https://doi.org/10.37434/tpwj2020.06.06

GEOMETRICAL PARAMETERS OF THE BRAZED SEAM AND ITS STRUCTURE IN PLASMA BRAZING OF GALVANIZED STEEL

S.V. Maksymova, I.V. Zvolinskyy and **V.V. Yurkiv**
E.O. Paton Electric Welding Institute of the NAS of Ukraine
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine. E-mail: office@paton.kiev.ua

The paper presents the results of investigations of brazed joints of 08Yu galvanized sheet steel, produced by welding, arc and plasma brazing. It is confirmed that in the first case, spattering of the liquid pool metal, zinc evaporation and porosity formation take place. The influence of energy input on brazed seam parameters was studied in plasma brazing with application of BrKMts 3-1 brazing filler metal. It was found that increase of energy input leads to reduction of face reinforcement height, but promotes increase of back reinforcement height, that requires a greater amount of brazing filler metal. It was empirically determined that energy input value in the range of 520–590 J/cm ensures producing butt joints of galvanized 08Yu steel with optimum size of back reinforcement. X-ray microprobe analysis showed that high-quality dense welds form in this mode that have the structure of copper-based solid solution with dispersed inclusions of iron-based phase, enriched in silicon. 11 Ref., 1 Table, 9 Figures.

Keywords: plasma brazing. galvanized steel, brazing filler metal, energy input, seam parameters, structure

Corrosion protection of different structures is often realized through wide application of galvanized steel. In a number of cases, application of galvanized steel is related to producing permanent joints, which causes considerable difficulties. It is known that zinc starts melting at the temperature of 419.58 °C and at 907 °C it evaporates. In welding when the temperature of base material edges exceeds that of zinc boiling, the zinc coating burns out from both sides. To ensure reliable corrosion protection, the destroyed zinc layer has to be restored that leads to additional expenses. More over, zinc penetration into the liquid metal of the weld pool leads to formation of porosity, cracks, spatter, incomplete penetration and unstable arc burning [1–3].

Brazing is a promising method of producing joints of sheet steel with zinc coating. Unlike welding, brazing makes a much smaller thermal impact on the base material. The process of consumable electrode brazing (MIG-brazing) is used extensively to produce galvanized steel joints. The brazing filler metal is fed into the joint zone instead of the welding wire. The disadvantages of MIG-brazing are the dependence of current on wire feed rate; relatively high value of current for brazing sheets (high heat input leads to weld shrinkage and greater deformation) and brazing filler metal spattering that is related to zinc evaporation and defect formation [4–8].

The process of plasma brazing can be used as an alternative to MIG-brazing. In this case, the filler material (brazing filler metal) that is fed into the arc, is not live, that allows controlling the parameters of the brazed seam, irrespective of the filler material feed rate, by smooth adjustment of voltage and current. It reduces the heat input and the HAZ, and also ensures the stability of the process of producing permanent joints. Moreover, the higher pressure of the plasma arc promotes formation of a sound dense joint with preservation of zinc coating integrity.

The objective of the work is investigation of the structure, establishing the interrelation between the geometrical parameters of the weld, energy input and the size of the gap in galvanized steel joints that were produced by plasma brazing with application of BrKMts3-1 brazing filler metal.

Materials and investigation procedures. A special stand was prepared for conducting the experiments, (Figure 1), which includes argon-arc welding machine Master TIG MLS 2300 of Kemppi Company, pilot arc ignition block, wire feed device with smooth regulation range within 0–130 mm/s and a device for torch displacement at the speed of 0–25 mm/s.

Used as the brazing filler metal was copper alloy in the form of BrKMts 3-1 wire of 1 mm diameter with solidus temperature of 980 °C, and liquidus temperature of 1020 °C [9]. For comparative studies, welding was performed with application of wire of Sv08G2S grade as the filler material. Base metal was used in

S.V. Maksymova — https://orcid.org/0000-0003-0158-5760, I.V. Zvolinskyy — https://orcid.org/0000-0003-1442-7980,
V.V. Yurkiv — https://orcid.org/0000-0001-8440-0391

Figure 1. Stand for arc (plasma) brazing

the form of plate samples of 08Yu galvanized steel of 150×60×0.8 mm size.

The composition of the used materials was as follows, wt.%:

BrKMts 3-1	2.75–3.5 Si; 1–1.5 Mn; 0.5 Zn; 0.3 Fe; 0.25 Sn; 0.2 Ni, Cu — base
08Yu steel	0.35 Mn; up to 0.07 C; 0.02–0.07 Al; 0.03 Si; up to 0.025 S; up to 0.02 P; Fe — base
Sv08G2S	1.82.1 Mn; 0.7–0.95 Si; 0.25 Ni; 0.2 Cr; 0.2 Cu; 0.15 Mo; 0.05–0.11 C; 0.015 P; 0.018 N; Fe — base

Investigations were conducted on galvanized steel samples, produced by MIG-welding, MIG-brazing and plasma brazing in the horizontal position. Samples were cut out of permanent joints, and microsections for metallographic investigations were prepared by a standard procedure.

Microstructure and local elemental composition of the brazed joints were studied, using scanning electron microscope TescanMira 3 LMU, which is fitted with energy-dispersive spectrometer Oxford Instruments X-max 80 mm^2 and INCA software. Local distribution of chemical elements was determined in back-scattered electrons that allows studying the microsections without chemical etching.

Measurements of brazed seam parameters in joints of galvanized steel produced using plasma brazing, were performed in keeping with the scheme (Figure 2).

The energy input value was calculated by the following formula

$$Q = \frac{q}{V},\ \mathrm{J/cm}, \qquad (1)$$

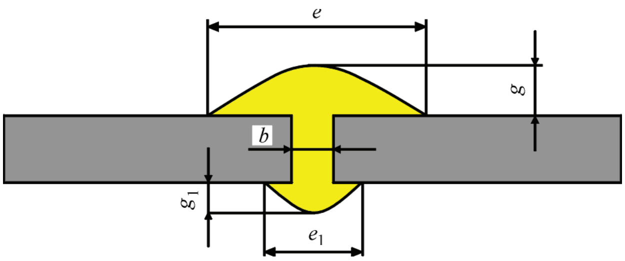

Figure 2. Scheme of brazed seam parameters: e — face reinforcement width; e_1 — back reinforcement width; g — face reinforcement height; g_1 — back reinforcement height; b — brazing gap size

where $q = \eta IU$ is the effective thermal power (J/s); η is the effective efficiency of the process of plasma heating of parts in an argon atmosphere (0.627; U is the arc voltage drop (V); I is the current (A); V is the welding-brazing speed (cm/s).

Experimental results and their analysis. Appearance of samples from galvanized steel, produced with application of MIG-welding (consumable electrode at reverse polarity) showed poor seam formation, and appearance of porosity (Figure 3, *a*, *b*) that is due to zinc evaporation from base metal surface.

MIG-brazing leads to spattering of filler material (through zinc evaporation), which is a disadvantage of this process (Figure 3, *c*).

In plasma brazing (Figure 4) of butt plate samples formation of dense brazed seams is observed without spattering of brazing filler metal (Figure 5, *a*), and without pores or defects (Figure 5, *b*).

Overlap joints are widely used in the car industry. As shown by experiments, producing overlap joints requires slight correction of the brazing process. So, the plasmatron is located at an angle to the vertical surface of base metal plates. As the vertical (at 90° angle) positioning of the plasmatron leads to the arc deflection towards the upper plate, in the optimized mode good formation of the overlap joint (Figure 6, *a*, *b*) is observed with appearance of a complete fillet section (Figure 6, *c*).

Results of investigation of the impact of energy input on the geometrical parameters of brazed seams showed that the back reinforcement height g_1 increases monotonically at a constant rate at increase of energy input (Figure 7, *a*). This leads to increase of the volume of metal from the weld back side, and has a

Figure 3. Appearance (*a*), and macrostructure (*b*) of the weld produced by MIG-welding and MIG-brazing (*c*) of galvanized steel

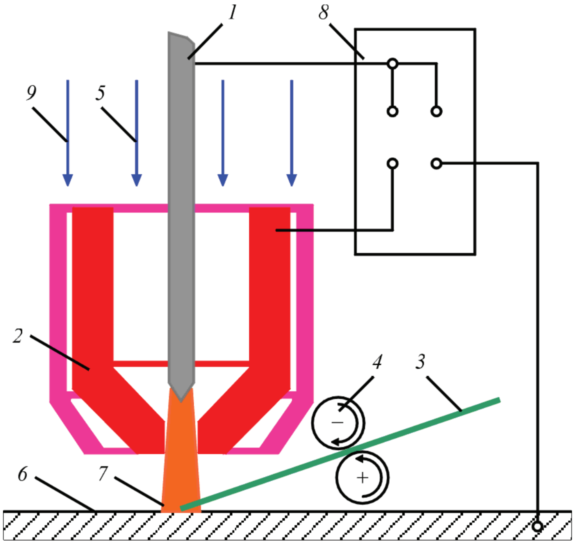

Figure 4. Scheme of plasma brazing process: *1* — tungsten electrode; *2* — plasma-forming nozzle; *3* — brazing filler metal; *4* — feed rollers; *5* — plasma gas; *6* — base metal; *7* — plasma arc; *8* — power source; *9* — shielding gas

negative impact on filler material consumption (Figure 7, *a*).

Another mode is observed when studying the height of face reinforcement *g*, which becomes smaller with increase of energy input. At the same time, the width of face reinforcement *e* first increases to 4.5 mm at energy input of 590–750 J/cm, then decreases, and starting from 916 J/cm it is stabilized.

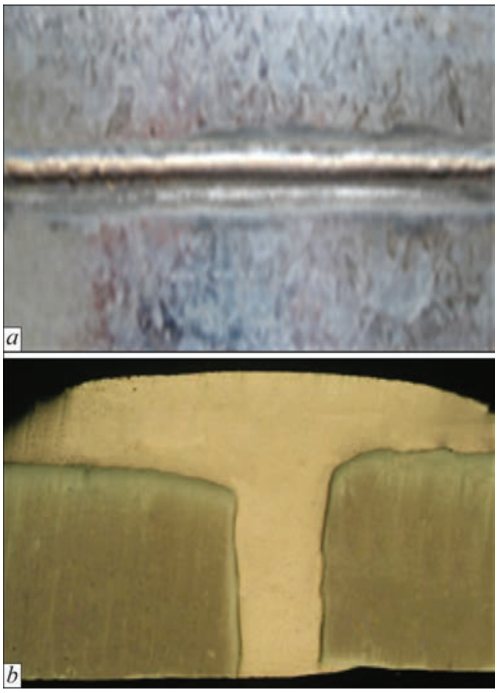

Figure 5. Appearance (*a*) and macrostructure (*b*) of brazed butt joint of galvanized steel (*b*), produced using plasma brazing

Conducted studies of the impact of energy input on formation of butt plate brazed joints show that sound dense brazed seams (without defects) with an optimum size of the face and back reinforcement form at the energy input value, which is in the range of 520–

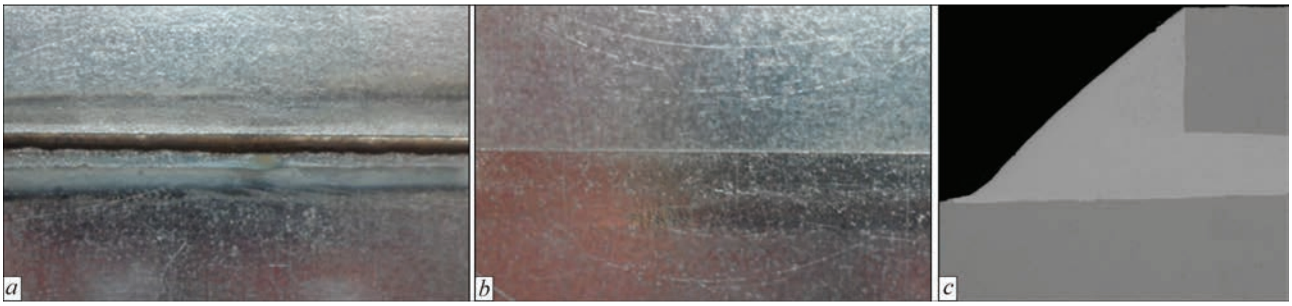

Figure 6. Face (*a*), back side (*b*) and macrostructure (*c*) of brazed overlap joint of galvanized steel

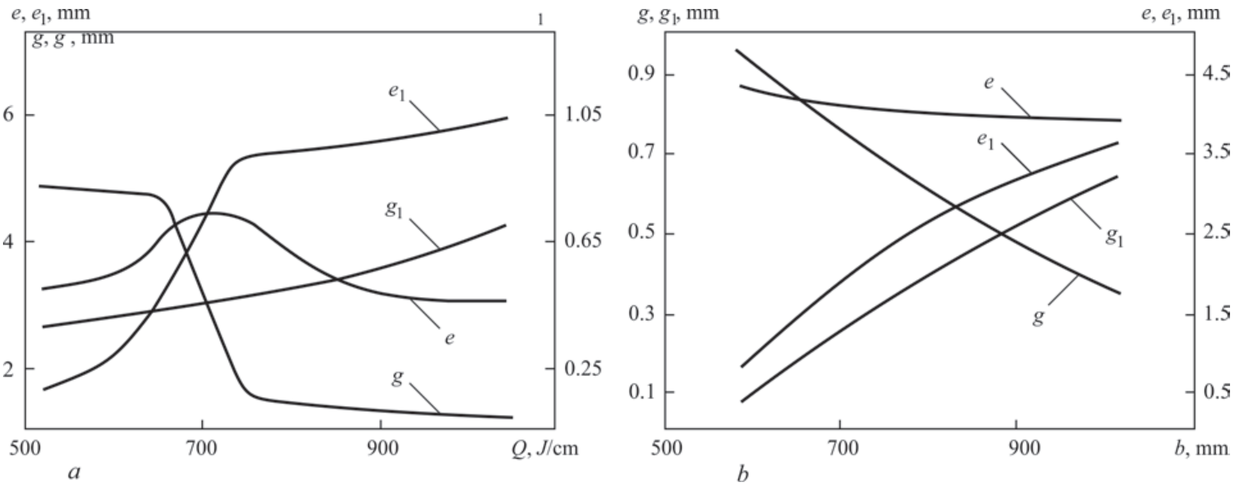

Figure 7. Dependence of brazed seam parameters on energy input value (*a*) and gap size (*b*): width e_1 and height g_1 of back reinforcement; width *e* and height *g* of face reinforcement

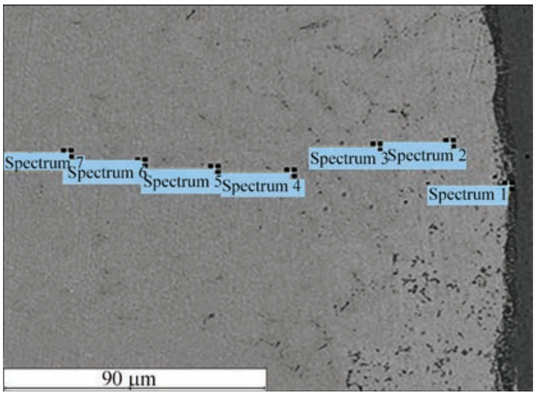

Figure 8. Electron image of the microstructure of brazed joint of galvanized steel produced with energy input of 567 J/cm and gap of 0.4 mm

590 J/cm. At brazing of overlap samples, the energy input value should be corrected, taking into account the features of the technological process of brazing and geometrical parameters of the joints.

In brazing without a gap (capillary brazing) there is the probability of partial filling of the capillary gap by the brazing filler metal. Conducted investigations of the influence of the gap size on formation of brazed butt joints revealed that it has a big role not only in seam formation, filler metal consumption, but also in energy heat transfer into the base metal. Experiments were conducted with a variable gap in the range of 0.2–0.6 mm. It follows from the derived results that at constant parameters of the mode (I, U, V and filler material feed rate) the width of face reinforcement (brazed seam) e decreases slightly, and that of back reinforcement e_1 increases rapidly with increase of the gap (Figure 7, *b*). This leads to reduction of the height of face reinforcement (brazed seam) g and increase of the height of back reinforcement g_1. It is obvious that brazing with small gaps is advantageous in terms of saving the brazing filler metal.

Content of chemical elements in the seam, %

Spectrum number	Si	Mn	Fe	Cu	Zn
1	9.08	1.08	43.35	35.01	11.48
2	2.71	1.18	0.89	77.87	17.35
3	3.67	0.92	0.68	79.91	14.82
4	3.15	1.04	–	87.30	8.51
5	3.53	0.97	–	93.05	2.44
6	2.77	0.97	–	96.26	–
7	2.96	1.05	–	95.99	–

The derived results of local X-ray microprobe analysis and determination of chemical inhomogeneity of brazed joints of galvanized steel are indicative of the fact that the brazed seam microstructure is formed by the copper-based solid solution, along the grain boundaries of which dispersed inclusions of an iron-based phase (43.35 wt.%) precipitate. They are enriched in silicon and contain other components of brazing filler metal (Figure 8, Table).

A thin layer (1–2 µm) of iron-based phase, that contains 9.08 wt.% silicon, forms on the interphase boundary. In keeping with the binary state diagrams of metal alloys [10], in iron-silicon system the latter is characterized by low solubility and forms silicides, which in this case precipitate in the form of a thin interlayer. They also contain up to 11.48 % zinc.

The binary state diagram of copper-zinc metal system is also characterized by limited solubility [10], but the area of zinc dissolution in copper is much larger, compared to silicon solubility in iron. That is why in the grains of the solid solution zinc concentration rises up to 17.35 %. With greater distance from the interphase boundary with the base metal, zinc concentration gradually decreases and no zinc was found at 100 µm distance from the base metal. Such features of brazed seam formation are due to the structure of state diagrams, presence of a concentrational gradient between the elements of brazing filler metal and base metal and nonequilibrium conditions of solidification of the brazed seam metal that leads to running of interdiffusion processes on the interphase boundary. The brazed seam metal is saturated by iron during brazing that promotes formation of an iron-based phase that is enriched in silicon.

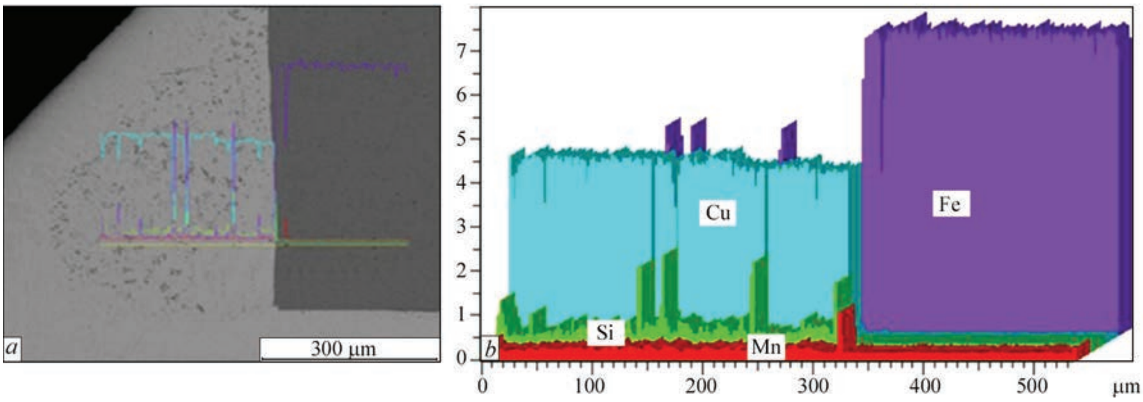

Figure 9. Microstructure (*a*) and characteristics spectra of elements (*b*) in the joint produced by plasma brazing

The characteristic spectra obtained with application of X-ray microprobe analysis by scanning of the overlap joint with an electron beam, correlate well with previous results and confirm formation of iron-based dispersed phases (Figure 9, *a*, *b*) that are enriched in silicon (silicides).

Copper concentration in this phase decreases. It should be noted that silicide inclusions, which are observed on the interphase boundary of brazing filler metal–galvanized steel, have an increased manganese content (Figure 9, *b*) that is indicative of partial substitution of iron by manganese and formation of a complex compound $(MnFe)_xSi_y$, the crystalline lattice of which is isomorphous to the lattices of Mn_xSi_y and Fe_xSi_y [11]. Formation of such phases in the brazed seam promotes increase of the temperature of unbrazing of the produced joint and increase of operating temperature.

Conclusions

Studying the geometrical parameters of welds, produced by plasma brazing of galvanized steel showed that the value of back reinforcement become larger with increase of the heat input. The width of face reinforcement first increases and then this parameter is stabilized after 900 J/cm.

It is determined that increase of the brazing gap width from 0.2 up to 0.6 mm promotes a reduction of face reinforcement height from 0.95 to 0.37 mm and increase of the height of back reinforcement from 0.1 up to 0.62 mm. Thus, increase of the heat input and value of the gap at plasma brazing leads to increase of the metal volume in the back reinforcement that has a negative impact on brazing filler metal consumption.

The value of energy input in the range of 520–590 J/cm was empirically established. This value ensures producing sound butt welded joins of 08Yu galvanized steel with optimum parameters of the brazed seam.

X-ray microprobe investigations showed that the microstructure of the brazed seam is formed by copper-based solid solution and dispersed inclusions of iron-based phase, that are enriched in silicon (silicides), which precipitate in the form of a thin interlayer (of 1–2 μm width) on the interphase boundary of base metal–brazing filler metal and along the grain boundaries of the copper-based solid solution.

1. Killing, R. (2005) Plasma brazing − Advantages and disadvantages compared with MIG brazing. *Welding and Cutting*, 4(**3**), 147−149.
2. Pavol, Sejc (2010) MAG zvaranie pozinkovanych plechov v ochrannom plyne CO_2 a Ar + 18 % CO_2. *Zvarac*, VII(**3**), 8−13 [in Slovak].
3. Pavol, Sejc (2002) Oblukove zvaranie MAG ocelovych plechov pokrytych protikoroznym naterrom na baze zinku. *Zvaranie-Svarovani*, 4(**3**), 71−73 [in Slovak].
4. Haller, H. (2002) Metal gas inverters from galvanized steel profiles. *Der Praktiker*, **10**, 377−380.
5. Wesling, V., A. Shram A. Ait-Mekideche (2003) Plasma soldering of surface-coated thin sheets. *Ibid*., **7**, 196−200.
6. Belkacem, Bouaifi (2003) Low — heat process enhances joining of coated sheet metals. *Welding J*., **1**, 26–30.
7. Chovet, C., Guiheux, S. (2006) Possibilities offered by MIG and TIG brazing of galvanized ultra-high strength steels for automotive applications. *La Metallurgia Italiana*, **7−8**, 47−54.
8. Walduck, B. (1999) Using plasma-brazing in car body fabrication. *Welding and Metal Fabrication*, 67(**8**), 11−14.
9. Smiryagin, A.P., Smiryagin, N.A., Belova, A.V. (1974) *Commercial nonferrous metals and alloys*: Refer. Book. 3rd Ed. Moscow, Metallurgiya [in Russian].
10. Massalski, T.B., Okamoto, H., Subramanian, P.R., Kacprzak, L .(1990) Binary alloy phase diagrams. The materials information society. *ASM International*, **1**.
11. Goldschmidt, X.D. (1971) *Implanted alloys*. Ed. by N.T. Chebotarev. Moscow, Mir, 56–68 [in Russian].

Received 27.05.2020