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*Article*

# Attempts of braze welding galvanized steel with a trifocal multi-beam laser system

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**Abstract:** The paper presents the evaluation of the brazing capabilities of the multi-beam Trifocal laser joint system made of galvanized steel DX51D with a thickness of 3 mm, covered with a protective coating of Magnelis type. The brazed joints obtained have been subjected to metallographic, strength and corrosion resistance tests in the Ascott CCIP450 salt cell. The tests have shown that there is a certain range of brazing process parameters that allow to make the correct overlap joints of high quality with small welding distortions and a narrow heat affected zone. The obtained joints are characterized by a slightly worse corrosion resistance than the basic material, and zinc evaporation by means of additional low-power laser beams improves the solder's flow.

**Keywords:** galvanized steel; brazing; laser beam; Trifocal

## Introduction

In recent years, modern laser technologies have found application in every aspect of everyday life, without which it would be impossible for people to function in the modern world. The fields in which devices using the principle of the laser are used are military technology, material engineering and many others. The accuracy and quality of operations performed using laser technology has resulted in the dynamic development of automation and robotization of laser technology. This technique has become irreplaceable in the automotive industry and in other industries, mainly in mass production. The growing demand for unconventional materials with special properties has caused a dynamic development of these welding technologies, which until recently were less used. These technologies include braze welding, a method that allows welding of engineering materials that differ in their chemical composition and physical properties. This method allows making joints with very high mechanical and anti-corrosive properties. The ever-increasing requirements for service life and corrosion resistance have meant that zinc-coated steel body sheets play an important role in today's automotive industry. They are characterized by very high mechanical properties and most importantly – thanks to covering these sheets with zinc – high corrosion resistance. Unfortunately, the process of joining these sheets is a significant technological problem. The evaporation temperature of zinc is 907 °C, which causes porosity of the joints and loss of corrosion resistance in the connection area. Mechanical zinc removal prior to welding and reapplication in places where evaporation has occurred is a very costly process. In addition, in the process of zinc evaporation, very high zinc vapor emissions occur, which have a harmful effect on human health. All these inconveniences can be avoided by using technologies that allow joining thin galvanized sheets with very low welding heat input, which is usually needed to heat the surface and melt low-melting additive material. Thanks to these methods, the coating is virtually undamaged, there is minimal element deformation and a very narrow heat-affected zone. Trifocal brazing uses three coordinated laser beams to connect materials. Oxides and impurities found in the thin anti-corrosion layer are very often responsible for the formation of chips and sharpness of the edges. In order to reduce the amount of impurities, in the Trifocal system two beams with lower power (usually about 0.5 kW) are designed to clean and preheat the surface, which further increases the ability of the brazing to dissolve and more accurately penetrate the metal gaps. The main beam of higher power provides the energy necessary to melt the wire to connect steel surfaces [1÷16].

## Own research

The aim of the study was to assess the possibility of braze welding with the Trifocal laser system with lap joints made of galvanized steel DX51D (Fig. 1), 3 mm thick, coated with a Magnelis type coating and to determine their corrosion resistance. Due to high anti-corrosive properties in industrial and marine conditions, this material has found wide application in the construction of road infrastructure, in the production of solar structures, roofing and roofs. The Magnelis coating mainly consists of zinc with the addition of 3.5% aluminium and 3% magnesium. This coating is applied on a standard continuous fire coating line, the difference is a bath that contains an admixture of aluminium and magnesium. This coating has a high passivity, which provides increased protection for cut edges and perforated elements. The coating exposed to external factors creates a low porosity passive layer. A similar process occurs on cut edges, perforations or scratches which ensures increased corrosion resistance. Magnelis has higher abrasion resistance and a lower coefficient of friction than ordinary hot-dip galvanized steel, which considerably facilitates processing by pressing or bending.

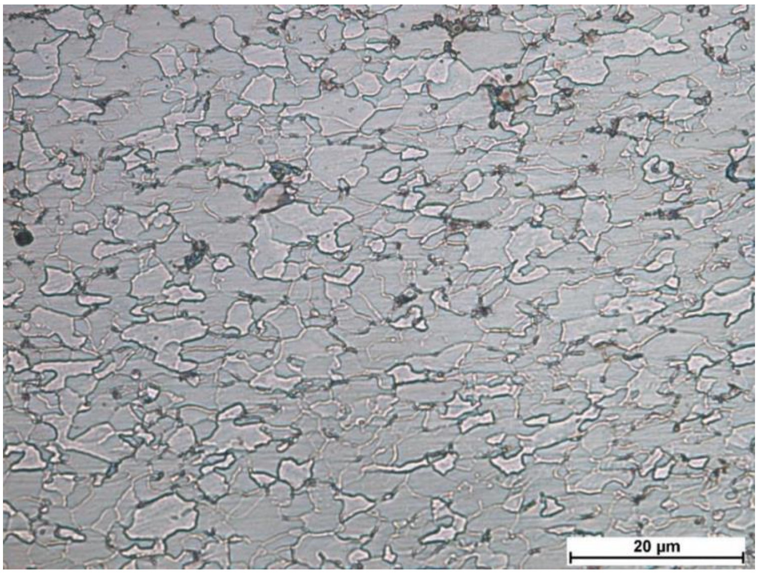



**Fig. 1.** Microstructure of the basic material – DX51D galvanized steel (PN-EN 10346)

### *Brazing process*

The braze welding process of lap joints was carried out at a robotic stand at IPG Photonics with the Trifocal three-beam system using the Scansonic ALO3 head. In the braze welding process, an additional material in the form of 1.6 mm diameter CuSi3 solid wire was used, which is intended for braze welding galvanized sheets, materials with increased strength, copper and copper-silicon alloys. Based on the preliminary tests carried out, process parameters were established (Table I). The process was carried out in the lateral position with the head tilting 45° from the vertical axis.

**Table I.** Brazing process parameters

| Number of the sample | Laser main beam power $P_C$ [W] | Auxiliary beam power $P_A$ [W] | Feed of additional material $V_D$ [m/min] | Welding speed $V_{Rob}$ [m/min] | Type of the joint |
|---|---|---|---|---|---|
| 1 | 3400 | 2 x 500 | 3 | 3 | lap |

Remarks: dimensions of the laser beam focus: ø600÷660 μm, dimensions of the auxiliary beams focus: ø100÷200 μm

### *Tests of the braze-welded joints*

The obtained braze-welded joints were subjected to:

- macroscopic metallographic tests using the Olympus SZX-9 light microscope and microscopic metallographic tests on the NIKON ECLIPSE MA100 microscope. In order to reveal the macro- and microstructure of braze-welded joints, an etching process was carried out in a mixture of nital and $FeCl_3$;

- measurements of hardness in the cross section of joints, on a Wilson Wolpert 401 MVD hardness tester at HV0.2 load;
- static tensile (shear) test on a Zwick 100 testing machine;
- electrochemical corrosion resistance tests using the galvanostatic method of neutral salt – NSS in a controlled environment of a 5% sodium chloride solution imitating marine atmosphere according to ISO 9227. The tests were carried out in a 5% solution of sodium chloride dissolved in distilled water, whose conductivity did not exceed 20 μS/cm and the pH of the solution was in the range of 6.5÷7.2.

## Tests results analysis

The visual tests carried out did not show any welding incompatibilities of the joints. The face of braze-welded joints is characterized by a correct appearance, even flakiness. No splashes were observed on the joint surface (Fig. 2).

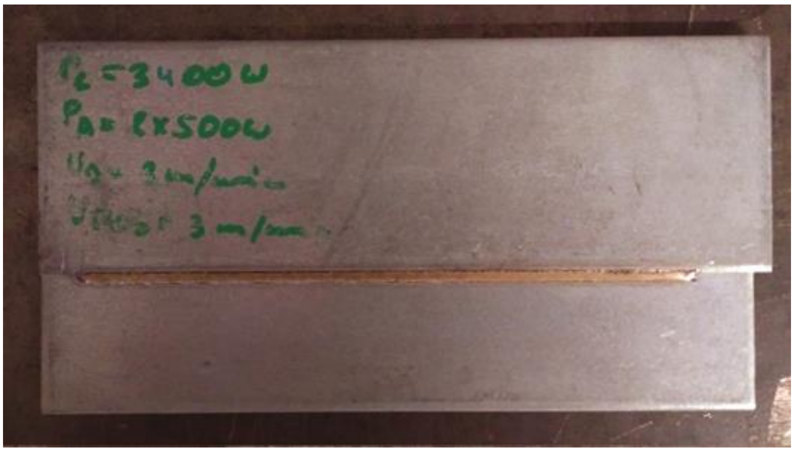


**Fig. 2.** View of the brazed lap joint

The macroscopic metallographic tests carried out showed the correctness of the connection made, without visible geometric defects and without partial melting of the joined elements (Fig. 3). Metallographic microscopic examinations revealed slight partial melting of the sheet surface and discontinuities that were filled with liquid solder (Fig. 4).

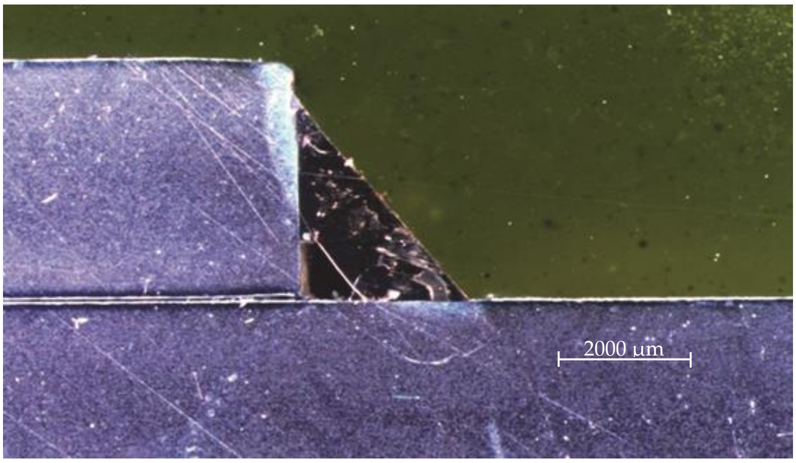



**Fig. 3.** Macrostructure of a brazed joint

The hardness measurements carried out by the Vickers method showed a slight increase in the hardness line to the level of approx. 220 HV0.2 in relation to the hardness of the native material (200 HV0.2).
The braze weld has a hardness of approximately 100 HV0.2 (Fig. 5).

A static tensile test (shear) showed that the braze-welded joint has a strength of 132 MPa. Joint breakage occurred in the area of braze weld, which is associated with lower strength properties of solder as well as the nature of the connection (Fig. 6).

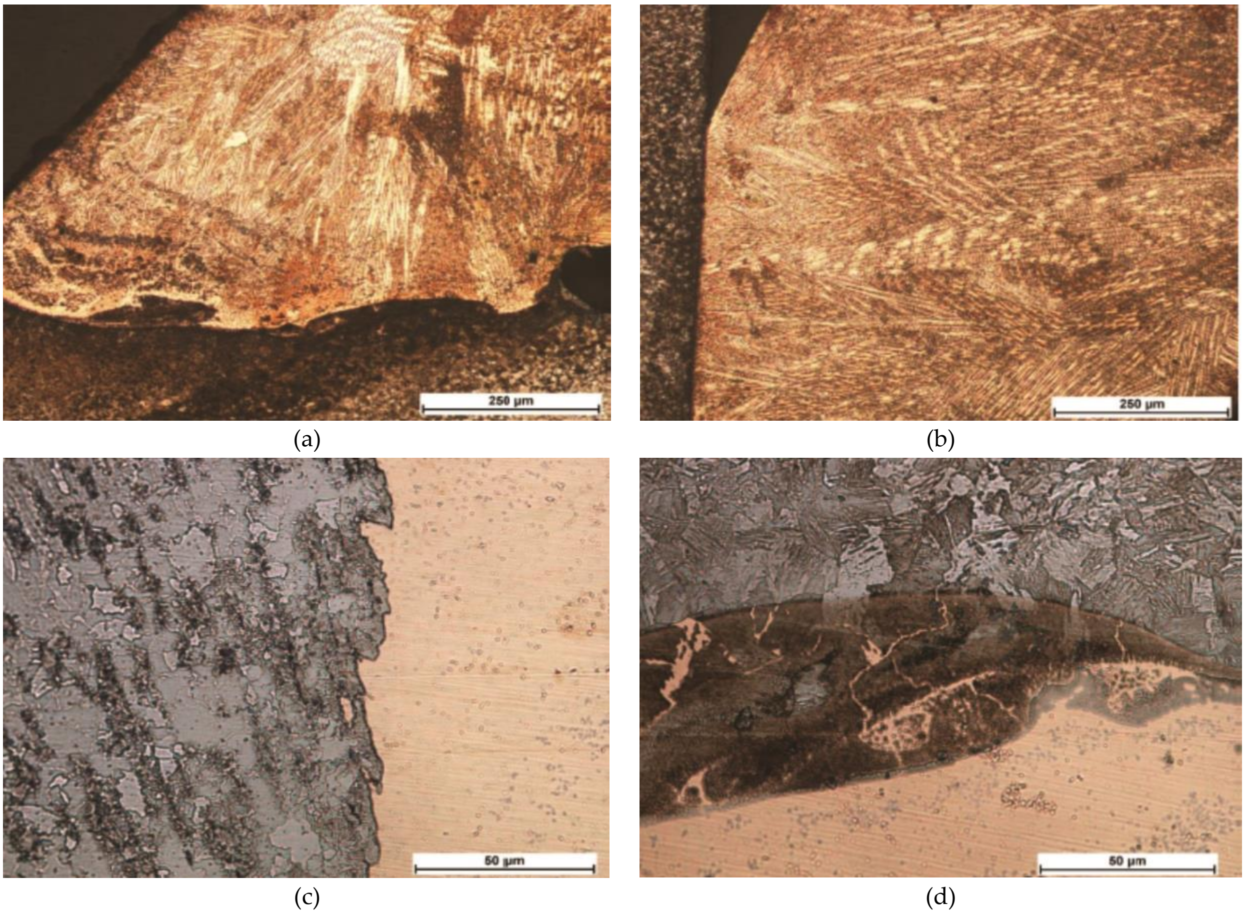



**Fig. 4.** The microstructure of the braze-welded joint: a) microstructure of the braze weld at the surface of the native material, b) microstructure of the braze weld at the edge of the native material, c) microstructure of the substrate in the area of the braze weld, slight weld penetration at the edge of the substrate, d) microstructure of the substrate in the area of the braze weld, weld penetration on the substrate's surface

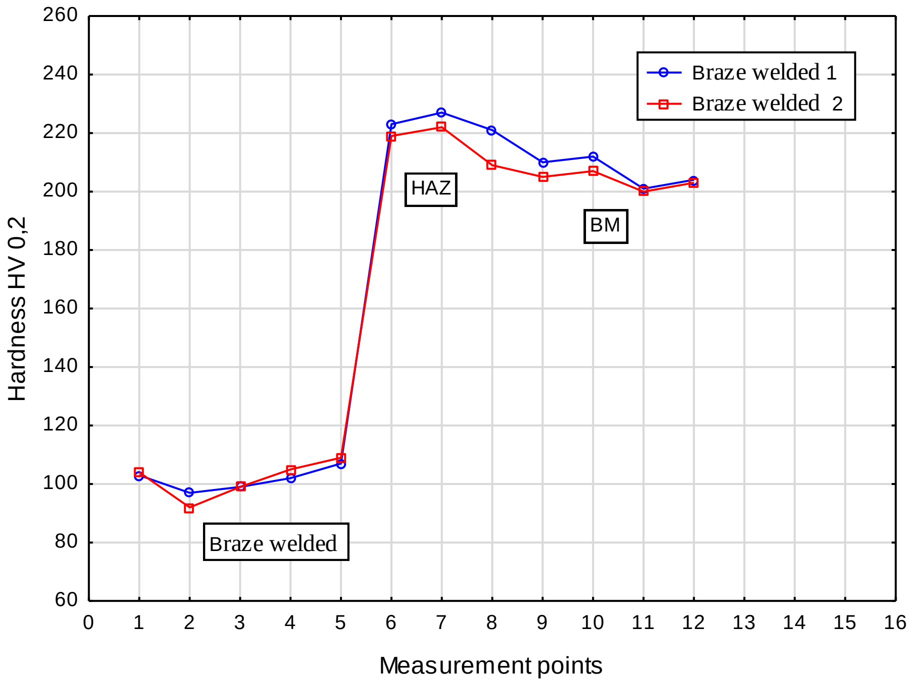



**Fig. 5.** Hardness distribution in a brazed joint

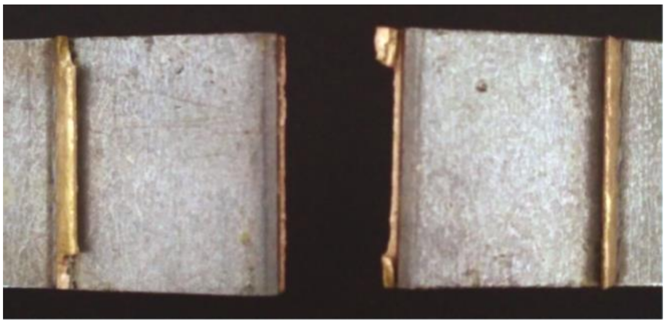
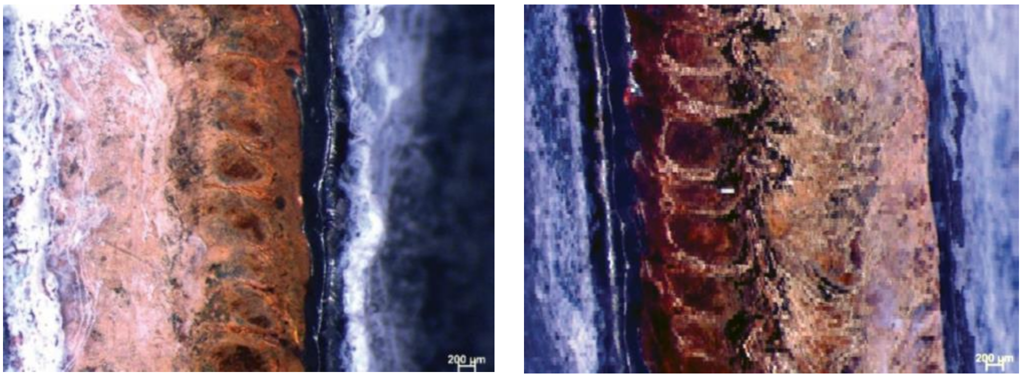


**Fig. 6.** View of the joint after tensile test (shearing)

Accelerated corrosion tests of the braze weld in salt fog were carried out in a salt chamber of Ascott CCIP450. Corrosion processes during the test occur about 100 times faster compared to environmental conditions and are used to quickly analyze discontinuities, damage or tightness of anti-corrosive coatings. The total study time in the salt chamber was 96 h, during this time observations of specific points were carried out with an unarmed eye and using the Zeiss SteREO Discovery V12 stereoscopic microscope at 24; 48; 72; 96 hours from the start of the test. Corrosion resistance tests in a salt chamber showed that the corrosion resistance of joints made is less than the corrosion resistance of DX51D steel with a thickness of 3 mm, coated with a Magnelis type coating. Under the influence of a 5% NaCl solution, which corresponds to the sea water environment, pitting formed in the weld can lead to permanent destruction and weakening of the mechanical properties of the braze weld. No major corrosion damage to the braze weld and the substrate was observed near the laser paths of the auxiliary beams (Fig. 7).




(a) (b)

**Fig. 7.** View of the joint after corrosion resistance tests: a) testing time 24 h, b) testing time 96 h

## Summary

The research and analysis of the results obtained allow the following conclusions to be made:

- there is a certain range of parameters of the braze welding process that allows high-quality lap joints to be made;
- the obtained braze-welded joints have small welding deformations and a narrow heat-affected zone;
- braze-welded joints have slightly lower corrosion resistance than the base material;
- evaporation of zinc with the help of additional low-power laser beams improves solder flow;
- the laser braze welding process requires a very precise beam guidance and wire feeding system as well as matching of the sheets.

**Author Contributions:** methodology J.G. and M.K.; validation E.F.; formal analysis J.G., M.K. and E.F.; investigation J.G.; references M.K.; data curation M.K.; writing—original draft preparation J.G.; writing—review and editing J.G.; visualization J.G.; supervision J.G.; funding acquisition J.G.;

**Conflicts of Interest:** The authors declare no conflict of interest.

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