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# Braze Welding of Zinc-coated Steel Sheets Using Variable Polarity GMA Flux-cored Welding

**Abstract:** The article presents the course and results of research aimed to determine the effect of the type of shielding gas on the shape of brazeweld, tensile strength and structure of braze welded joints made using Variable Polarity GMA, flux-cored consumable electrode and one of 3 types of shielding gas, i.e. Ar and Ar + 1% $O_2$ and Ar + 18% $CO_2$ mixtures. The study involved macro and microscopic examinations and tensile strength tests performed on overlay brazes and braze welded joints. The study-related tests have revealed that the use of mixtures containing active gases, especially $CO_2$, increases the heat input of braze welding processes and provides greater wettability of sheets to be jointed. However, the use of the mixtures mentioned above also causes greater damage to sheet coatings in braze welding areas and in some cases can even lead to the partial melting of elements being joined, deteriorating the aesthetics of joints and reducing their tensile strength.

**Keywords:** braze welding, shielding gases, variable polarity GMA, zinc-coated steel

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## Introduction

Braze welding can be described as "non-capillary brazing performed by means of welding" [1]. In this process, welding is performed using filler metals of melting points significantly lower than the melting point of the base material. As a result, the mechanism of joint formation is identical to that taking place during brazing. As regards the heat source, braze welding processes utilise flame, arc and laser.

Arc braze welding is usually used for joining elements made of 0.2-3 mm thick unalloyed and alloy steel sheets or steels provided with zinc (coating thickness between 5 and 100 μm) and aluminium coatings. Arc braze welding can also be applied in joining materials of extremely different physico-chemical properties, e.g. steel sheets with copper elements, steel sheets with aluminium, steels with cast iron or for surfacing of elements made of steel characterised by limited weldability or non-weldable steels (due to the necessity of ensuring an appropriately low sliding friction coefficient) [2]. The most popular arc braze welding process is MIG

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braze welding (MIG-131), and in particular, its variants enabling limited heat input, i.e. CMT, ColdArc, etc. Recent years have seen a growing use of variable polarity current in welding and braze welding thin elements [3,4].

Publication [4] presents the results of tests concerning VP (Variable Polarity) MIG braze welding of zinc-coated sheets using a solid wire. These tests were performed in order to determine the effect of shielding gas and EN ratio on the process and geometry of braze welds and on damage to zinc coatings. Publication [5] presents the effect of shielding gases during VP MIG braze welding using solid wires on the microstructure of braze welded joints.

This article presents the effect of the type of shielding gas (Ar, Ar+1% $O_2$ and Ar+18% $CO_2$ mixtures) on the shape of braze welds, tensile strength and structure of joints made using VP GMA flux-cored braze welding.

## Test rig, Materials and Methodology

Technological tests of filler metal overlay brazing and braze welding (making overlap and butt joints) were performed on a robotic station equipped with a DW 300 welding machine (manufactured by Daihen) and a Romat 310 industrial robot (made by Cloos) ensuring the repeatable movement of a welding torch in accordance with an assumed programme. All the technological tests were performed by means of fixing tooling whose clamping system enabled the repeatable fixing of workpieces to be braze welded and prevented their deformation during the process (Fig.1).

Fig. 1. Tooling used in the technological tests of the braze welding process

The welding torch movements were ensured due to the pre-set sequence of robot arm movements, including the approach to the braze welding starting point, the process performed at a pre-set rate and the return to the starting point.

The base materials used in the tests were DC04+ZE75/75 galvanised steels (unalloyed, ferritic and dead steels) according to PN-EN 10152:2011 and Dogal 800DP according to SSAB (equivalent to HCT 780X according to PN-EN 10152:2011 – ferritic-martensitic dual phase steel) of 1.0 mm thickness. The nominal thickness of galvanised zinc coatings applied on both sides of these sheets amounted to 7.5 µm. Steel DC04 was used in the technological tests focused on the braze welding of overlap and butt joints, whereas 800DP steel was used for making butt joints intended for tensile tests. The filler metal used in the tests was a MECUFIL 903 AL flux-cored (1 mm in diameter; designated SG-CuSi3MnAl according to DIN 1733), manufactured by Drahtzug Stein.

All of the braze welding tests were conducted using the following shielding gases:

- argon (PN-EN ISO 14175 – I1 – Ar),
- argon mixed with oxygen (99% Ar + 1% $O_2$) (PN-EN ISO 14175 – M13 – ArO-1),
- argon mixed with carbon dioxide (82% Ar + 18% $CO_2$) (PN-EN ISO 14175 – M21 – ArC – 18).

The process technological tests involved the development of braze welding initial parameters, followed by technological tests connected with filler metal overlay brazing onto the surface of specimens made of galvanised sheets as well as making overlap and butt joints using all shielding gases and previously developed parameters.

The technological tests performed first were connected with the overlay brazing of the filler metal onto the surface of zinc-coated sheets (DC04+ZE75/75) (1.15 × 50 × 150 mm) using all the shielding gases tested. As the DW 300 device was provided with a programme for braze welding using CuAl and CuSi filler metals, the tests were performed using ready characteristics, i.e. for braze welding using a solid wire (the device was not equipped with a synergic line for braze welding using flux-cored wires). The preparation of test specimens was preceded by the development of initial parameters using argon as shielding gas. The primary criterion governing the adjustment of the most advantageous braze welding parameters was the appearance of the overlay braze, paying attention to its shape, geometry and aesthetics (wetting of the substrate – spreading of the filler metal, regularity of a bead along its entire length, degree of thermal changes and damage to the zinc coating on the overlay braze face side and from the bottom of the specimen). All these factors were assessed visually after each overlay brazing tests.

The initial tests revealed that the range of parameters ensuring the obtainment of the proper quality of overlay welds was very narrow, with the greatest role played by the torch travel rate and of the angle between torch and the specimen. The parameters developed during the tests and used afterwards, when overlay brazing the specimens and when making overlap and butt joints, were the following:

- distance between the contact tube and the material – 5 mm,
- shielding gas flow rate – 15 l/min,
- current $I$ = ~70 A, arc voltage – 19 V,
- braze welding rate ($V_1$) - 80 cm/min, (for butt joints – 55 cm/min)
- angle α between the welding torch and the specimen (Fig. 2) – 55° for argon and Ar+1% $O_2$, and 45° for Ar + 18% $CO_2$,
- EN ratio for current and voltage waveforms – 60 %.

Afterwards, the technological parameters presented above were used when making specimens with overlay brazes and overlay and butt joints using all the shielding gases tested. Next, the specimens were cut in the plane perpendicular to the longitudinal axis of the overlay braze and of the joint - in order to sample the specimens for macroscopic metallographic tests. In order to reveal their macrostructure, the specimens were subjected to grinding and etching with the Adler's reagent. The following stage involved microscopic metallographic tests of the specimens with overlay brazes and braze welded joints. The objective of these tests was to determine the effect of the type of shielding gas on the structure of overlay brazes, braze welds and of the material in the HAZ. The metallographic tests were performed using a Nicon Eclipse Ma200 light microscope with the system of digital image analysis. The observations of braze weld and HAZ areas were performed at magnification of between 50 and 500x.

The tests of mechanical properties included static tensile tests of braze welded butt joints made of DC04 and 800DP steels shielded by all the gases tested (Ar, Ar+1%$O_2$, Ar+18%$CO_2$). The testing machine used was Instron 4200. The test results obtained are presented below.

## Test Results

The technological tests of overlay brazing involved making only one bead (overlay braze) on each specimen made of galvanised sheet. This approach was used to protect the specimens from overheating due to excessive heat input. Figure 3 presents the face and the other side of the specimen as well as the macrostructure of the overlay welds made using all the shielding gases tested. The figure demonstrates the effect of the type of shielding gas and its oxidation index on the quality and geometry of the overlay brazes.

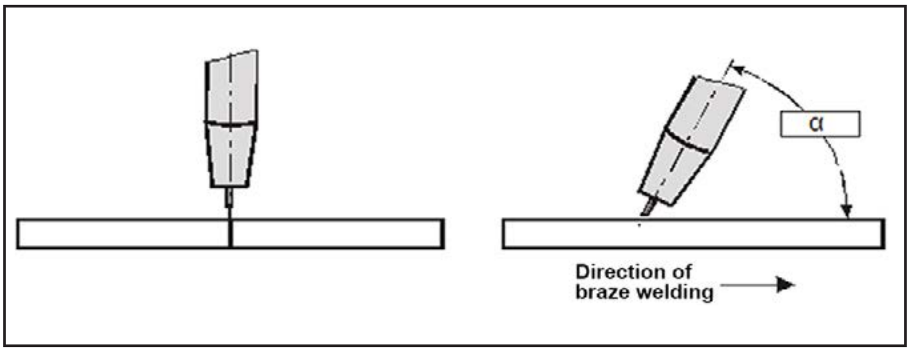

Fig. 2. Angle between the welding torch and the specimen

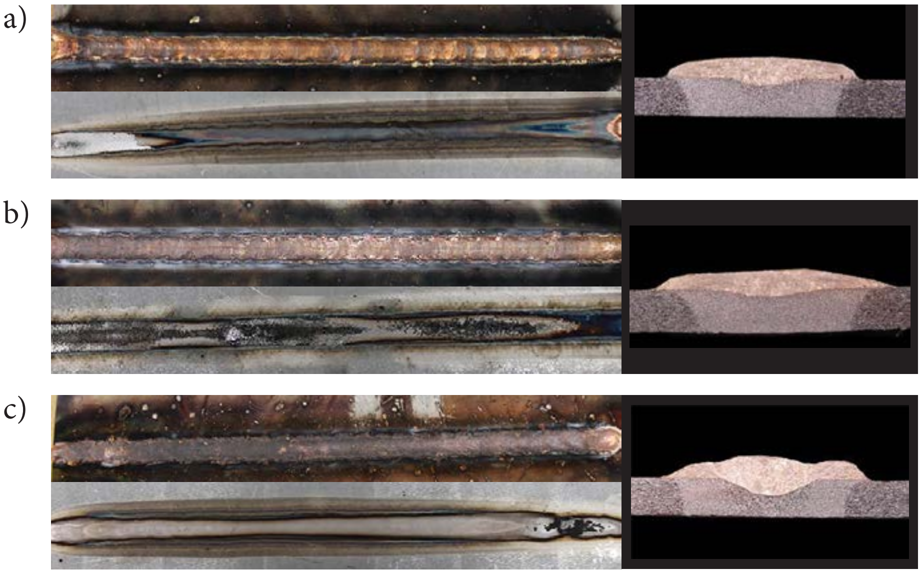

Fig. 3. Face (top), the other side of the specimen and the macrostructure of the overlay brazes made using the flux-cored wire and argon (a), Ar+1% $O_2$ mixture (b) and Ar+18% $CO_2$ mixture (c)

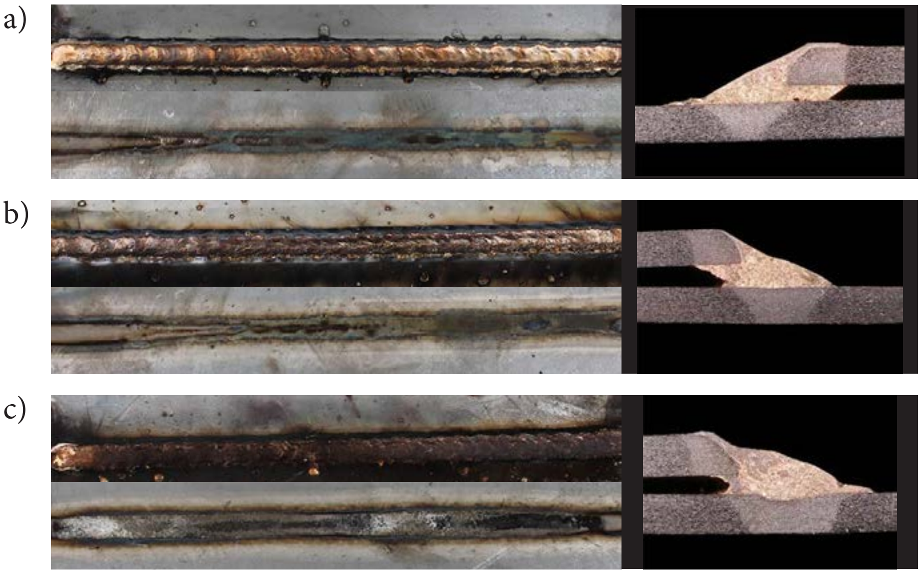

Fig. 4. Face (top), the other side of the specimen and the macrostructure of the overlap joints made using the flux-cored wire and argon (a), Ar+1% $O_2$ mixture (b) and Ar+18% $CO_2$ mixture (c)

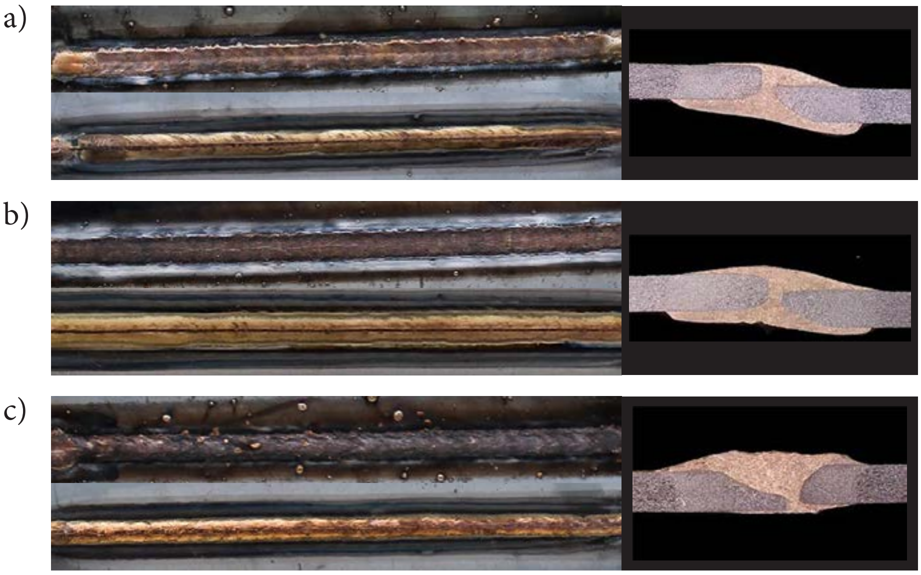

Fig. 5. Face (top), the other side of the specimen and the macrostructure of the butt joints made using the flux-cored wire and argon (a), Ar+1% $O_2$ mixture (b) and Ar+18% $CO_2$ mixture (c)

Figures 4 and 5 present the braze weld face and the specimen from the other side, as well as the macrostructure of related overlap and butt joints made using VP current and flux-cored wire. Figures 6-8 present the microstructure of the butt joints made using the shielding gases applied in the tests.

Table 1 presents the mechanical properties of the steel and of the flux-cored wire weld deposit used in the tests, whereas Table 2 presents the results of the tensile tests involving butt joints made of DC04 and 800DP steels. The results presented in Table 2 are the arithmetic average of three tensile strength tests. As regards DC04 steel, the rupture took place in the base material, in the case of 800DP steel – in the braze weld.

Table 1. Mechanical properties of steels and electrode wire weld deposit

| Grade of steel/ electrode wire | Re/Rp$_{02}$ [MPa] | Rm [MPa] |
|---|---|---|
| DC04 | 210 | 270-350 |
| 800DP | 500-640 | 800-950 |
| SG CuSiMnAl | 360 | 500-580 |

Table 2. Tensile test results for braze welded butt joints

| Steel grade | Shielding gas | Rm [MPa] |
|---|---|---|
| DC04<br>sheet ≠ 1.0 mm | Ar | 305.4 |
| | Ar + 1% $O_2$ | 307.5 |
| | Ar + 18% $CO_2$ | 302.9 |
| 800DP<br>sheet ≠ 1.0 mm | Ar | 546.7 |
| | Ar + 1% $O_2$ | 536.3 |
| | Ar + 18% $CO_2$ | 511.5 |

## Analysis of Test Results

The technological tests of VP GMA braze welding as well as the visual and macroscopic metallographic tests of braze welded joints have revealed that the use of filler metals in the form of flux-cored wires when braze welding enables the obtainment of good quality overlap joints (Fig. 3-5). As regards the choice of shielding gases, the best quality is ensured by argon, as the damage to the zinc layer is the smallest and the shape of a braze weld is the most convenient (weld face regularity and angle of wetting). The use of oxidising gases deteriorates the aesthetics of joints (excessive impurities, irregular shape of a weld face, significant amount of spatters) and increases heat input to the joint. The photographs presenting the face and the opposite side of the weld reveal that an increase in the amount of active gas is accompanied by a greater amount of copper oxide in the shielding gas mixture leading to the greater partial melting of elements joined and the greater width of the HAZ (visible on the macroscopic photographs of the joint cross-section). [4,5]. The use of variable polarity current enables making overlap joints with the distance between elements being joined of up to approximately 1.5 mm.

The technological tests and macroscopic metallographic examinations have revealed that only argon used as shielding gas guarantees the obtainment of butt joints characterised

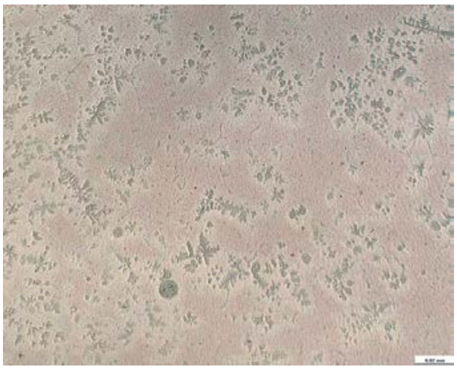

Fig. 6. Microstructure of the braze weld of the butt joint made using argon, near the boundary between the braze weld and the base material, etchant: $FeCl_3$, mag. 500x

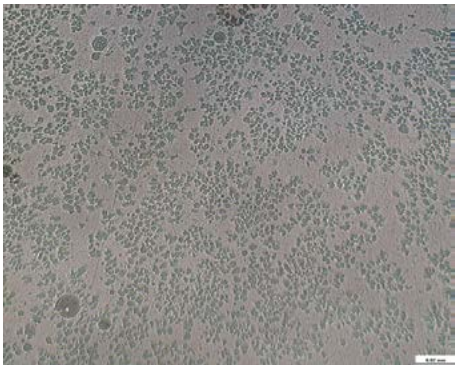

Fig. 7. Microstructure of the braze weld of the butt joint made using the Ar+1%$O_2$ mixture, near the boundary between the braze weld and the base material, etchant: $FeCl_3$, mag. 500x

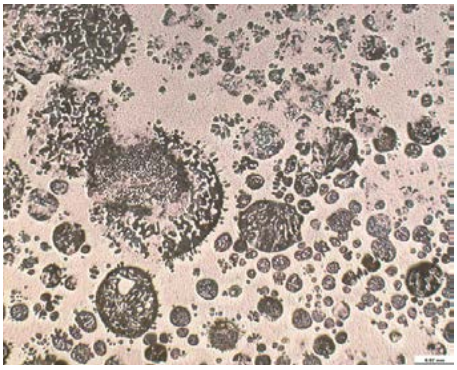

Fig. 8. Microstructure of the braze weld of the butt joint made using the Ar+1%$CO_2$ mixture, near the boundary between the braze weld and the base material, etchant: $FeCl_3$, mag. 500x

by good quality and aesthetics. Argon provides the smallest spatter, the highest purity of the joint surface, the smallest damages to the zinc layer and the smallest partial melting of joined elements [2,3]. Also, the Heat Affected Zone is in such cases significantly smaller than that obtained using oxidising mixtures. The worst quality resulted from the use of the argon and carbon dioxide mixture (Fig. 3-5), where the face of the braze weld was very irregular, the amount of spatters in the joint area was excessive and the amount of zinc oxide formed on the surface of elements being joined was the greatest.

The microscopic metallographic tests of VP GMA braze welded joints (Fig. 6-8) made using a flux-cored electrode wire revealed that the braze weld structure was composed of a copper matrix (solid solution of Si, Fe and Mn in copper) and fine precipitates of intermetallic phases. The structure was dominated by fine precipitates having complex shapes; there were fewer globular precipitates than in the braze welds made using the solid wire [5]. The phase precipitates in the form of dendrites were not present. The tests have revealed that the type of shielding gas affects the shape of the precipitates, their amount and degree of coagulation. When argon was used, precipitates were smaller and fewer than where gas mixtures were used (Fig. 6). The use of oxidising mixtures (Fig. 7, 8) increased the size of precipitates. In addition to the increased size of precipitates, the use of Ar+18%$CO_2$ caused their coagulation and the formation of greater clusters (Fig. 8). The greater amount of intermetallic phase precipitates accompanying the use of oxidising mixtures was probably due to the greater partial melting of the base material and the solution of its greater amount in the liquid brazing metal. Hence, the presence of numerous phases rich in iron, particularly in the braze weld boundary area [2]. The greater the amount and coagulation of such phases, the lower the tensile strength of the butt joints.

The tests revealed that the tensile strength of braze welded butt joints was very high. It should be noted that the specimens used in the mechanical tests were previously appropriately prepared, i.e. the excess weld metal on the face and root side was removed. The test results revealed (Table 2) that argon provides the highest tensile strength of braze welded joints, whereas the mixture of argon and carbon dioxide – the lowest. The strength of the joints was restricted within the range of the nominal strength of electrode wire weld deposit (500-580 MPa). As regards DC04 steel, the strength of the braze weld significantly exceeded the strength of the base material (Table 1), therefore the rupture took place in the material. It should be emphasized that braze welding enables the obtainment of butt joints of tensile strength comparable with the strength of welded joints made using the G3Si1 type electrode wire and meeting the requirements of the minimum strength for unalloyed structural steels, e.g. S355J2 steel according to PN-EN 10025-2:2007 (min. 470 MPa).

## Conclusions

1. The use of VP GMA braze welding using the CuSi3MnAl flux-cored wire and argon as shielding gas ensured the obtainment of joints characterised by very good quality and aesthetics.

2. In comparison with argon, the use of Ar+1% $O_2$ and Ar+18% $CO_2$ active mixtures improves wetting and enables the obtainment of braze welds of more advantageous shape coefficient when a solid wire is used. However, these mixtures deteriorate the quality (irregular face) and provide greater heat input to the joints, which leads to the partial melting of the base material and its mixing with the liquid brazing metal.

3. Braze welded butt joints made in accordance with the developed conditions presented above are characterised by very high tensile strength (above 500 MPa) resulting from the joint structure.

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