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Influence of the shielding gas on the properties of VP MIG/MAG braze-welded joints in zinc coated steel sheets

Abstract: The article presents the results of research on overlay brazing and weld-brazing of hot-dip galvanized sheets carried out in order to determine the influence of shielding gas composition and electrode-negative (EN) ratio on the process and properties of overlay brazes and weldbrazed joints. The parameters analysed included joint geometry, wettability, zinc coating oxidation, spatter and porosity.

Keywords: MIG/MAG welding, shielding gas, zinc-coated steel sheets;

Introduction

In many industries, thin coated and uncoated sheets with a thickness between 0.7 mm and 3.0 mm are becoming increasingly popular. This trend creates a significant demand for high quality joints made of, for instance, thin galvanised steel sheets. This in turn entails the use of efficient welding methods ensuring proper joint quality without compromising the primary anticorrosive properties of the base metal [1, 2].

The use of conventional, e.g. MIG/MAG arc welding methods is connected with excessive heat input to the joint leading to deformations of welded elements and, in the case of zinc-coated sheets, to the evaporation and oxidation of zinc. This results in the loss of anticorrosive properties of the base metal as well as in the development of joint imperfections and defects such as gas pores and the lack of or incomplete fusion. Brazing enables the reduction of heat input, yet it fails to provide the adequately high efficiency of the process. Sheet deformations and damage to anticorrosive coatings are also encountered in MIG/MAG standard arc braze welding, commonly used by such automotive concerns as Volkswagen, Audi and BMW [2-4].

Braze welding methods which ensure high quality and aesthetic joints are low-energy methods such as CMT, ColdArc etc. These methods enable limiting heat input and obtaining high welding process stability. As a result, deformations and damage to protective coatings are smaller and, through spatter reduction, the aesthetics of joints is greater. The latest solution is the use of variable polarity pulsed current in MIG welding [5-7].

The efficiency and heat transfer during braze welding also depend on shielding gas thermal conductivity (Fig. 1), the value of which is related to the percentage fraction of individual gases in the shielding gas mixture. Apart from preventing atmospheric gases from entering the weld pool, the shielding gas affects material

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wettability, fusion as well as the geometry and the surface of welds [8].

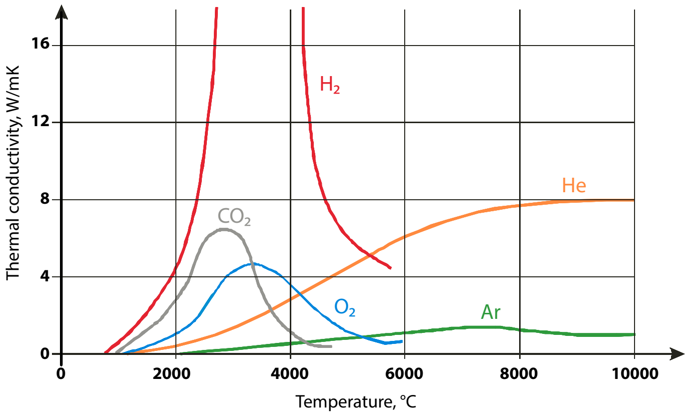


Fig. 1. Thermal conductivity coefficient of selected gases [8]

MIG/MAG arc braze welding

Arc braze welding is a joining process defined as the process of brazing with the use of welding methods [9]. The process utilises filler metals having the melting point lower than that of the base metal. The physic-chemical conditions accompanying the formation of joints are similar to those of brazing, and the preparation of the edges of materials to be joined, the design of a joint, the production technique and devices used in the process are similar to those of arc welding [10]. The process of braze welding is presented schematically in Figure 2.

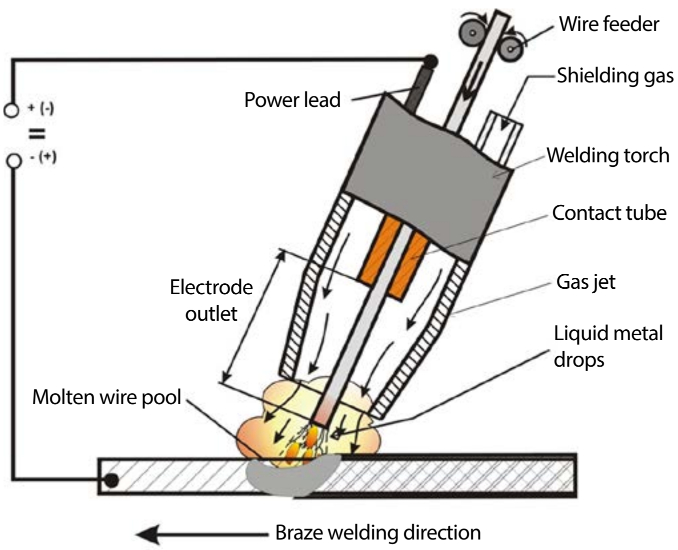


Fig. 2. MIG/MAG braze welding [4]

MIG/MAG braze welding is an alternative to arc welding of thin unalloyed steel sheets and thin sheets provided with various protective coatings. If compared with welding, the characteristic features of braze welding are the following [3, 11-13]:

- low heat input, particularly important while joining thin sheets (significantly fewer deformations),
- maintaining the anticorrosive coating of the base metal during braze welding of steel sheets having protective coatings,
- stable arc burning and the minimum number of spatters,
- possibility of preventing the edges of elements being joined from melting,
- high process efficiency and adequate strength of joints,
- aesthetic appearance of weldbrazes and their easy mechanical working,
- possibility of joining dissimilar materials and hard-to-weld materials,
- significantly lower emissions of welding fumes than those accompanying welding, particularly while joining zinc-coated sheets.

Braze welding processes increasingly often incorporate so-called "low-energy MIG/MAG processes", in which heat input is limited using the advanced control of arc voltage and welding current parameters. Such a precise approach to controlling current-voltage parameters enables obtaining very good quality during braze welding of galvanised and hot dip zinc coated elements as well as making it possible to join aluminium with steel [15-17].

In low-energy braze welding methods utilising variable polarity pulsed current the waveforms of current and voltage are repeated cycles containing electrode positives and negatives [17]. The diagrams in Figure 3 present exemplary current and voltage waveforms used in variable polarity braze welding – AC Pulse.

In the period of the negative polarisation of the electrode (T en) the value of the basic current (I bn) is lower than the critical value (the value of current, at which the manner of metal transfer changes from dripping to spraying), which prevents the formation of a drop on the

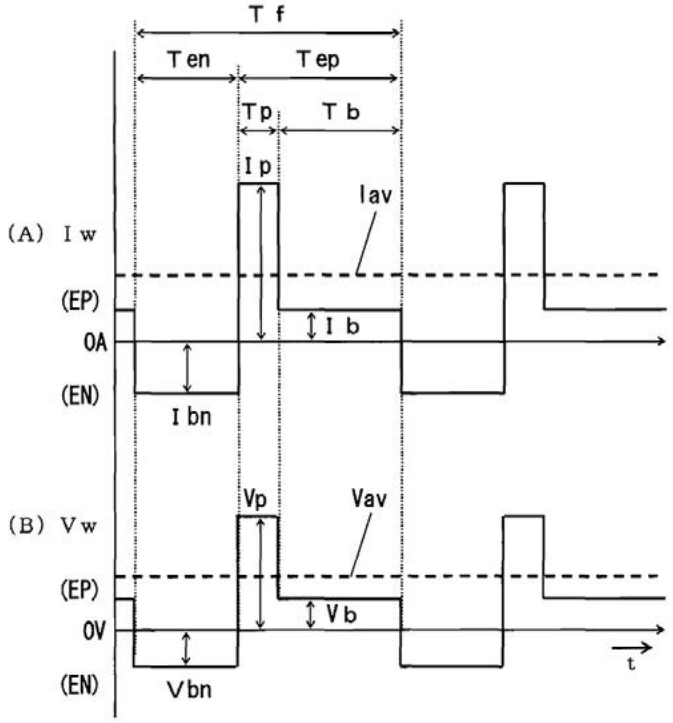


Fig. 3. Current waveform (A) and voltage waveform (B) during variable polarity welding – AC Pulse [18]

tip of the electrode wire. The critical value of current depends, among other things, on the type of shielding gas. The change of polarisation is very short and takes place in the time when high voltage of several hundred volts applied between the wire and the base metal prevents arc extinction. The period of the positive polarisation of the electrode (T ep) is divided into two stages. During the first stage (T p) the peak values of current, higher than the critical values, enable the formation and transfer of the drop, whereas during the second stage (T b) the basic values of current and voltage prevent the formation of the drop [18].

Solutions applied presently include, among others, AC Pulse, Cold Process and CMT Advanced [17]. These methods help reduce the spatter and deformations of heated elements as well as make it possible to improve the mechanical properties of elements and limit the emission of noxious gases formed during the process of joining. Using such methods in industrial practice allows increasing efficiency by reducing the number of operations carried out in order to remove spatters. The application of these methods in production is possible thanks to modern digital equipment enabling the precise adjustment and control of arc parameters [19].

In MIG/MAG braze welding the most popular shielding gas is argon or its mixtures with active gases having oxidising properties such as carbon dioxide or oxygen. In active mixtures the content of carbon dioxide is between 1% and 3%, whereas that of oxygen is between 1% and 2% [20]. Shielding the process of braze welding against the access of air by means of inert gas prevents unwanted chemical reactions with the electrode and the liquid filler metal in the pool.

The protective zone created by active gases is decisive for the transfer of the filler metal. The increased wettability of the material being joined along with the improved spreadability of the filler metal help obtain better aesthetics of the weldbraze face. These gases additionally increase the stability of arc burning, yet they are also responsible for reducing the plastic properties of a joint. Arc stability combined with lower current values in low-energy methods increases the quality and appearance of the weld run as well as deoxidises the zinc layer in the joining area [16, 21-24].

Test rig and materials

The investigation carried out at Instytut Spawalnictwa in Gliwice involved tests of braze welding zinc-coated sheets in order to determine the effect of a shielding gas and that of the VP EN ratio on the process and properties of overlay brazes and braze welded joints. Weldbrazes were subjected to visual testing. The investigation also involved the analysis of joint geometry, wettability, damage to a zinc coating, spatter and porosity.

The repeatability of conditions for making weldbrazes and overlay brazes was ensured by using a ROMAT 310 robot manufactured by Cloos (Fig. 4). The tests required the use of a DW-300+ welding device produced by DAIHEN (Fig. 4) and enabling braze welding with a low energy method known as MIG/MAG AC Pulse.

The EN ratio (EN_{Ratio}) in current and voltage waveforms is a non-dimensional setting defined by the producer between -30 (45%) and +30 (80%) [6].

Fig. 4. Test rig for braze welding (left), a DW-300+ welding device by DAIHEN (right)

The tests involved the use of 1.15 mm thick unalloyed steel sheets with 100 μm hot dip zinc coatings (grade DC04 ZE75/75 according to PN-EN 10152:2011) and a Bedra-produced CuSi3Mn filler metal wire with a diameter of 1.0 mm (according to PN-EN 13347:2004P). The tests were carried out using three types of shielding gas:

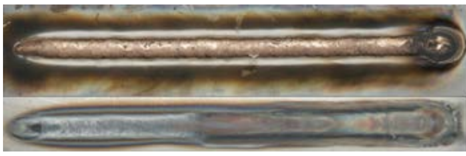
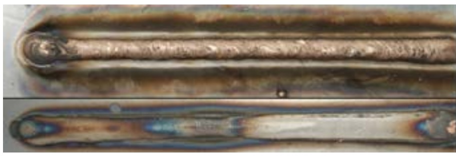
- argon,
- argon mixed with oxygen 99%Ar+1%O_2,
- argon mixed with carbon dioxide 82%Ar+18%CO_2.

Tests and results

The first stage involved joining two sheets on their edges (so-called tacking) by means of plasma welding. After making overlay brazes and weldbrazes test elements were cut in the plane perpendicular to the longitudinal axis of the joint. Test pieces sampled from the test elements, indented for macroscopic metallographic examination, underwent grinding and etching with the Adler's reagent in order to reveal their macrostructure.

Table 1 presents the faces and macrostructures of overlay brazes as well as the opposite side of the test pieces made with various values of the EN_{Ratio}. Based upon these test results it was possible to determine the effect of the EN ratio in current and voltage waveforms on the properties of overlay brazes.

Table 1. Overlay brazes made with argon used as the shielding gas and with various values of the EN ratio in current and voltage waveforms

View from the face and from the opposite side of the test piece	Overlay braze macrostructure (Adler's etchant)
EN_{Ratio} = -10	
	
EN_{Ratio} = 0	
	
EN_{Ratio} = 10	
	

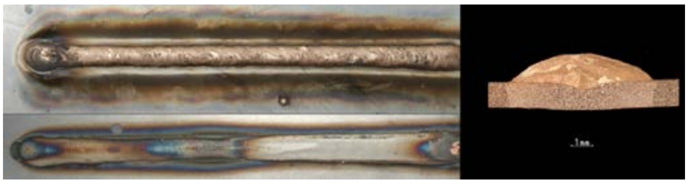
The technological tests revealed that an increase in the EN ratio (EN_{Ratio}) in current and voltage waveforms is accompanied by the following phenomena:

- fewer impurities along the overlay braze,
- narrower HAZ,
- smaller amount of white tarnish (oxidised zinc) on the opposite side of the test piece,
- lower penetration into the base metal.

Table 2 presents the faces and macrostructures of overlay brazes as well as the opposite side of the test pieces made with various shielding gas mixtures.

The overlay brazing tests revealed that the smallest amount of impurities and white tarnish on the opposite side of the test pieces were on the test pieces made with argon used as the shielding gas. Macroscopic examination revealed that the partial remelting of the base metal and the HAZ width were the smallest

Table 2. Overlay brazes made with various shielding gas mixtures

View from the face and from the opposite side of the test piece	Overlay braze macrostructure (Adler's etchant)
Shielding gas: argon	
	
Shielding gas: 99%Ar+1%O_2	
	
Shielding gas: 82%Ar+18%CO_2	
	

when argon was used as the shielding gas, and the greatest when the 82%Ar+18%CO_2 shielding gas mixture was applied. The average value of the shape coefficient of the overlay braze cross-section (the quotient of overlay braze height and width) (Fig. 5) was the lowest for argon and the greatest for the 82%Ar+18%CO_2 gas mixture. In turn, the average value of base metal surface wettability angle was the greatest for argon and the lowest for the 82%Ar+18%CO_2 gas mixture.

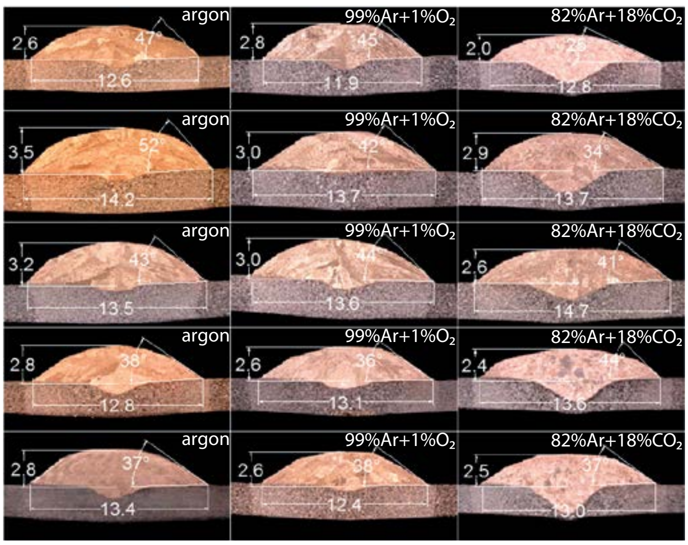
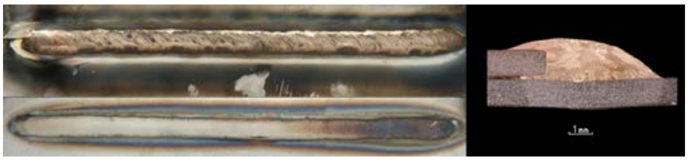
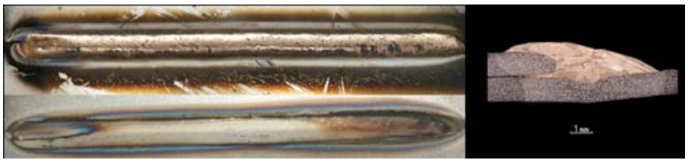
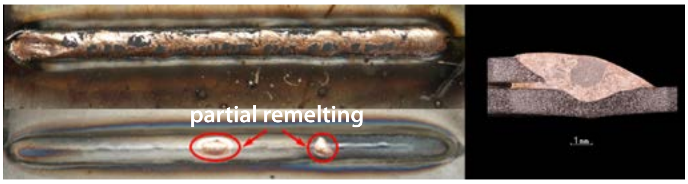


Fig. 5. Macrostructures of overlay brazes made with various shielding gas mixtures (Adler's etchant)

Afterwards, the effect of the type of a shielding gas on the properties of overlap joints was used. Table 3 presents the faces, roots and macrostructures of weldbrazes.

Table 3. Overlap joints made with various shielding gases

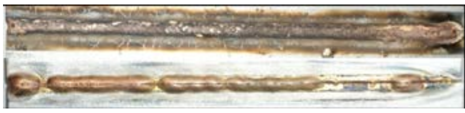
Face and root	Weldbraze macrostructure (Adler's etchant)
Shielding gas: argon	
	
Shielding gas: 99%Ar+1%O_2	
	
Shielding gas: 82%Ar+18%CO_2	
	

The tests revealed that argon-shielded braze welding leads to the formation of the smallest amount of impurities and the white tarnish on the opposite side of the test piece. The partial remelting of the base metal and the HAZ width were the smallest when argon was used as the shielding gas and the greatest when the 82%Ar+18%CO_2 gas mixture was used (partial remelting of the lower sheet took place).

Afterwards, the effect of the type of a shielding gas on the properties of butt joints was used. Table 4 presents the faces, roots and macrostructures of weldbrazes.

Braze welding of butt joints in the 82%Ar+18%CO_2 gas mixture appeared difficult and failed to ensure process repeatability. During braze welding with argon as the shielding gas a smaller amount of the filler metal flowed through the gap forming a greater face. The joints made with the 99%Ar+1%O_2 shielding gas mixture were characterised by a greater

Table 4. Butt joints made with various shielding gases

Face and root	Weldbraze macrostructure (Adler's etchant)
Shielding gas: argon	
	
Shielding gas: 99%Ar+1%O_2	
	

width of the HAZ. In both cases partial melting of the base metal was observed.

Summary

MIG/MAG arc braze welding can be successfully used for joining thin sheets with anticorrosive coatings. Small heat input enables joining elements with limited damage to the zinc layer and reduced deformations of elements joined. The limited amount of energy also decreases the effect of heat on the structure of base metals. For industry the important aspect of MIG/MAG braze welding and alternative low-energy methods is a significant increase in the joining rate, the elimination of cleaning and straightening of joints as well as the significant limitation of fume emissions, which improves occupational health and safety conditions. A very important is also the fact that MIG/MAG braze welding is carried out using the same equipment as MIG/MAG welding, which eliminates additional costs if a joining method is changed.

Concluding remarks

On the basis of the tests conducted it was possible to formulate the following conclusions:

1. The lowest heat input accompanies the use of argon, whereas the greatest the use of the 82%Ar+18%CO_2 mixture. This is demonstrated by the fact that the narrowest HAZ and the lowest oxidation of the zinc layer on the opposite side of the test piece were observed during argon-shielded overlay brazing.
2. Argon ensures the best aesthetics of overlay brazes and weldbrazes (the smallest amount of impurities and the smallest spatter).
3. The value of the shape coefficient of overlay brazes made with argon used as the shielding gas is the lowest. The highest value is connected with the use of the 82%Ar+18%CO_2 gas mixture.
4. The 82%Ar+18%CO_2 gas mixture provides the best wettability of the base metal surface.
5. Increasing the EN ratio in current and voltage waveforms reduces the value of the shape coefficient of the overlay braze cross-section and increases the angle of wettability of the base metal surface.

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