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Effect of Braze Welding Parameters on the Structure and Mechanical Properties of Joints Made of Steel CPW 800.

Part 1: Arc Braze Welding

Abstract: Presently, the reduction of kerb weight consists in the replacement of previously used structural materials with new ones, characterised by more favourable operating parameters. Advantageous mechanical properties of steel elements are primarily obtained through precise hot treatment performed after cold rolling or, in cases of hot-rolled products, through thermo-mechanical treatment. When subjected to welding, the above-named materials reveal high sensitivity to intense thermal cycles accompanying welding processes. The article presents the results of technological tests concerning the effect of arc weld brazing on the structural and mechanical properties of joints made of multiphase steel CPW 800.

Keywords: braze welding, multiphase steel CPW 800, properties of joints

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Introduction

Increasingly high strength-related requirements and the necessity of ensuring the appropriate durability of the structural and panelling elements of car bodies necessitate the use of advanced steels, often provided with protective coatings. The greatest achievement of today's metallurgy is the production of Advanced High Strength Steels (AHSS), including complex phase (CP) steels, dual phase (DP) steels as well as TRIP or TWIP effect-hardened steels [1]. Appropriately high mechanical properties combined with required plasticity and plastic workability are obtained primarily through grain refinement as well as by expert and precise control of phase transformations [2, 3]. However, such materials are sensitive to the exceeding and holding at high temperatures. As a result, intense thermal cycles accompanying welding processes can thwart the entire favourable effect of previous metallurgic procedures used during the production of the steels [4, 5].

The maintenance of appropriate resistance to atmospheric corrosion is relatively easy to obtain by using anodic coatings, i.e. made of metals more electronegative than iron, e.g. zinc.

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Unfortunately, the boiling point of zinc amounts to a mere 906°C. Although slight anodic coating depletions do not lead to corrosion, the surface area from which zinc evaporates during welding is large enough to constitute a corrosion centre [6, 7].

To avoid the above-presented phenomena during technological processes connected with the joining of car body elements, the previously used process of arc welding has been replaced by braze welding defined as non-capillary brazing utilising welding techniques. This means that the most significant difference between welding and braze welding comes down to the use of a given filler metal type. The braze welding of steel elements usually involves the use of bronzes (usually silicon or aluminium bronzes as regards the automotive industry) with process temperatures not exceeding 1050°C. The limitation of a heat input to a joint entails numerous advantages, e.g. the reduction of unfavourable structural changes in the base material or the limited width of zinc and/or convertive coating evaporation making it possible to maintain the resistance to atmospheric corrosion and to reduce deformations characteristic of arc welding [8].

This articles presents the results obtained during tests investigating the effect of arc braze welding process parameters on the mechanical properties and structural changes in joints made of steel CPW 800.

Base Material and Filler Metal

The effect of arc braze welding linear energy on the structure and properties of joints in steel CPW 800 involved the use of 2.5 mm thick sheets having dimensions of 150 × 350 mm and corresponding (in terms of size) to specimens used when testing welding technologies in accordance with the PN-EN ISO 15614 series of standards. The sheets used in the tests were cut out of bigger sheets (500 × 1000 mm) using laser cutting. The chemical composition of steel CPW 800 is presented in Table 1.

The filler metal used in the tests was a Mecufil 214 Al flux-cored wire having a diameter of 1.0 mm (Drahtzug Stein). The chemical composition of the wire included copper with a 10% addition of aluminium as an alloying constituent. The properties of the weld deposit provided by the manufacturer were the following: $R_m = 560 \div 650$ MPa, $R_p > 320$ MPa and elongation $A_5 > 40\%$. According to the data provided by the manufacturer, the above-presented filler metal is indented for the braze welding of regular quality galvanised unalloyed steels and steel DP 600.

In accordance with the guidelines specified by the manufacturer, the shielding gas used in the process of MAG arc braze welding was the Iso 14175-M11-ArC-2.5 mixture.

Making of Test Joints

The identification of the effect of MAG arc braze welding process parameters on the structure and mechanical properties of the joints required the making of test joints using various sets of parameters (Table 2). The selection of parameters was conditioned by the obtainment of joints characterised by the proper brazeweld geometry along the entire length of the joint, the lack of spatters and the lack or the minimum partial melting of the base material. The arc braze welding tests were performed using a rig provided with a table equipped with a system

Table 1. Chemical composition of steel CPW800, % by weight

C	Mn	Si	Cr	S	P	Nb	Ti	N	Al	Mo	Ce
0.08	1.72	0.56	0.34	0.003	0.010	0.005	0.125	0.002	0.29	0.016	0.46

Note: Carbon equivalent (Ce) calculation formula: $C_e = C + \frac{Mn}{6} + \frac{Si}{24} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4}[\%]$

Table 2. Parameters of the MAG arc braze welding of 2.5 mm thick sheets in steel CPW 800

Specimen no.	1	2	3	4	5	6	7	8	9
Welding rate, cm/min	50	50	50	70	70	70	80	80	80
Welding current, A	80	100	120	80	100	120	80	100	120
Arc voltage, V	22	22	22	22	22	22	22	22	22
Linear energy, kJ/mm	0.17	0.21	0.25	0.12	0.15	0.18	0.10	0.13	0.16

enabling the fixing of elements being joined, an electric-powered car ensuring the constant welding torch travel rate and a DW 300 semiautomatic welding machine (OTC Daihen). The test also involved the use of was a Mecufil 214 Al filler metal (Drahtzug Stein).

Test Results

Visual and Macroscopic Tests

The MAG arc braze welded joints were subjected to visual tests performed in accordance with PN-EN ISO 17637:2011E *Non-Destructive Testing of Welds. Visual Testing of Fusion-Welded Joints and to macroscopic metallographic tests*. The performance of visual and metallographic tests aimed to verify the correctness of brazeweld geometry, select joints for further tests and eliminated joints failing to meet the requirements of quality level B according to PN-EN ISO 5817:2009 *Welding. Fusion-Welded Joints in Steel, Nickel, Titanium and Their Alloys (Beam Welding Excluded). Quality Levels for Imperfections in Arc Welded Joints*. It should be mentioned that until today there has been no standard related to the quality assessment of braze welded joints. For this reason, when assessing the quality of braze welded joints it was necessary to use the requirements specified in standards concerning the quality of fusion welded joints. In industrial practice, the quality of braze welded joints is assessed based on special company-developed standards considering the specific character of a given structure, requirements for this structure as well as methods of measurements of characteristic quantities related to specific welding imperfections. The assessment manners related to the

Table 3. Faces of MAG arc braze welded joints made of 2.5 mm thick steel CPW 800 using various process parameters

Specimen no.	Brazeweld face
1	
2	
3	
4	
5	
6	
7	
8	
9	

quality of braze welded joints may vary depending on a product and a braze welding method.

When assessing the quality of MAG braze welded joints made of 2.5 mm thick steel CPW 800, the primary criterion was the aesthetics of the joint (weld face regularity along the entire length of the joint and little spatter). The above-presented conditions were satisfied by the joint made using a welding current of 80 A, an arc welding of 22 V and a braze welding linear energy of 50 and 70 cm/min – specimens nos. 1 and 4 respectively (Table 3 and 4). Joints 2, 5 and 7, despite having properly shaped brazeweld faces and the minimum amount of spatter, revealed the partial melting of the base material disqualifying them as proper joints.

Braze welded joints nos. 3, 6, 8 and 9 revealed the significant amount of spatter and the partial melting of the surfaces of the elements joined (identified in macroscopic tests). Further, i.e. microscopic metallographic tests were performed on joint no. 1 as it satisfied the criteria of visual and macroscopic tests. The cross-sectional hardness measurements were performed on joints made using the lowest, intermediate and highest braze welding linear energy, i.e. nos. 1, 3 and 7.

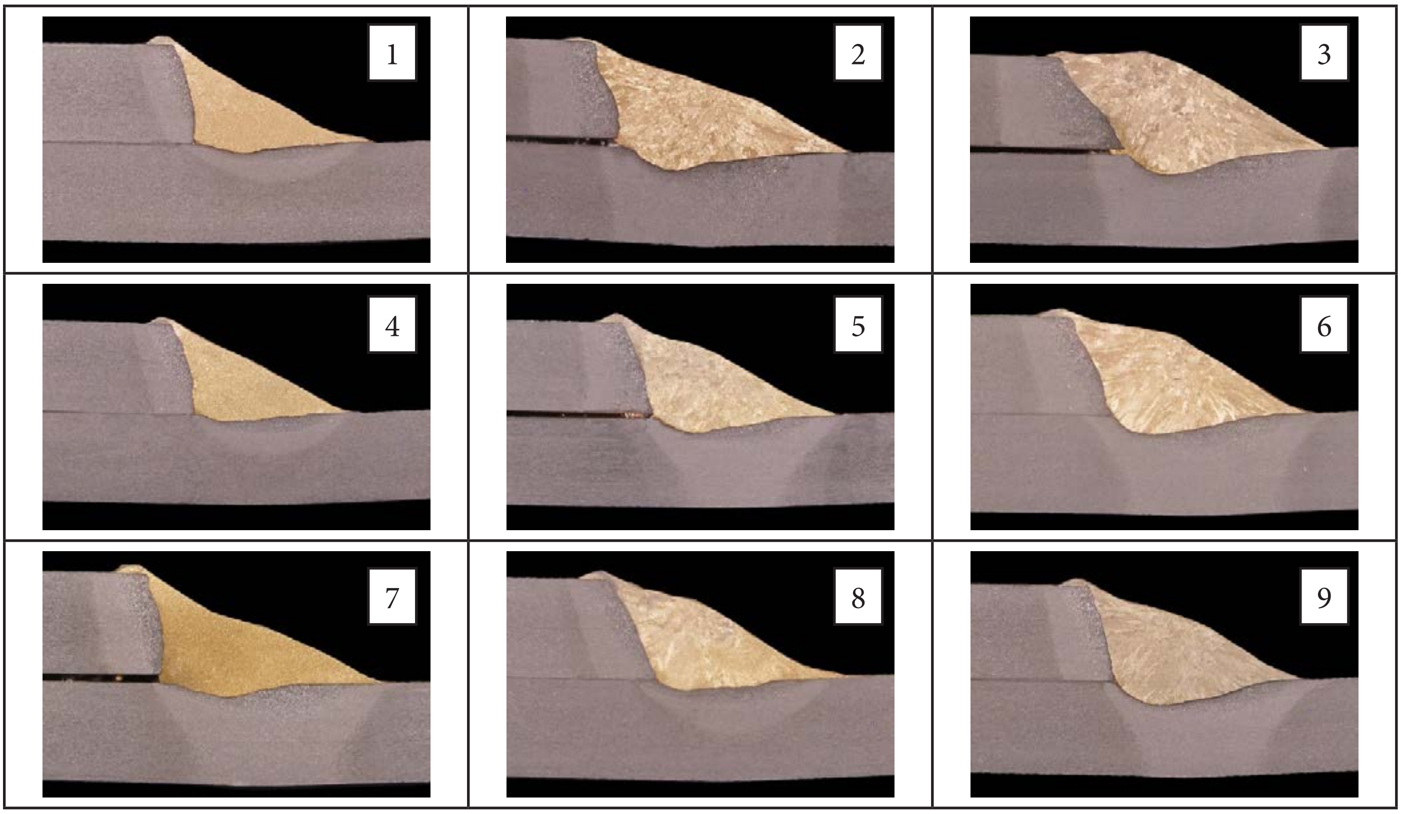
Microstructure of the Brazeweld and HAZ of MAG Arc Braze Welded Joints

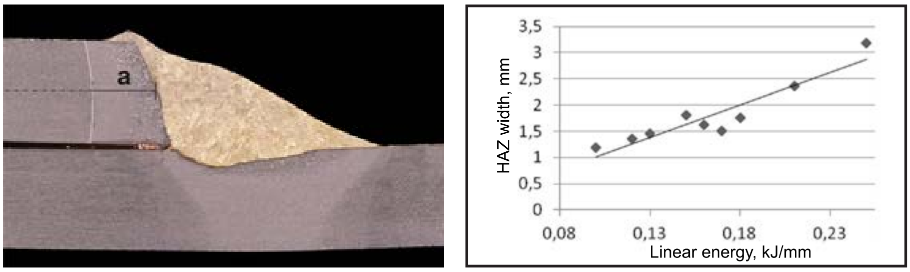
The microscopic metallographic tests of the braze welded joints were performed using an MeF4 light microscope (Leica). The microscopic tests involved the base material and the braze welded joint, i.e. the brazeweld and the heat affected zone.

The arc braze welded joints made with various parameters were used to identify the effect of process linear energy on the width of the heat affected zone. Measurements were performed by pasting the raster image of the braze welded joints in the AutoCad software programme and next by determining the HAZ at the half of the sheet thickness (only in the upper sheet). The HAZ width-related measurement results in the function of braze welding linear energy are presented in Figure 1.

The measurements of the HAZ width in the braze welded joints were performed on a sheet, the upper edge of which was wetted (upper

Table 4. Macrostructure of MG overlap braze welded joints made of 2.5 mm thick steel CPW 800





Specimen no.	1	2	3	4	5	6	7	8	9
Linear energy, kJ/mm	0.17	0.21	0.25	0.12	0.15	0.18	0.10	0.13	0.16
HAZ width, mm	1.5	2.37	3.18	1.36	1.81	1.75	1.18	1.45	1.63

Fig. 1. Effect of arc braze welding linear energy on the HAZ width (determined in the upper sheet)

sheet). The HAZ width results confirmed the proportional dependence of the width in the function of braze welding linear energy. The narrowest HAZ of 1.18 mm was found in the joint made using a linear energy of 0.1 kJ/mm, whereas the width of the joint made using a linear energy of 0.18 kJ/mm amounted to 1.75 mm. The widest HAZ of 3.18 mm was found in the joint made using a linear energy of 0.25 kJ/mm.

The results of the microscopic metallographic tests are presented in Figure 2. The MAG braze welded joint selected for the microscopic metallographic tests was designated as no. 1, made using a linear energy of 0.17 kJ/mm, a braze welding current of 80 A, an arc voltage of 22 V and a braze welding rate of 50 cm/min.

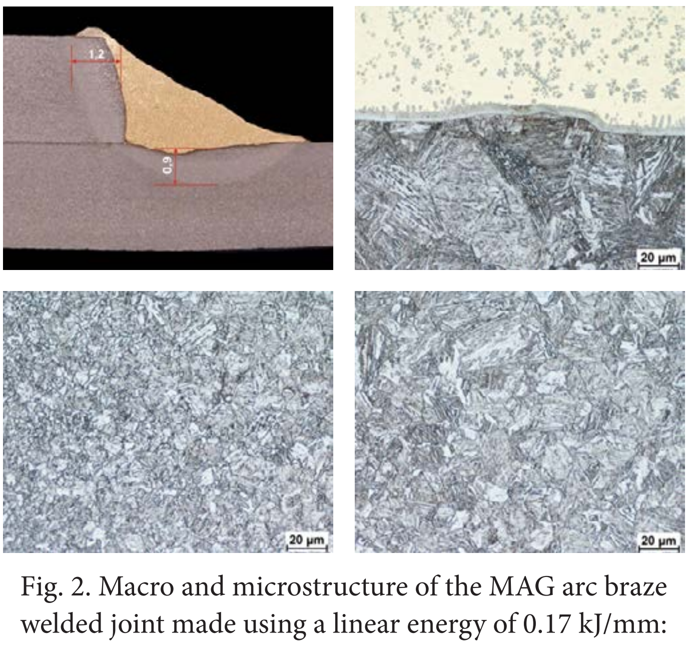


Fig. 2. Macro and microstructure of the MAG arc braze welded joint made using a linear energy of 0.17 kJ/mm: joint macrostructure (a), brazeweld microstructure (b), HAZs (c and d)

Figure 2b presents the area along the line of dissolution and mutual diffusion. The brazeweld microstructure was typical of aluminium bronze, where the inter-boundary area (the line of dissolution and mutual diffusion) revealed the presence of a 3 µm thick film identified only after the use of electron microscopy. The microstructure of steel directly neighbouring the brazeweld was composed of low-carbon martensite containing grains having the size of primary austenite greater than approximately 40 µm. The microstructure of the principal part of the HAZ was composed of low-carbon martensite containing variably-sized grains of primary austenite as well as of variously-sized martensitic laths (Fig. 2c). The heat affected zone neighbouring the base material contained the martensitic-bainitic mixture of the smallest-sized laths (Fig. 2d). The similar structure of the steel was observed during laser welding tests [9].

Cross-Sectional Hardness Measurements of Braze Welded Joints

The cross-sectional hardness measurements of braze welded joints were performed using a KB50BYZ-FA machine (KB Prüftechnik GmbH). The measurements were made in three points of the base material, in three points of the heat affected zone (in both sheets being joined) and in three points of the brazeweld. The cross-sectional hardness measurements of MAG arc braze welded joints involved three joints made using the lowest, highest and intermediate linear energy, i.e. 0.1 kJ/mm, 0.25 kJ/mm and 0.17 kJ/mm respectively; the joints were marked 7, 3 and 1. The area of the cross-sectional hardness measurements along with related results are presented in Figure 3.

In all the braze welded joints, the hardness of the base material was restricted within the range

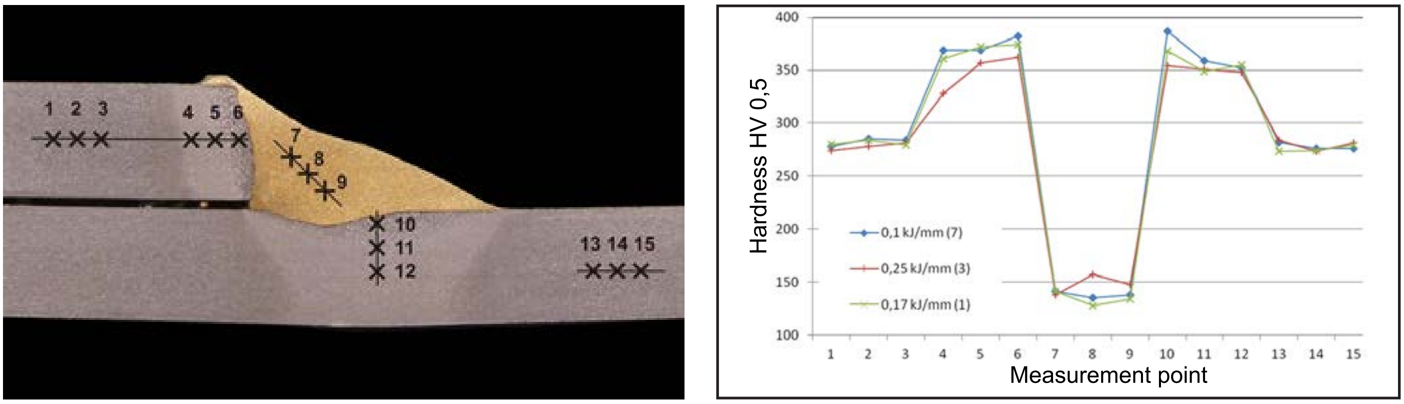


Fig. 3. Arrangement of measurement points on the cross-sections of braze welded joints (a) and hardness distribution on the cross-sections of braze welded joints made using the MAG method and a linear energy of 0.1 kJ/mm – specimen no. 7, 0.25 kJ/mm – specimen no. 3, 0.17 kJ/mm – specimen no. 1

of 270 ÷ 284 HV 0.5. Hardness rose significantly in the HAZ (in all the welded joints), which was connected with the presence of low-carbon martensite. It was possible to observe the effects of braze welding linear energy on the base material hardness in the HAZ. The greatest HAZ hardness (359 ÷ 387 HV 0.5) was identified in the braze welded joint made using a linear energy of 0.1 kJ/mm. In turn, the lowest HAZ hardness (361 ÷ 374 HV 0.5) was identified in the braze welded joint made using a linear energy of 0.25 kJ/mm. It should be noted that steel CPW 800 is specific, where even the high hardness of the joint or HAZ area related to the presence of martensitic structure is not tantamount to the high brittleness of joints. In each of the test cases, the hardness of a brazeweld amounted to approximately 128 ÷ 157 HV 0.5. Such a low hardness is characteristic of the weld deposits of filler metals used in braze welding.

Mechanical Properties of MAG Arc Braze Welded Joints Made of Steel CPW 800

Because the cross-section of the brazeweld (necessary for the identification of mechanical properties) was difficult, or in some cases even impossible to determine, only the shear strength was identified. The test specimens were prepared in accordance with the requirements of PN-EN ISO 4163:2013; the width of the specimen amounted to 20 mm. The shear strength test was performed for all the joints made using the MAG method, i.e. nine joints designated from 1 to 9. For each joint 3 tensile tests with the shearing of the brazeweld were performed. The test results are presented in Table 5.

Table 5. Shear force values

Specimen no.	Shear test results, kN	Average shear strength value, kN	Standard deviation, kN
1	23.3; 21.4; 23.1	22.3	1.1
2	19.6; 20.4; 20.1	20.0	0.4
3	27.9; 27.9; 26.7	27.2	0.6
4	19.6; 19.9; 19.7	19.6	0.2
5	20.1; 18.7; 18.9	19.2	0.7
6	20.2; 20.0; 20.5	20.2	0.3
7	19.3; 17.7; 19.4	18.8	0.9
8	18.4; 18.9; 18.5	18.6	0.2
9	22.3; 22.6; 22.2	22.3	0.2

The shear tests results related to the braze welded joints revealed that in each case the rupture took place in the brazeweld material; the shear force causing the rupture of the brazeweld amounted to 18.6 ÷ 27.2 kN. It should be noted that in cases of properly made joints in terms of braze welding technology, i.e. with the minimum partial melting of the edges and surfaces being joined (joint nos. 4, 7 and 8), the shear force was low, usually amounting to 18 ÷ 20 kN. In cases of joints with the greater partial melting of the edges and the surface of material (joint nos. 3, 6 and 9 (Table 4), the force was slightly higher and amounted to 20 kN in each test. As regards joint no. 3, the average of three tests amounted to 27.2 kN.

Concluding Remarks

1. The MAG arc braze welding technique enables the obtainment of overlap welded joint made of steel CPW 800, characterised by high and repeatable quality as well as by the minimum partial melting of the edges and the base material surface.

2. The effect of the MAG arc braze welding cycle leads to the structural changes in the base material in the HAZ and the resultant hardening of this zone (in relation to the base material) from 270 ÷ 284 HV10 to approximately 359 ÷ 387 HV10.

3. For the process parameters used in the tests, the shear strength of the MAG arc braze welded overlap joints made of steel CPW 800 using the Mecufil 214 Al filler metal amounted to 18.6 ÷ 27.2 kN.

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