EVALUATION OF CORROSION RESISTANCE OF MIG BRAZED STEEL SHEETS

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Abstract
The paper presents the results of quality evaluation of brazed joints made by Gas Metal Arc Brazing (GMAB) method. The influence of brazing direction and brazing current on the quality of joints as well as the influence of brazing parameters on the corrosion resistance of joints were evaluated. The brazing was realized on the device CLOOS 303 MC4 with the shielding gas of Argon 4.60. The $CuSi_3$ braze was used as a filler material. A drawing-grade steel sheet DX51D was used as a brazed material. Corrosion resistance of joints was evaluated on the base of accelerated tests in three environments namely wet atmosphere, NaCl solution and atmosphere of SO_2. The duration of the test was chosen according to STN EN ISO 3231 standard, with the following number of testing cycles: 1, 2, 3, 7, 14, 21 and 28 days. The using of right-hand method of brazing causes the destruction of zinc coating in the places of joint in a longer distance from braze in comparison to left-handed method. The results were obtained from accelerated corrosion test with the most aggressive environment of SO_2.

Keywords: brazing, corrosion, surface, coating, deep-drawing sheets

1 Introduction

Automotive industry makes safe and reliable automobiles with low fuel consumption. Therefore, in order to decrease the car-body mass, combinations of deep-drawing surface modified sheets, high-strength sheets for reinforcement, aluminum alloys, sandwich sheets, compounds, and plastics are used in automobile production [1, 2]. Utilization of these materials requires applying vast knowledge and precise optimization of parameters in the technologies of their joining production [3-5]. One increasingly used method of car-body joining is MIG brazing (Metal Inert Gas). This technology was applied in automotive production in early seventies and its usage is still growing [6, 7].

The main reasons for using this process include the following: Increasing of the corrosion resistance requires the use of Zn coated plates, instead of the usual non-coated steel plates; arc brazing needs to replace arc welding of the thin Zn coated plates, due to obvious advantages, such as zinc evaporation, residual stresses and distortions reduction; reduction of the Zn burn-off during brazing, as well as the optimization of the couple gas-wire, in order to assure an optimum quality of the seam [8,9]. Coating on steel sheets (especially zinc coating) causes some problems during the process of welding, such as relatively low melting temperature of Zn (419ºC) or Zn vaporization at the temperature exceeding 908 ºC [10]. Since the melting temperature of steel is higher, some destruction of coatings occurs and subsequently corrosion resistance at the joints

decreases [11-12]. Some authors [7, 11] describe the advantages of MIG brazing in comparison with MIG welding, such as lower thermal input in the place of bond, which leads to lesser coating destruction of joined materials. Damage of the coating is less significant during MIG brazing due to chemical composition of braze. The area of the bond, where evaporation of zinc occurs, is relatively small; thereby the corrosion resistance is provided by passive protection of the zinc. The above mentioned facts were observed during accelerated corrosion tests in three corrosion environments which are not complex described in available scientific works [11, 12].

2 Material and experimental methods

A drawing-grade steel sheet of DX51D + Z EN 10142/2000 of U.S. Steel production were used for the experiments. The surface was treated by dip-zinc galvanizing with the zinc coating thickness of 16 μm stated by the producer. The chemical composition of the tested sheet is presented in **Table 1**. The chemical composition of the used types of solders and their strength characteristics are presented in **Table 2**. Brazes A 384 were made by UTP company.

Table 1 Chemical composition and mechanical characteristics of DX51D + Z EN10142/2000 steel

Material	C [%]	P [%]	S [%]	R_m [MPa]	$R_{p0,2}$ [MPa]	A_{80} [%]
DX51D+Z	0.15	0.040	0.040	270-500	≤180	23

Table 2 Standard chemical composition and mechanical characteristics of brazes (*MT-melting temperature) [13]

Material	Cu [%]	Mn [%]	Si [%]	R_m [MPa]	$R_{p0,2}$ [MPa]	A_5 [%]	KU [J]	*MT [°C]
SG-CuSi3	96	1	3	300	160	23	25	910-1025

Samples of dimension 400 mm x 780 mm were cut from sheets of 0.9 mm thickness. Brazing surfaces were cleaned with the shearing emulsion CH_3COCH_3. Brazing of car-body sheets was carried out on CLOOS 303 MC4 equipment. One of the possibilities of compensating the negative influence of zinc evaporation on the lapped joint is modifying the position of brazed sheets. Modification of the parallel position of brazed sheets contact areas by an angle α (1-5º) enables better Zn evaporation from the area of brazing, and thus decreases the possibility of melting metal transfer into the joint. The brazing parameters (**Table 3**) and marking of the tested samples are shown in **Fig. 1** in the direction of brazing from right to left. **Fig. 2** shows used brazing parameters for brazing from left to right.

The joint made by the brazing technology was formed with shielding gas of argon 4.6 at the lapped sheets [14]. The angle of torch slope during brazing was 45º. The width of the lapping was from 18 to 20 mm.

The macrostructure and microstructure analysis of the brazing joints quality were carried out according to STN EN 1321 standard. The metallographic scratch patterns were observed in the light microscope Olympus CX-31. 3% Nital was used as the etchant to enable the visualization of the basic material microstructure. The microstructure of braze CuSi3 was observed after etching with a solution of ammonium persulphate (10g of ammonium persulphate + 100 cm^3 of distilled water).

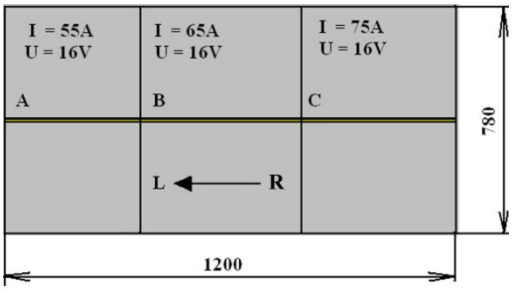

Fig.1 Brazing parameters for brazing from right to left and marking of samples

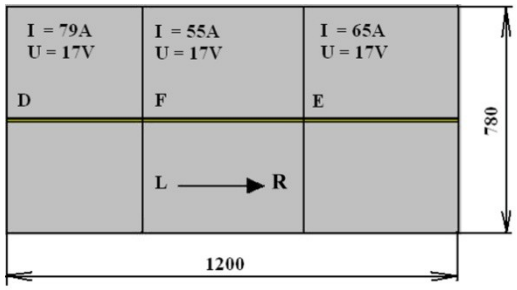

Fig.2 Brazing parameters for brazing from left to right and marking of samples

Table 3 Brazing parameters [8]

Thickness of brazing sheets	Wire	Impulse	Brazing Current [A]	Voltage [V]	Inert Gas
0.9 mm + 0.9 mm	1.0 mm	Yes	55 - 79	16 - 17	Argon 4.6

The technology of MIG brazing is presented in specialized literature as a technology that is friendly to protective coating. Therefore, the influence of brazing on the corrosion resistance, and the speed of corrosion were evaluated on the tested samples [12, 15, 16].

Corrosive losses belong among the basic quality characteristics. They characterize the corrosion resistance of metals under specific conditions. Ten samples were tested in each corrosive environment. The accelerated corrosion tests were realized in the condensation chamber SC/KWT 450 under three corrosion environments. The first experiment was carried out according to STN EN ISO 6270 standard (samples I). It is an informative test for preliminary determination of corrosion resistance of materials under specific conditions. The corrosion resistance of coatings was observed under continuous exposure of the samples to pure wet atmosphere at the temperature of 40 ± 2°C and with relative humidity at 100 %. The second experiment was carried out according to ISO 7253 standard. The principle of the test is in continual splashing of 5 % NaCl solution. The splashing of solution is carried out with compressed air of 0.7 – 1.4 bar (samples II). The last experiment was conducted according to STN EN ISO 6988 standard. The test was carried out at the temperature of 40 ± 2°C, the relative humidity of 100 % in aggressive environment of 0,008 vol. % SO_2 , (samples III).

In terms of STN 038102: Evaluation of corrosion tests by determination of weight and dimension changes were the samples immersed in the bath of the following composition: 50 ml of 98 % acetic acid, 950 ml of distilled water. The corrosion loss value is stated in accordance with the abovementioned standard by the extrapolation of a part of line B to the vertical axis. The point of intersection with the vertical axis expresses the corrosion loss value. The influence of the corrosive environment on the tested samples was evaluated by a weight loss test. They were immersed in one-minute time intervals. After the immersion, the samples were rinsed, dried and weighed on digital scales RADWAG XA 220 with the accuracy of 10^{-4}g. The corrosion losses were observed at respective time intervals after immersing. The accelerated corrosion test was used only for the samples brazed with the lowest values of brazing current due to less significant influence of thermal effect on the zinc coating destruction.

The volume of the condensation chamber was 300 litres. The duration of the test was chosen according to STN EN ISO 3231 standard, with the following number of testing cycles: 1, 2, 3, 7, 14, 21 and 28 days. The total duration of the test was 28 days.
The evaluation of the samples was carried out according to STN EN ISO 10 289 standard and by a visual test. The surfaces of both sides of the joined materials were tested.

3 Results and analysis

Material DX51D + Z EN 10142/2000 underwent a microstructural analysis. A typical ferrite-pearlite structure was observed in the tested material [8].
At the chosen 45º angle of the torch slope toward the area of brazing, the process of more intense metal melting starts from the upper edge of the sheet – see **Fig. 3**. This is in compliance with the fact that the Fe particles diffused in the brazed metal near the edge of the top brazed material were observed in higher resolution [12].
In the macrostructure of the joint there was observed a relatively small thermal impact on joined sheets in the process of MIG brazing. The detailed picture shows good braze wettability and fluidity. A presence of pores was detected in the brazed metal. An increase in the porosity in the brazed metal decreases the strength properties of the joint.

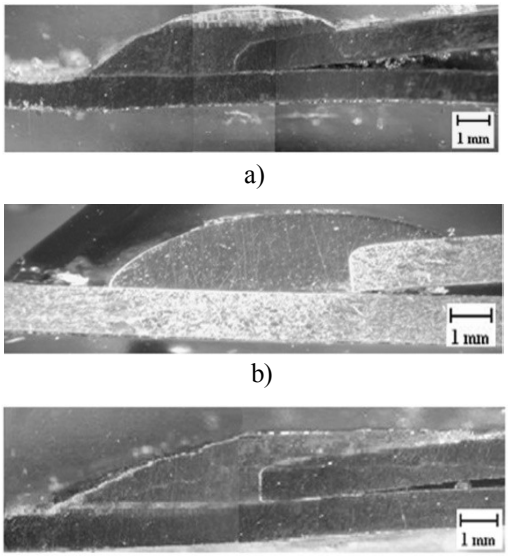

Fig.3 Macrostructure of sheets jointed by SG CuSi3 braze with brazing from right to left, a) sample A, b) sample B, c) sample C

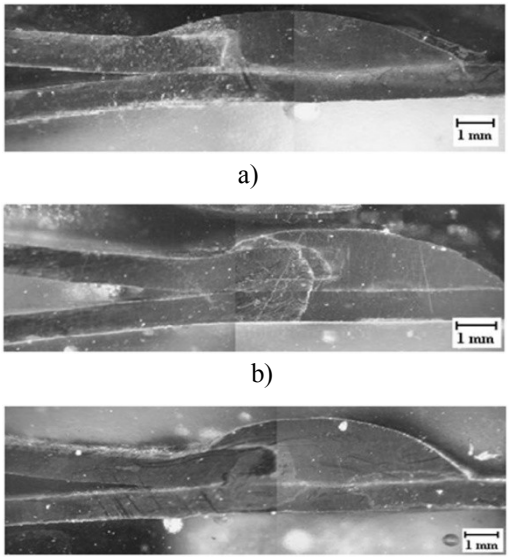

Fig.4 Macrostructure of sheets jointed by SG CuSi3 braze from right to left a) sample D, b) sample E, c) sample F

The influence of the brazing parameters (brazing current I) on the dimensions of the brazed joints and behaviour of CuSi3 metal is documented in the macrostructures in **Figs. 3 a-c** . The stress and the speed of brazing were constant. The microstructural analysis presented in [8] confirmed the ferrite-pearlite structure with a higher content of pearlite was observed in HAZ, which corresponds to the processes of basic material changes, an increased brazing current had a

significant thermal influence on the basic material. In the area of brazed material, there occurred significant grain coarsening.

In the evaluated parameters of brazing from right to left, the brazed metal had good wettability and capillarity. The adhesion of the brazing solder on the sheet can be assessed as good. Pores, cavities or other defects were not observed on the interface between brazing solder and basic material.

Samples A had a brazing bead with the maximum reinforcement in comparison to the other tested samples. However, the observation by the light microscope Olympus CX-31 showed that the width of the bead was smaller in comparison to samples B. Using of brazing current I = 55 A had the lowest heat influence on the basic material. The highest heat influence on the basic material and the highest diffluence of the brazing solder were observed in samples C with brazing current I = 75 A.

Fig. 4 shows the macrostructures of joints made by MIG brazing from left to right. On the basis of analysis of macrostructure of the evaluated samples D, E and F, it can be stated that lap joints of high quality were formed in case of all of the observed brazing parameters. The biggest diffluence with the smallest height were observed in the samples made with brazing current 79 A, as shown in **Fig. 4a),** was observed. The narrowest brazing bead with the biggest overlap was made with brazing current 55 A. Despite of lower brazing current, the brazing metal had good wettability and capillarity.

On the base of macrostructure analyses it can be stated, that more significant heat influence was observed on the samples brazed from right to left (A, B, C). Lower heat influence was observed on sample F.

Brazing metal has its typical casting structure with numerous pores caused by the applied inert gas - Argon 4.6, see **Table 3**.

The heat in the brazing process negatively influences cohesion and the quality of protective coatings, mainly Zn. The value of brazing current can be optimized to 55 A. Good quality of joints was observed in both types of brazing made with this current. Therefore, these samples were used for the evaluation of influence of brazing parameters on the corrosion resistance.

During brazing the sheets were in the contact angle α (1-5°), so the sheets were in the full length contact.

The molten metal of the braze has such a good fluidity and wettability, that the brazing solder got to the distance of 1.8 to 2.0 mm from the contact edge of the sheets. In the macrostructure it is possible to observe lifting of the top sheet.

Good wettability is obvious from the continual covering of the upper sheet and its edge being without pores, cavities and other defects. The brazing metal covered the surface of the lower sheet, corresponding to the diameter of the used brazing solder and parameters.

Poor wettability, **Figs. 4 b) and c),** caused by inappropriate type of brazing solder or impurities on the surface, decreases the strength properties of the joint, because the solder-surface interaction does not arise.

The samples made with both types of brazing were used for the corrosion resistance test according to the above mentioned methodology. The samples brazed with the lowest brazing parameters (brazing current) are shown in **Fig. 5**. **Figs. 5 a) and b)** show the samples after 240 hours exposure to in the condensation chamber in pure wet atmosphere, **Figs. 5 c) and d)** present the samples after 240 hours exposure to a condensation chamber test in water solution of NaCl solution and **Figs. 5 e) and f)** show the samples after 240 hours exposure in aggressive environment of SO_2.

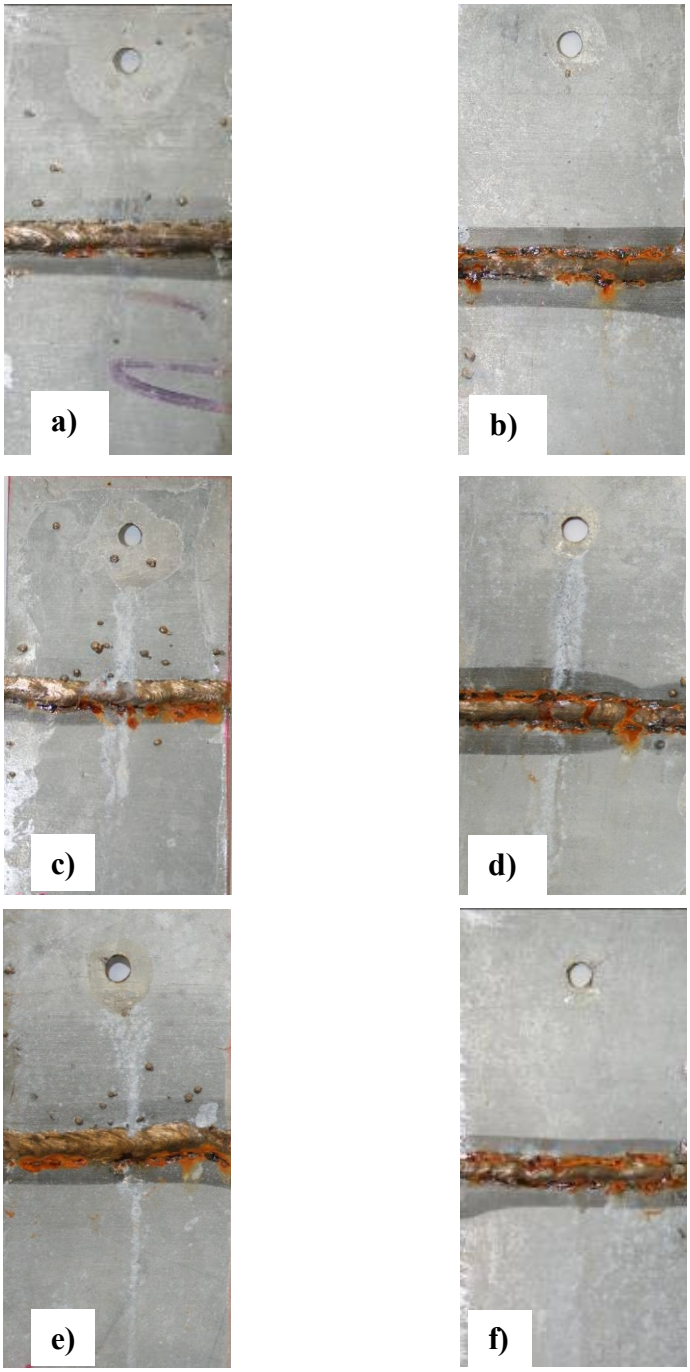

Fig.5 Samples after 240-hours exposure:
a) left-hand brazing – sample I_A b) right-hand brazing – sample I_F
c) left-hand brazing – sample II_A d) right-hand brazing – sample II_F
e) left-hand brazing – sample III_A f) right-hand brazing – sample III_F

Corrosion attacks were observed in both types of brazing processes. So-called white corrosion occurred in the zinc surface of the base material. The main factor that caused the white corrosion of the zinc layer and consequently the corrosion of steel core was the condensation of air humidity [17,18]. Because of the humidity impact, a zinc coated sheet becomes a galvanic cell with the zinc layer functioning as the anode and the steel core as the cathode.
During the condensation chamber test, the samples made by left-hand brazing were covered with corrosion from 15 to 45 % of the evaluated brazing solder area. The visual test observed white corrosion covering the whole surface of the base material. The samples made by right-hand brazing were covered with corrosion from 70 to 80 % of the evaluated brazing solder area. White corrosion was observed in visual test, covering the whole surface of the base material. The results of experiments are in concordance with findings of [19-20] describing the influence of heat on the surface of joint materials.
The results of the condensation chamber test were influenced by the brazing process, where the evaporation of zinc coating occurred in a longer distance from the zone of metal transfer from the electrode into the brazing bath in the right-hand direction of brazing. The samples showed predominantly staining corrosion; the affected area grew linearly depending upon the length of exposure, **Figs. 5 a) – f).**
The corrosion changes were observed only on the surface of the base material (**Fig. 6** and **Fig. 7**) in both types of brazing in the places where evaporation of zinc layer occurred. The scratch patterns confirmed staining corrosion in the back area of the overlapped joint due to the discontinuance of the coating caused by overheating during brazing **(Fig. 6)**, or on the interface of the base material – brazing solder joint caused by the heat of the arc in the transfer of the melted brazing solder **(Fig. 7).** Based on mentioned it is assumed as a bimetallic corrosion.

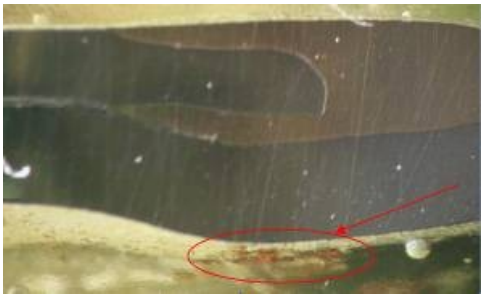

Fig.6 Detail of corrosion attack in left-hand brazing on sample F1, extension of 10x

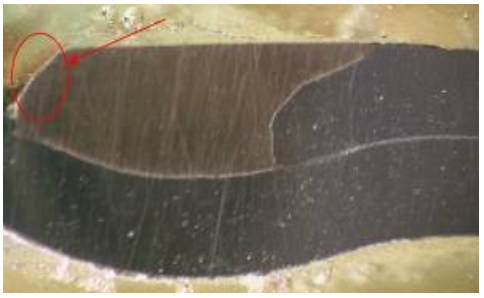

Fig.7 Sample A1 (right-hand brazing) after 240-hours exposure

The value of the corrosion loss was estimated by a graphical extrapolation of the straight line section to the vertical axis. The intersection of the straight line extrapolation with the vertical axis is the value of corrosion loss provided that the slope of the straight line approaches zero.
The achieved corrosion losses of sample I with particular brazing regimes are shown in **Fig. 8** in pure wet atmosphere. Graphically estimated values of corrosion losses are: 0.008 g in left-hand brazing, 0.014 g in right-hand brazing. **Fig. 9** shows the corrosion losses of sample II with particular brazing regimes NaCl solution. Values of corrosion losses were increasing: 0.016 g in left-hand brazing, and 0.022 g in right-hand brazing. The maximum values of average corrosion

losses are shown in **Fig. 10** in aggressive environment of SO_2. Graphically estimated values of corrosion losses are: 0.021 g in left-hand brazing, 0.036 g in right-hand brazing.

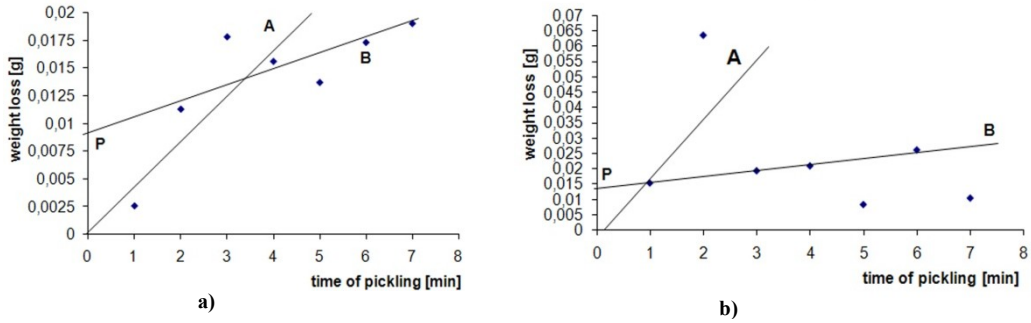

Fig.8 Average corrosion loss in pure wet atmosphere: a) Sample I_A - left-hand brazing, b) Sample I_F - right-hand brazing. A – dissolving of corrosive product, B – dissolving of tested metal, P – corrosion loss

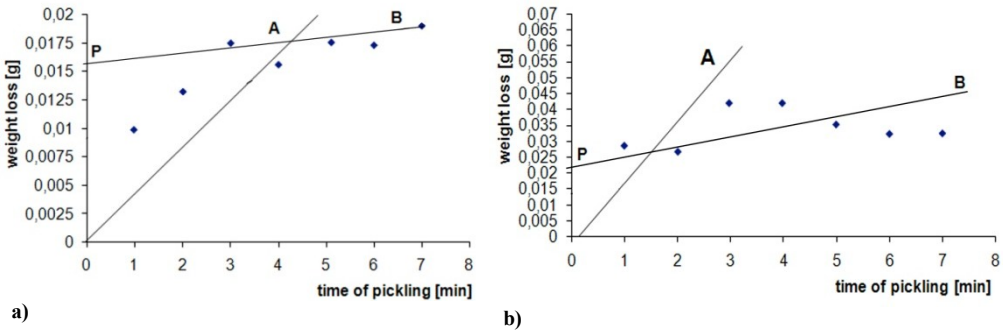

Fig.9 Average corrosion loss in NaCl solution: a) Sample II_A - left-hand brazing, b) Sample II_F - right-hand brazing. A – dissolving of corrosive product, B – dissolving of tested metal, P – corrosion loss

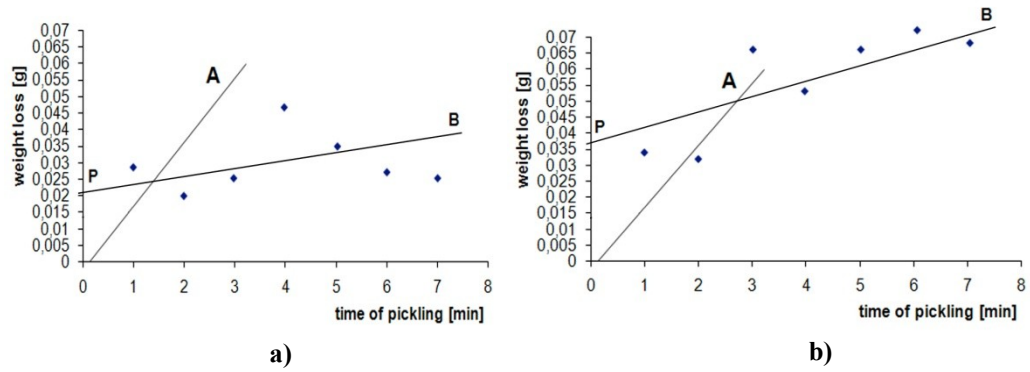

Fig.10 Average corrosion loss in aggressive environment of SO_2: a) Sample III_A - left-hand brazing, b) Sample III_F - right-hand brazing. A – dissolving of corrosive product, B – dissolving of tested metal, P – corrosion loss

4 Discussion

Surface treatment by Zn, Al, Sn metals and their alloys has a negative influence on all conventional and unconventional brazing processes. The main of the negative impacts on the welding process is mostly the low melting temperature of these metals as well as their low evaporation temperature. The instability of weld arcing was caused by the evaporation of Zn during the arc welding. The evaporated zinc from the sheet surface moves the arc from the place of joint to an area with lower electrical resistance. It is convenient to use arc about 2-3 mm long in the brazing process.

The evaporation of zinc during brazing of zinc coated sheets causes instability of the process in general, i.e. unstable arc burning, faults in the gaseous shield flow and transferring the brazing solder to the brazing bath. The above mentioned influences increased splashing of the brazing solder to the surroundings of the joint. In order to eliminate the influence of zinc evaporation on the stability of arc burning, left-hand movement of the torch is recommended where evaporation of zinc coating occurs in further distance from the zone of metal transfer from the brazing solder to the brazing bath.

On the basis of the conducted experiment, the conclusion can be formed:

- the least aggressive environment was the pure wet atmosphere, where the lowest corrosion loss of 0.008g was observed – left-hand brazing and the corrosion affected area covered 15% of the surface. In the right-hand brazing, the corrosion loss amounted to 0.014 g and 70 % of the surface was affected.
- the aggressive environment of SO2 has the most significant influence on the corrosion resistance of bonds, the weight loss in left-hand brazing was 0.021g affecting 45 % of the surface, while the right-hand brazing showed the corrosion loss of 0.036 g affecting 80 % of the surface.

5 Conclusion

Results show that the influence of zinc vapours on the joint quality could also be decreased by the choice of direction of the torch motion (bead storing). Left-hand burner operation decreases the influence of Zn vapours on the welding arc, because the evaporation occurs before the transfer of additional melting material. However, this method is very sensitive to the optimization of the torch motion speed during brazing. Right-hand torch operation provides only a short time for zinc evaporation from the metal which has negative influence on the electric arc. The dynamic effect of zinc vapours could cause a splash of the additional melting metal.

References

[1] E. Spišák, Ľ. Kaščák, J. Viňáš: Chemické listy, Vol. 105, 2011, No. 16, p. s488-s490
[2] L. Quintino, G. Pimenta, D. Iordanescu, R. M. Miranda, N. V. Pépe: Materials and Manufacturing Processes, Vol. 21, 2006, No. 1, p. 63-73
[3] P. Mohyla, V. Foldyna: Materials Science and Engineering A, Vol. 510-511, 2009, p. 234-237
[4] M. Ebbinghaus: Welding and Cutting, Vol. 10, 2011, No. 4, p. 232-235
[5] M. Hagarová, P. Lacková: Koroze a ochrana materiálu, Vol. 55, 2011, No. 3, p. 109-113
[6] C. Chovet, S. Guiheux: La Metallurgia Italiana, Vol. 3, 2006, No. 7-8, p. 47-54
[7] G. Qin, Y. Su, S. Wang: Acta metallurgica Sinica, Vol. 48, 2012, No. 8, p. 1018-1024
[8] J. Viňáš, Ľ. Kaščák, M. Ábel, D. Draganovská: Mechanika, Vol. 80, 2010, No. 273, p. 285-290

[9] P. Sejč, R. Bielak, P. Švec, M. Roško: Kovove materialy, Vol. 44, 2006, No. 4, p. 225-234
[10] J. Ševčíková, M. Hagarová: *Surface engineering,* 1st ed., HF TU Kosice, 2007, (in Slovak)
[11] M. Popescu, G. E. Mocuta, A. Raduta, A. Magda: Journal of Environmental Protection and Ecology, Vol. 13, 2012, No. 2A, p. 1038-1046
[12] M. Kusch, F. Podlesak: Welding and Cutting, Vol. 11, 2012, No. 4, p. 250-253
[13] B. Magnabosco, F. Coppo: Welding International, Vol. 26, 2012, No. 11, p. 829-838
[14] H. T. Zhang, J. C. Feng, P. He, H. Hackl: Materials Characterization, Vol. 58, 2007, No. 7, p. 588-592
[15] D. Iordanescu, L. Quintino, R. Miranda, G. Pimenta: Materials & Desing, Vol. 27, 2006, No. 5, p. 381-390
[16] Z. Yu, R. Li, K. Qi: Transaction of Nonferrous Metals Society of China, Vol. 16, 2006, No. 6, p. 1391-1396
[17] D. Q. Zhang, T. Liu, H. G. Joo, L. X. Gao, K. Y. Lee: International Journal of Refractory Metals and Hard Materials, Vol. 35, 2012, p. 245-250
[18] N. Leborec, N. Blandin, D. Thierry: Materials and Corrosion, Vol. 59, 2008, No. 11, p. 889-894
[19] N. Leborec, A. Legac, D. Thierry: Materials and Corrosion, Vol. 63, 2012, No. 5, p. 408-415
[20] S. Fujita, D. Mizuno: Corrosion Science, Vol. 49, 2007, No. 1, p. 211-219

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