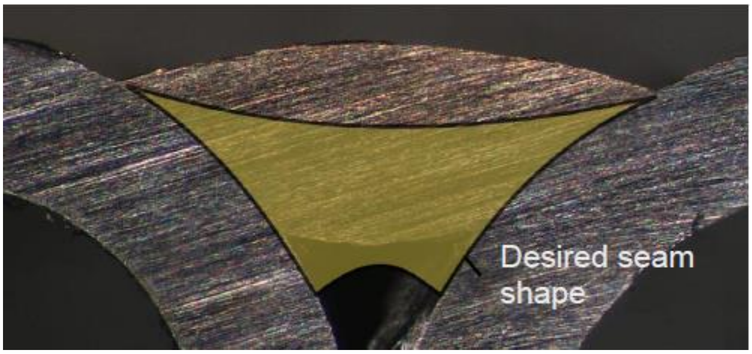

Fig. 7. Optimal shape for brazed seam

High-speed cameras are able to take more than 20000 shots per second. They give us a great possibility to analyze the process with high accuracy. Here two photos from trifocal and monofocal brazing are shown. Explosive vaporization of zinc and oxide residues particularly in the edge region of the seam cause micro splashes. Two leading beams make the process calm through ablation of the zinc coating just before brazing.

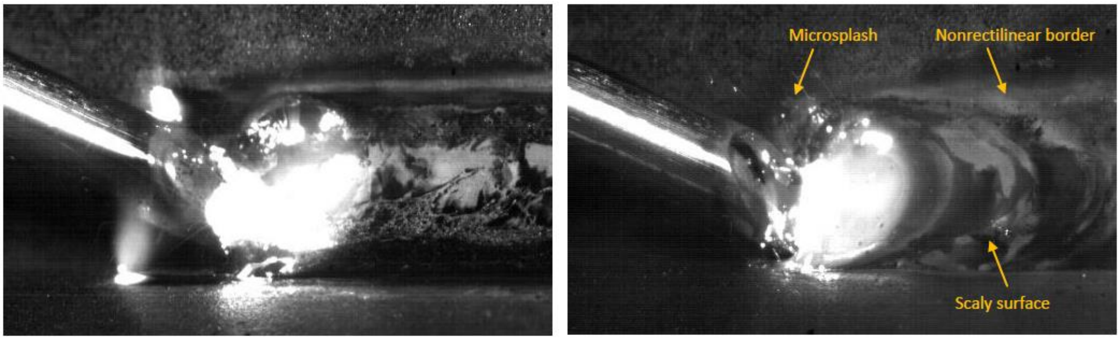

Fig. 8. (a) Trifocal brazing; (b) Monofocal brazing

4. Conclusion

The new technology introduced by IPG for brazing with the three-focal fiber demonstrates clear advantages over the conventional monofocal laser brazing. An outstanding influence of the triple fiber for brazing is proved and brazed seam with high quality surface is achieved. The current fiber with its individual spots arrangement is very promising. The leading twin spots seem to meet multiple process-supportive functions such as:

- Preheating of the filler wire
- Removal of the zinc coating layer

- Heat input into the filler and base material

Brazed joints have a smooth seam surface. Correct settings of the whole braze system and the components e.g. laser beams power, joint type, appropriate filler wire and feed rate are crucial. Position of the ablation tracks affects the seam properties. Best results could be obtained with ablation tracks corresponding to the seam width, but not exceed. Too tight distance between ablation tracks lead to a more turbulent boundary connection of the seam and base metal. Too wide distance between them leads to partial melting of the base material and a correspondingly dirty connection. The results prove clearly that the three-focal fiber brazing technology can substitute the traditional methods in industry and guarantee the joint with high quality. Suitable parameters have been used to braze the deck lid of a VW product and a brazed joint with high quality is reported. Important for the braze joint in the car body is a good connection in the depths. The experiments on flat samples show great potential. The desired joint geometry has already been implemented with great connections area at high speeds.

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