

Metal inert gas welding-brazing technological development and experimental results

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In the welding process of metals, two materials are joined by a filler material with low melting point (below 450°C), also below the melting point of materials to be joined. The braze-welding filler material has a melting point over 450°C to 1000°C. Filler material is distributed between two surfaces of the joint by capillary action close, the blended material is applied on an electrode specially manufactured and intended operation. This paper proposes an analyze of the techniques, features, technology requirements, process gaseous, materials (standard data base) and conditions used in braze-welding processes. The secret of solder bonding and weld seems to be the opening that supposes to be small. Two methods are proposed and analyzed for welding process based on braze welding. Scanning electrons microscope and EDAX detector were used to characterize the weld line by micro-structural and chemical point of view. The microstructure analysis concentrated on the weld line area presents reduced dimensional variation and a modification of the materials surface smoothness. Chemical elements distribution exhibits an increase of carbon percentage on the weld line and a decrease of iron in the same time and area.

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1. Introduction

MIG welding processes in gas environment (with fusible electrode, inert gases) and MAG (with fusible electrode, with active gas) are generally used in semi-mechanized or mechanized version (sometimes automated). Semi mechanized version meets most; welder is running most operations except bringing the welding wire and protective gas in the arc area. These materials come in the welding arc area through a flexible tube from the gas distribution panel and the electrode wire feeding mechanism.

Mechanized or automated version uses a sled or a cart carrying the arc movement along the joint elements to be combined. The sled/cart system is the wire welding electrode head of coming gas protection and cooling water of the nozzles welding head.

Advantages of MIG/MAG welding processes are [1, 2]:

- the deposit rate, deposition coefficient, productivity and operator factor are much greater than the ones corresponding to manual welding electrodes, comparable to those of the submerged arc welding;
- the electric arc is visible, and the operator performance is so much easier;
- at the end of the welding process does not result a significant amount of clay (due to no use of feeds or coatings for electrodes), which eliminates its cleaning operation, also decreases the likelihood of slag inclusions

in the cord. In this way it is much more easier the repeated welding, because there is no need for a slag cleaning, productivity is increasing significantly;

- high degree of universality, being able to weld most metallic materials in any position;
- high concentration of heat in small areas, which reduces deformations of welded parts;
- minimum harmful action of atmospheric oxygen and nitrogen;
- the possibility of welding metals and special alloys, with thickness that varies widely.

Disadvantages of MIG and MAG processes refer to:

- welding equipment is more expensive due to its complexity (the existence of the wire electrode mechanism, water cooling equipment and gas management plant protection);
- the welding torch is heavier - it must be coupled to gas and water cooling, to the flexible conductive cable of the welding wire and power cable;
- it may not pursue the protection of the welding because the gas around the arc area is not observable;
- sensitivity to atmospheric conditions in the work area, for example, movement of the protective gas from the welding area because of the wind.

Technological scheme of welding MIG/MAG is shown in Fig. 1. Welding is done using electric arc formed between the electrode (1), fusible or not-fusible and welding piece. Protection is assured by means of an inert or active gas jet found in laminar flow (2) sent by discharge nozzle (3). Arc

is formed between the welding piece and filler wire. Metal droplets (4) reach the weld (5), which solidified, forms the cord (6).

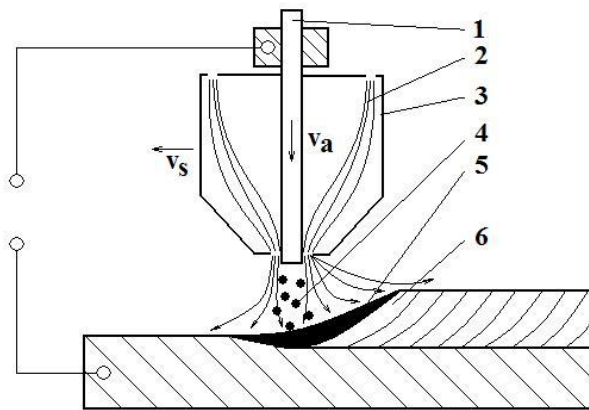


Fig. 1. MIG/MAG welding scheme, v_a - feed rate of filler wire, v_s - welding speed, 1 - wire electrode, 2 - protective gas, 3 - nozzle, 4 - drops of metal, 5 - metal bath, 6 - weld cord [3].

Primary technological parameters on MIG/MAG welding are:

- welding current intensity $50 \div 500$ A;
- $16 \div 35$ V arc voltage;
- Welding speed $30 \div 150$ cm/min;
- electrode wire diameter $0.6 \div 3.2$ mm;
- gas flow $10 \div 25$ L/min.

MIG/MAG procedure can provide material transfer with arc either the short-arc version (SHA) or spray arc (SPA). The first option is usually used in thin sheets with thicknesses of 0.5 to 6 mm. Variant spray arc is effective for the thick plates (greater than 5 mm). Short-arc welding is done in continuous current, both in direct polarity (DC-) and the reverse polarity (DC +). Spray-arc welding is performed only continuous current reverse polarity (DC +).

In the steel construction wide category, that can be applied the welding-brazing technologies, can enter various types of metallic materials used in various fields, such as profiles and sheets used in automotive and automotive equipments, in the electrical industry, for electrical panels and cabinets construction, in the materials for construction industry (for scaffolding, metal panels and the curtains), architecture and urbanism, in food, consumer goods, shipbuilding and other related fields. In this thesis I aim to achieve the elaboration of a technology that uses the steel components combination, protected by layers of zinc, so that, during the joint operation to eliminate the possibility of zinc coating evaporation from the intervention area and also the combination area study in terms of micro-structural and typical welding defects [3].

Technology would lead to maintaining the material's original quality and would enable the joint operation by the welding-brazing of steel structures; and would eliminate the factors that lead to the evaporation of surface structure zinc coating, as happens when welding these

materials. Comparing to classical solutions: like welding or brazing [4], the following advantages appear:

- contribution to maintaining the material original quality even after assembly;
- it eliminates the use of steel sheets parts with no zinc protection;
- a corrosion resistance is achieved, identical to the original material one after intervention by the welding-brazing assembly, including the joint area;
- simplifies the repair and maintenance technology of certain structures, while obtaining mechanical and corrosion resistant joints;
- can perform rapid assembly interventions or reshuffle interventions and remove metal exposure without cathode-type protection in the intervention areas.

In the last few years, technological development in high performance materials, determined the appearance of new materials and made the research activity in materials science leading to the test solutions and obtaining possibilities of new etching materials and for welding-brazing, but also new possibilities for testing and investigation of intervention areas [5-11].

By brazing it may be deposited a filler material with melting temperatures under 450°C , using the welding-brazing techniques the melting material temperature can be $870 \div 890^\circ\text{C}$, thus eliminating the possibility of zinc protective layer evaporation.

Using joining technology by welding-brazing has certain advantages over the classical solutions (steel welding electrode or joining with mechanical assembly elements), the most important for us is removing zinc unprotected portions of the assembled structure.

Thus, corrosion resistance will be identical in the intervention area with the rest of the assembled components. Joints will be done in terms of quality and safety, technology contributing to limiting the impact on the environment and extending the average use of structures [12].

2. Technical considerations

It is obvious that one of the development perspectives of MIG welding-soldering materialize in more industrial applications that require the use machines and specialized programs leading to welds in three-dimensional space. In this case we can talk about the integration of MIG robotic cells, in which case it is sufficient to make the speed programming in advance of the welding-brazing head in accordance with different geometric configurations of the base material and weld cord geometry to be deposited [13].

In the conception and equipment construction for MIG welding-brazing it is necessary the use of microprocessor driven equipment that gives to the system a greater flexibility and precision in its functionality. Regarding the system development, it may be proposed a future approach; it must be known and developed the system to accelerate the implementation in the active industrial areas, with large volumes of welded-brazed galvanized steel. A fast development in this case could be

achieved by applying the following industrial strategy measures [14-16]:

- those directly involved in welding-brazing activities of galvanized steel sheet, must be convinced that the process is viable and can be developed on an industrial scale;
- to increase efficiency of operations and to prevent damage and stationing, is better to ensure spare parts stocks and flow production sufficient materials, in this case can be achieved cost production up to 35% lower for medium and high range products.

We can say that MIG welding-brazing is a controlled welding-brazing process and controlled by the "advanced speed" parameter of the welding-brazing material. In the workflow process the system can achieve the arc high stability even at automatic power, where if no spring instability occurs then no damage will be produced in the cord.

Analyzing various MIG technology aspects, its characteristic advantages compared with other work processes, are presented in table 1.

Table 1. The advantages of welding-brazing technology in pulsating MIG system

Advantages	Summary Comment	Application area
Produces the input heat on a smaller area.	MIG technologies produce lower heat input compared to welding brazing manual technology with coated electrodes or flow welding-brazing.	Mass production and technological systems with limited interchangeability.
Allows also the thin sections welding-brazing.	The pulsating MIG welding-brazing system reduces the average current similarly by short circuit transfer.	For steels with variable zinc coatings thickness.
There is a limitation of deformations caused by stresses such as heat (contractions and dilations variables).	This will limit the thermal influence area (the appearance of dangerous internal voltages).	Applicable to various types of steel on which were made zinc coatings.
In some cases it may be more economical.	It is according with the application type.	Medium and large industrial applications series

The MIG welding-brazing process has the following main limitations [17-23]:

- MIG process is characterized by low heat input, when welding-soldering thicker sections there is a danger of damage the joints and the zinc layer destruction. The better stability in case of pulsating current welding-soldering, can reduce the probability of damage compared to other techniques applied, by the average current control, the welding speed, the operating equipment and protective gas used;
- Manual MIG welding-brazing with coated electrodes, and flow welding-brazing are very flexible processes by means of achieved cord properties control, by maintaining zinc protection and use a wide range of materials. The filled wire category available for MIG welding-brazing is much smaller. However, lately was tested the use of coated tubular wire;
- There is a technological limitation due to the equipment complexity and that is because MIG welding-brazing is more complex than manual flame welding-brazing. In this case it is important to ensure an appropriate program on wire devices maintenance and preparation of galvanized steel sheet heads to be assembled.

3. Experimental data

In the bonding process, metals are joined by a filler material with low melting point (below 450°C), also below the melting point of materials to be joined. The welding-brazing filler material has a melting point over 450°C to 1000°C. Required heat input process is usually obtained through a chemical reaction, often by oxy-acetylene flame (oxy-fuel).

Filler material is distributed between the two surfaces of the joint by capillary action closing, the blended material is applied on an electrode specially manufactured and designed for the operation.

The secret of brazing and welding by brazing is that the welding opening has to be small. As long the amount of filler is less, the welding is stronger.

There are several technological processes to achieve welding-soldering like:

- oxy-fuel brazing burner and electrode;
- dip brazing;
- soldering in an inert atmosphere or vacuum oven.

Soldering and brazing have been widely used for centuries, but the difference between soldering, brazing and braze welding is less known. The alloys used for the soldering welding-duplex steels, steels respectively obtained by electroplating zinc layers are alloys of copper-zinc system.

Fig. 2 shows the state diagram of the system Cu-Zn, the main phases changes and technological areas of interest for brazing operations and welding-brazing [20].

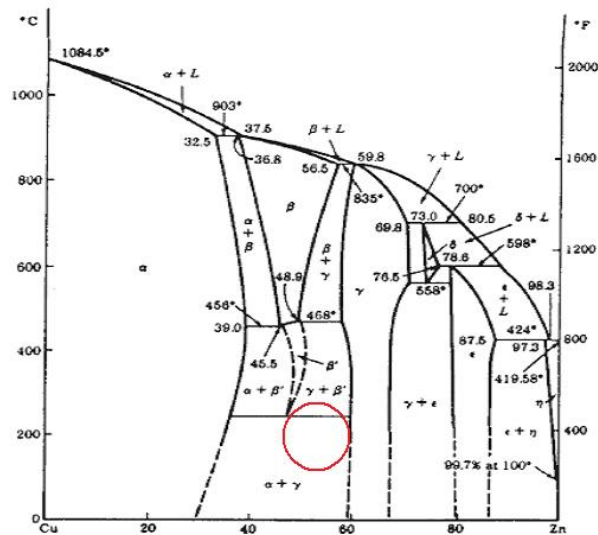


Fig. 2. The binary alloy systems Cu-Zn diagram.
The presentation area of interest for welding-brazing
technology [20]

For industrial applications involving bonding steel, Cu-Zn alloys with 40% Zn content present interest (Fig. 2). In solid state and with content up to 39% Zn, Cu-Zn alloys are composed of single phase, α brass.

When zinc content is higher, β and γ intermediate crystal are produced, giving also single-phase alloys called ξ , which have large enough areas of concentration. δ and ϵ crystalline phases that are occurring in higher zinc content and do not have practical importance because by exceeding their appropriate concentrations, the steel brazed joints made with the use of such alloys become brittle.

Main brands of brass for brazing, according to Romanian (STAS 204-77), from copper-zinc system, used for steel are presented in Table 2.

Table 2. Brasses for brazing

Alloy brand	Chemical composition, (%)							
	Cu	Si	Sn	Zn	Impurities max.			
					Pb	Fe	Sb	Sn
BCu58Zn	58-62	0,2-0,3	-	rest	0,5	0,5	0,3	0,3
BCu59Zn	59-61	0,2-0,3	0,8-1,2	rest	0,5	0,5	0,3	-

In bonding the steel with copper-zinc alloy process should be considered that zinc boils at 912°C, but the vapour pressure is elevated even in this temperature, so we will see the zinc evaporation from 650°C [19]. The boiling point of zinc, for Cu-Zn system alloys increases with decreasing zinc content, the difference between the melting temperature of brass solder and evaporation temperature of zinc is small.

In air Zinc vapour turns into zinc oxide, whose melting temperature is 1975°C. Avoiding the appearance of pores in brazing cord is done by reducing zinc vaporization. This is possible by avoiding excessive

heating of copper-zinc alloy and solders shortening. It is indicated that welding-brazing the steel with copper-zinc alloy to run slightly in oxidizing environment to allow the first quantity of zinc, which evaporates, to oxidize and form a solid zinc oxide film on the molten alloy bath, which make it difficult to further evaporation of zinc.

Chemical composition of copper-zinc alloy grades used for bonding steels are presented in Tables 3÷10.

To minimize zinc evaporation losses, in obtaining the electrodes materials for brazing copper-zinc alloy, changes in chemical composition are required by adding alloying elements.

Table 3. Copper-zinc alloys used for soldering steel (according to American National Standard Institute - ANSI, USA).

Symbols ANSI/AWS/A5.8	Chemical composition, (%)						
	Cu	Zn	Sn	Fe	Mn	Ni	Other elements
BCuZn-A	57,0-61,0	rest	0,25-1,0	-	-	-	0,50
BCuZn-C	56,0-60,0	rest	0,8-1,10	0,25-1,20	0,25-1,20	-	0,50
BCuZn-D	46,0-50,0	rest	-	-	-	9,0-11,0	0,50

Table 4. Copper-zinc alloys used in steel bonding according to GOST 16130-72.

Alloy brand	Chemical composition, (%)									
	Cu	Si	Sn	B	Impurities max.					
					Zn	Pb	Fe	Sb	Bi	P
AK60	60,05-63,50	0,10-0,30	0,30-0,70	0,03-0,10	rest	0,08	0,15	–	–	–
AK59	58,00-60,00	0,20-0,40	0,70-1,10	–	rest	0,10	0,15	0,01	0,003	0,01
AK62	60,50-63,50	0,30-0,70	–	–	rest	0,08	0,15	1,00	0,002	0,01

From common alloying elements, silicon is the most important. In small amounts, from 0.1 to 0.5%, it reduces the tendency of formation of pores by preventing the oxidation of zinc and decrease hydrogen solubility. This effect of silicon is explained by the formation of an

impervious layer of zinc silicate on brazing cord surface, preventing excessive evaporation.

The second main alloy element is tin. Tin lowers the melting temperature and improves the solder to flow.

Table 5. Copper-zinc alloys used for bonding steel according to DIN 8513

Alloy brand	Chemical composition, (%)						
	Cu	Zn	Sn	Fe	Mn	Ni	Other elements
CU 303/ L-CuZn40	59,00-62,00	rest	0,00-0,50	0,00-0,20	0,00-0,30	–	0,10-0,40
CU 304/ L-CuZn39Sn	56,00-62,00	rest	0,50-1,50	0,00-0,50	0,20-1,00	0,00-1,50	max.0,1
CU 305/ LCuNi10Zn42	46,00-50,00	rest	–	–	–	8,00-11,00	max.0,5
CU 106/ S-CuAg (DIN 1733)	56,00-62,00	rest	0,00-1,00	–	0,20-1,00	0,00-1,50	max.0,1

According to European Standard EN 1045 the flows for welding-soldering steel are from FH Class, being of several types. The flows for brazing are nonmetallic materials, which in steel combination removes impurities and the oxides from the combined surfaces. Flows for bonding steels are intended to contribute to cleaning the combined surfaces by dissolving superficial oxides, to change the surface tension and increase melt fluidity.

Table 6. Copper-zinc alloys used for soldering steel as NF A81362.

Alloy brand	Chemical composition, (%)		
	Cu	Zn	Other elements
60 C1	60	39,7	Si

The composition of an implant for welding-brazing gas flame and Brenner burner of galvanized steel products consists in:

- generator to produce acetylene or acetylene cylinder fitted with pressure reducer;
- chemical scrubber or filter;

- Oxygen cylinder with pressure reducer;
- two gas hoses (red - C₂H₂, blue - O₂);
- welding torch (or welding kit);
- various accessories (wire brushes, hammers, etc.).

Acetylene generators are divided according to different criteria, the basic criteria is to generate acetylene pressure and contact system between carbide and water. Thus, there may be low pressure generators ($p < 0.3$ daN/cm²), medium pressure ($p = 0.3$ to 0.8 daN/cm²) and high pressure ($p = 0.8$ to 1.5 daN/cm²) and system-generators carbide in water, water over carbide and by intermittent contact (contact and discharge). The most used generator is GA 1250. The generator works by contact and discharge system, debit 1.25 Nm³/h at a pressure of 0.1 to 0.3 daN/cm². Acetylene produced passes by a scrubber or chemical filter separating the chemical contaminants (H₂S, H₃P) and any unrestrained mechanical impurities of water.

Required oxygen for oxidation is admitted out of the cylinder through a pressure reducer that reduces the oxygen pressure from 147 daN/cm² at working pressure of 2-5 daN/cm². The pressure reducing valve for acetylene cylinder is similar to that of oxygen only that instead of tightening screwed connection there is a yoke or bracket.

By the hose (red for fuel gas, blue for oxygen) the gases are reaching welding-brazing burner.

59			
LATON S-3	57	39,6	Ni, Si

Table 7. Copper-zinc alloys produced in Spain by Metales of Aportacion – MEDASA.

Alloy brand	Chemical composition, (%)		
	Cu	Zn	Other elements
LATON MS-60	60	39,7	Si
LATON MS-	59	40,0	Si, Sn, Mn

Welding-setting regime is to optimize the power choice of the brazing torch, filler metal selection, the form and structure of flame. Filler metal is chosen with values of diameter and composition depending on the thickness and chemical composition of base metal. Filler metal diameter is chosen based on empirical relationships: $d_{ma} = (0.5 \div 0.25)s$, in mm, $d_{ma} = (1.2 \div 1.5)s$ in mm.

Table 8. Copper-zinc alloys used for soldering steel according UNI-EN 1044.

Alloy brand	Chemical composition, (%)						
	Cu	Zn	Ag	Ni	Si	Mn	Sn
Cu60Zn	60	rest	–	–	–	Impurities	Impurities
Cu59ZnSn	59	rest	–	–	–	Impurities	–
Cu59ZnAg	59	rest	1	–	Impurities	Impurities	Impurities
Cu59ZnSnNi	59	rest	–	Impurities	–	Impurities	Impurities

Relative to the chemical composition, the electrode's filler metal must have the basic metal composition or enhanced by the addition of alloying elements, to

compensate their burning during welding process or to improve the final properties of the product welded-brazed.

Table 9. Correlation between copper-zinc alloys marks used for brazing (standard/mark alloy)

STAS 204/80 (România)	ANSI/AWS/A5.8 (SUA)	GOST 16.130-72 (Rusia)	DIN 8513 (Germania)	NF A81362 (Franța)	UNI-EN 1044 (Italia)
BCu58Zn900	BCuZn-A	AK62-0,5	L-CuZn40	LATON MS-60	Cu59ZnSn
BCu59Zn900	–	AK59-1-0,3	L-CuZn39Sn	LATON MS-59	Cu60Zn
–	BCuZn-D	–	CuNi10Zn42	–	Cu48ZnNi10

Table 10. The main characteristics of copper-zinc alloys

Alloy brand	Tensile strength (N/mm ²)	Melting range (°C)	Area of application
Cu60Zn	400	890-910	Bonding of steel by processes as: - Flame - Induction - Resistance
Cu59ZnSn	450	870-890	
Cu59ZnAg	400	870-890	

Copper-zinc alloys with contents of up to 60% copper can therefore be used with good results in bonding steel. Copper-zinc solders have a good capacity for brazing (with reference to the wetting properties, tensile and capillary) and provide high features glued joints. They can be used to make solid steel components by any process of soldering (brazing flame, induction brazing, soldering furnace braze strength, etc.).

4. Results and discussions

The surfaces of the metal must be cleaned so that the capillary action to take place. When necessary, it is preferred to chemically clean the surface by dipping it in acid. Remove the acid by washing the surface with warm

water. For mechanical cleaning, you can use steel wool, a file, or abrasive paper.

One way to follow the influence of the weld line over de forming characteristics is to investigate what is happening in the weld line area from the metallographic and chemical point of view. Energy dispersive X-ray spectroscopy (EDX) is an analytical technique used for the elemental analysis or chemical characterization of a sample having based on the software facilities different analysis modes like Line, Point or Mapping.

The steel sheet named FeP05MB has the thickness of 0.75mm and the other steel sheet named SPE220BH has the thickness of 0.7mm. In figure 3 microscopy analyze of the welded area are presented characterizing by micrometer measurements the weld line evolution. From Fig. 3a can be observe different thicknesses between 50

and 500 μm of the metallic cordon and a near modify area exemplify in detail in figure 3b. The thermal affected area is evidenced in figure 3b and structural modifications are observed on a extended area.

In Fig. 3c a light intensity distributions on the welded area is presented on a 2.2 mm line passing to weld cordon as well and were can be observe a decrease of intensity

similar to a hole fact that represent a surface modification in the welded area as roughness property.

In Fig. 4a chemical elements distribution is presented on a 1.2 mm line that includes both metallic materials and the welded area. The main results are given by the iron decrease in the connected area and in the same time the carbon increase.

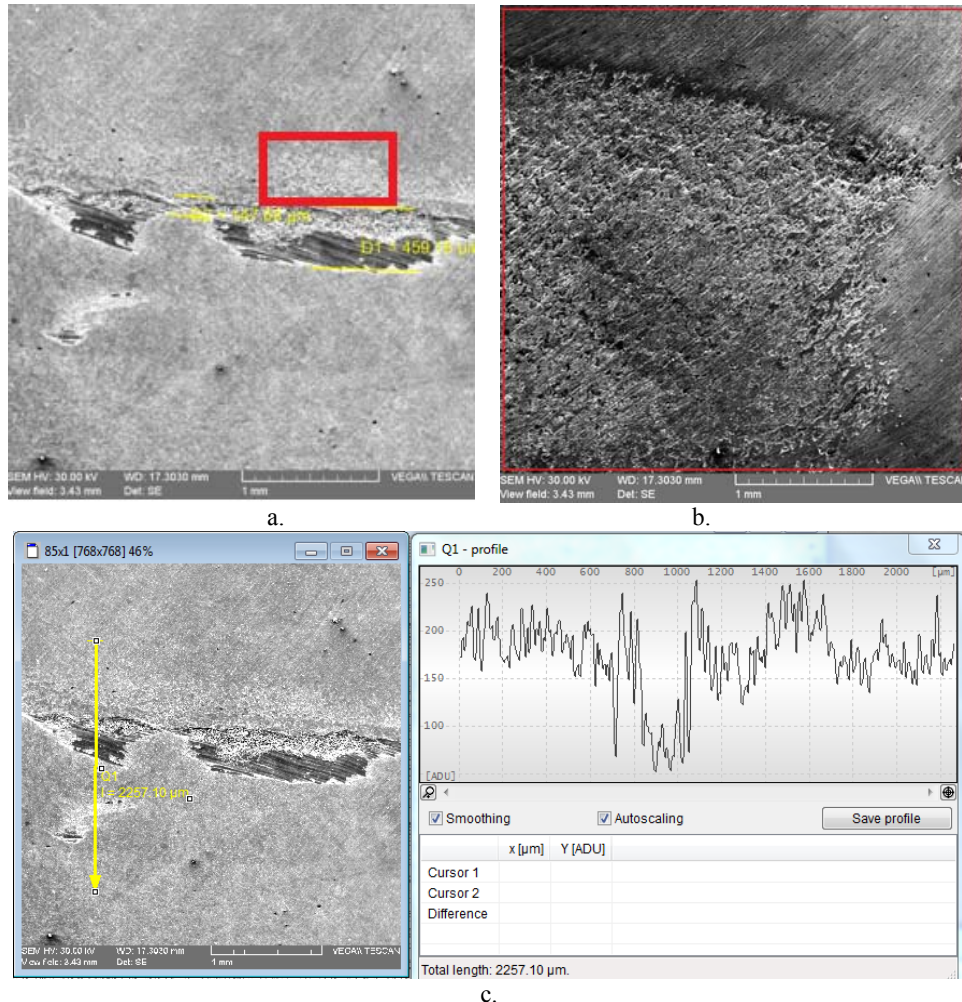


Fig. 3. SEM microscopy of the welded area: a) microscopy at 250x with welding cordon and a near area presented in b) and c) surface morphology on the welded area

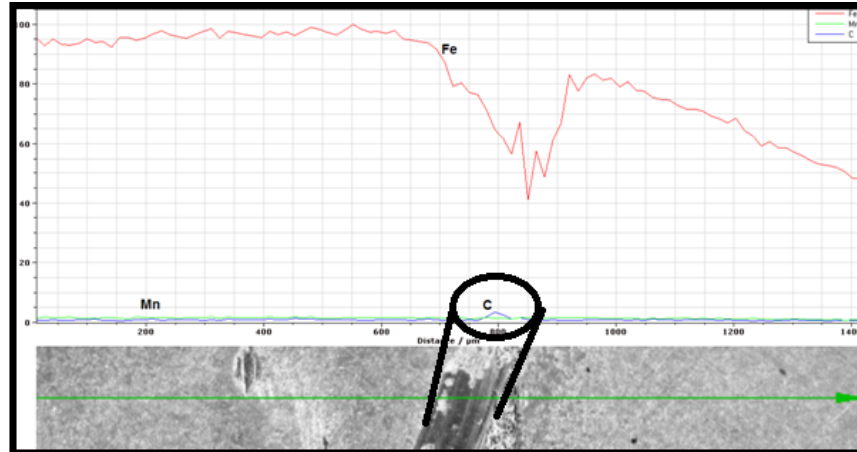


Fig. 4. Chemical elements distributions on a 1.2 mm line

Same chemical elements variation is observed on the mapping mode distribution presented in figure 5 where carbon agglomeration on the welded cordon can be seen.

The distribution analysis was made on a 2.56 mm² area following the iron, manganese and carbon elements evolution. Iron content variation is based on the difference percentages from the materials connected contents. The sheets contact area is characterized by carbon agglomerations observed from figure 4 and 5 as contaminated area of the braze process but with much reduced quantitative amounts and basically on the materials surface. In Fig. 5 chemical elements distribution on a selected area is presented.

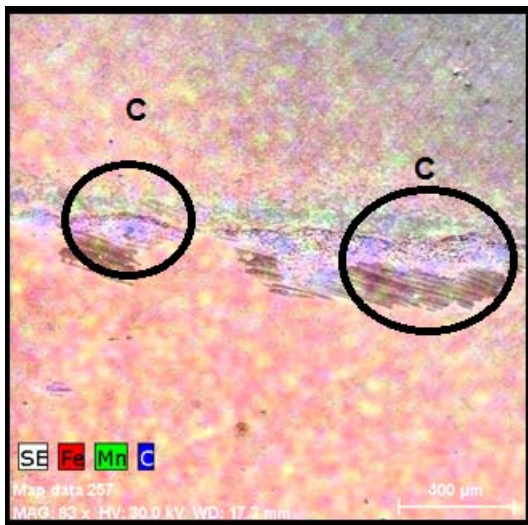


Fig. 5. Chemical elements distribution on a selected area by mapping of iron (Fe), manganese (Mn) and carbon (C) with selected areas of C agglomeration

The manganese element is fine distributed in both materials with a higher presence at the upper part of the cordon based on the higher percentage of manganese of the top material.

5. Conclusions

Welding-brazing has many advantages comparing to the classical solutions like welding or brazing: contributes to quality of original material also after assembly it eliminates the use of pressed steel parts without zinc protection; it is achieved corrosion resistance identical to the original material after intervention by welding-brazing assembly, including the joint area; simplifies the repair and maintenance technologies of certain structures, while obtaining mechanical and corrosion resistant joints; can perform rapid assembly interventions or reshuffle interventions and avoids metal exposure without assuring cathode type protection in the intervention areas.

MIG welding-brazing process has several main limitations: the low heat input, for thicker sections could cause the joints damage and destruction of the zinc layer, the manual MIG welding-brazing with wrapped electrodes and welding-soldering in the flow are very flexible processes by achieved cord properties control by maintaining zinc protection and use of a wide range of materials. There is a limitation due to the complexity of technological equipment and that is because MIG welding-brazing is more complex than manual flame welding-brazing. By brazing it can be deposited a filler material with melting temperatures under 450 ° C, by welding-brazing techniques, melting temperature for the filler material can be 870 ÷ 890 ° C, thus eliminating the possibility of zinc coating evaporation. Using welding-brazing technology has certain advantages over classical solutions (steel welding electrode or combination with mechanical assembly elements), the most important for us is removing zinc unprotected portions from the assembled structure.

Thus, corrosion resistance will be identical in the intervention area with the rest of the assembled components. Joints will be done in terms of quality and safety, technology contributing to limiting the impact on the environment and extending the average time-use of structures.

It should be noted that MIG welding-brazing process only leads to good results for galvanized steel profiles up to 1.6 mm thickness. Over these dimensions, obtaining

quality joints is very difficult, requiring switching to oxy-fuel process. The wide range of galvanized steel construction which may apply welding-brazing technology, among several types of metallic materials, such as profiles and sheets used in automotive and automotive equipment in the electrical industry, construction panels and cabinets, electrical construction materials industry are used for: scaffolding, panels and metal curtain, in architecture and urbanism, in food, consumer goods, shipbuilding and other related fields.

Copper-zinc alloys with contents of up to 60% copper can therefore be used with good results in bonding steel. Copper-zinc solders have a good capacity for brazing (with reference to the wetting properties, tensile and capillary) and provide high features glued joints. They can be used to make solid steel components by any process of soldering (brazing flame, induction brazing, soldering furnace braze strength, etc.).

Microstructural characterization of the laser welded area give a dimensional variation of the weld cordon between 50 and 500 μm and evidence a roughness modification in the connection area. Chemical investigations mark a loss of iron percentage on the weld line in the same time with a gain of carbon that seems to agglomerate on the entire welded cordon.

The forming characteristics are significantly reduced in the stretching area of the forming limit diagram, corresponding to axial strain. This means that welded assemblies will extend less before failure when an axial force (along the weld line) is applied.

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