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PHYSICAL METALLURGY AND HEAT TREATMENT

Investigation on Effect of Pulse Correction on Structure Property in Dissimilar Welds of Galvanized Steel and Aluminum Alloy Obtained by Gas Metal Arc Welding Cold Metal Transfer[1]

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Abstract—Gas metal arc welding cold metal transfer (GMAW-CMT) method with $AlSi_3Mn$ filler wire was performed on welding of the 5754 aluminum alloy with thickness of 3 mm to the galvanized steel with thickness of 2 mm aluminum alloy to investigate the effect of pulse correction on structure and mechanical properties of welded samples. In accordance with results, GMAW-CMT provides good tensile performance. It was attributed to the various throat weld size and wetting actions because of the influence of pulse correction on structure of welded joints. It was inferred that on employing +5 pulse correction resulted in better and consistent tensile strength of 209 MPa. Furthermore, the results showed that increasing the pulse correction led to increasing of flow in the filler wire and in fact raising of brazed seam width and throat weld size. In addition, the thickness of intermetallic compound layer which was formed along the interface during the GMAW-CMT was varied by changing of pulse correction. It has been found that by increasing the pulse correction from –5 to +5, the throat weld size increased and consequently led to a change in the tensile strength of the welded joints.

Keywords: galvanized steel, 5754 aluminum alloy, mechanical properties, pulse correction, and tensile strength

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1. INTRODUCTION

The aluminum alloys and galvanized steels extensively applied in the automotive industries are needed to be joined. Aluminum can reduce the weight of structural parts for its light weight and stainless steel has a high strength and excellent corrosion resistance. Hybrid structures of aluminum alloy and stainless steel are suggested in spacecraft, automotive and steamship to improve the fuel efficiency, increase the fly range and control air pollution by reducing the weight [1–4]. Because of large differences in physical properties of these two alloys joining of galvanized steel and aluminum alloys is so difficult by conventional fusion welding process.

CMT low heat input with high wire melting coefficient when compared with the pulsed GMAW process provided high welding speed and inconsiderable distortion on welded specimens. CMT is a modified metal inert gas welding process, developed by Fronius in 1991 [5]. It is based on a short-circuiting transfer process via an oscillating wire and is characterized by low heat input and no-spatter welding [5–7]. For instance, Milani et al. [6] investigated the influence of filler wire and wire feed speed on metallurgical and mechanical properties of MIG welding–brazing of automotive galvanized steel to 5754 aluminum alloy in a lap joint configuration. They results depicted that the thickness of intermetallic compound (IMC) layer during GMAW-CMT process was varied by changing of parameters. They also reported that kind of filler wire affected on tensile strength and the best consistent tensile strength was produced with $AlSi_3Mn$ filler wire. Another parameter which was used in welded specimens by GMAW-CMT is the pulse correction. In this investigation, the GMAW-CMT of these dissimilar alloys was investigated with the aim of improving the properties of joints.

2. EXPERIMENTAL

The parent materials used were aluminum alloy 5754 and galvanized steel with thickness of 3 and 2 mm, respectively. Dimensions of the galvanized steel

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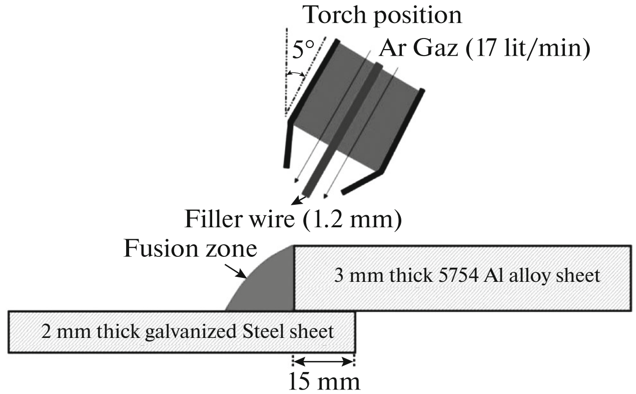

Fig. 1. A Schematic of the experimental set up utilized for GMAW-CMT process in this present work.

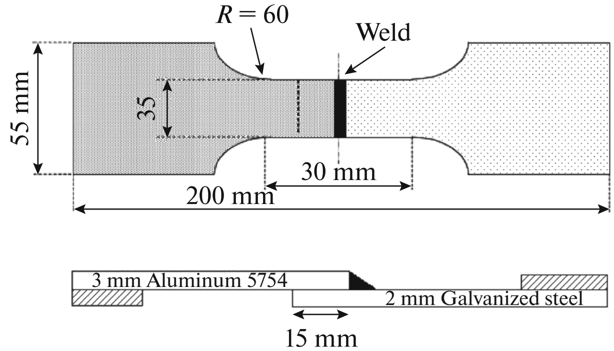

Fig. 2. Dimensions of the tensile test sample.

and aluminum alloy sheets were 300 mm × 150 mm. The mechanical properties and chemical composition of these materials are provided in Tables 1 and 2, respectively. Filler wire $AlSi_3Mn$ with diameter of 1.2 mm was used. Moreover, flow rate, stick out, and welding speed were kept constant and equal to 17 L/min, 17 mm and 10 mm/s, respectively.

Figure 1 shows the schematic image of experimental setup used for GMAW-CMT. The overlap was 15 mm. The angle between the filler wire (nozzle) and the vertical line was maintained at 5°. The dimensions of the tensile test specimens used according to AWS C1.1: 2007 standard in this present work is shown in Fig. 2. The tensile tests were performed at room temperature with a loading rate of 1 mm/min.

Table 1. Mechanical properties of 5754 aluminum alloy and galvanized steel sheets

Material	UTS, MPa	YS, MPa
Aluminum	187	112
Galvanized	402	292

Three tensile samples were cut from each weld to evaluate the tensile strength of the welded specimens. During metallography, the specimens were polished and then etched using 3 vol % Nital reagents (3 mL HNO_3 and 97 mL H_2O) for 8 s. The microstructure of the joints was investigated by optical microscope (Olympus CK40). The composition of the reaction layers was determined through an energy dispersive X-ray spectroscopy (EDS).

3. RESULTS AND DISCUSSION

3.1. Macro and Microstructure

There are different parameters during the GMAW-CMT process. For instance, the wire feed speed that affects the heat input generated during the CMT process is one of the most important parameters [8]. As inferred from the earlier studies, there exists a direct correlation between the wire feed speed and the heat input generated during the GMAW-CMT process [8].

Moreover, by increasing of the wire feed speed, the wetting angle decreased which can be attributed to the increasing flow of the filler wire [6]. In brief, it can be noted that increasing in the wire feed speed led to increasing of the heat input. But in this present work, the effect of pulse corrections (–5, 0 and +5%) were

Table 2. Chemical composition of the investigated alloys (wt %)

Material	Mg	Si	M	Cr	Fe	Al
Aluminum	3.217	0.365	0.454	0.265	0.311	Bal
Material	C	Si	Mn	Al	S	Fe
Galvanized Steel	0.25	0.093	0.071	0.032	0.021	bal

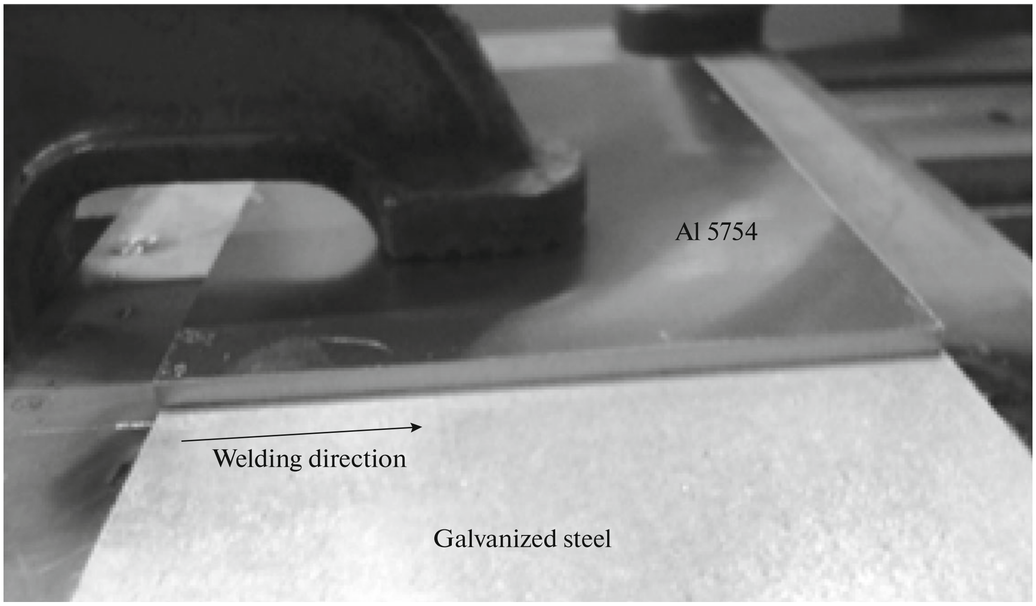

Fig. 3. A close-up view of the clamp, the specimens and the backing plate.

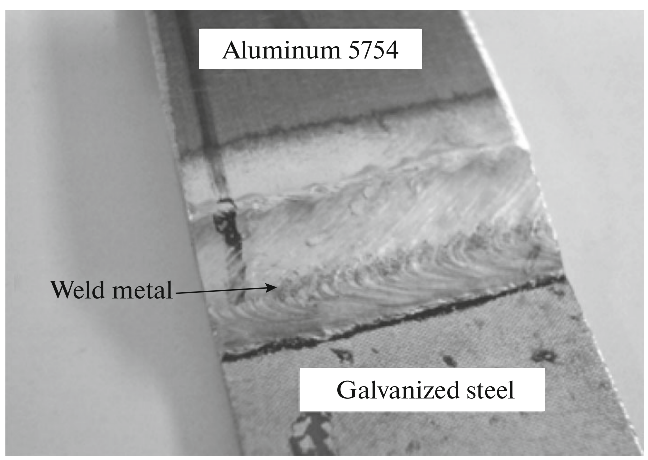

Fig. 4. Photo after GMAW-CMT process for welded joint of Al 5754 to galvanized steel.

investigated and discussed on the structure property and mechanical properties of welded samples. The effect of pulse correction on the macrostructure (wetting angle) during GMAW-CMT process is shown in Fig. 5. As illustrated, increasing the pulse correction decreases the wetting angle. In other words, it can be said that increasing the pulse correction led to decrease of surface tension force and also increase of flow in the filler wire and consequently led to increasing of brazed seam width and throat weld size.

Figures 6a and 6b show the variation of throat weld size and the brazed seam width as a function of the pulse correction with $AlSi_3Mn$. As shown in Fig. 6, since more pulse correction subsequently increased the flow of the filler wire and thereby caused an increase in brazed seam width, therefore affect the thickness of IMC layer and tensile strength results which is discussed subsequently.

Figure 7 shows the varying thickness of IMC layers were observed at the welded joints as a function of the pulse correction. As shown in Fig. 7, the IMC layer thickness has decreased with increasing of the pulse correction. It should be pointed out that within one joint, the pulse correction not only affected the macrostructure of the GMAW-CMT welds, but also followed the thickness variation of IMC layer. On the

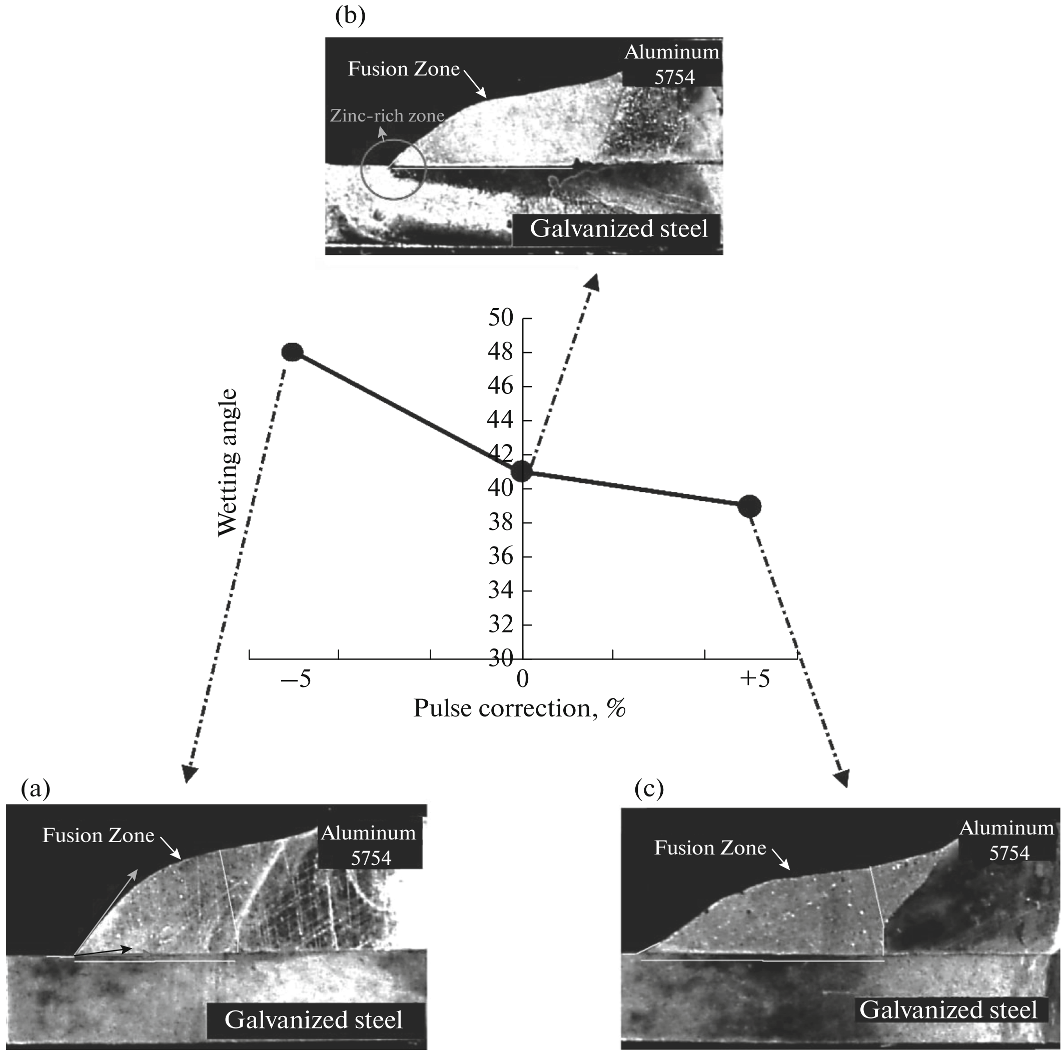

Fig. 5. The variation of the macrostructure (wetting angle) as a function of pulse correction: (a) –5%, (b) 0% and (c) +5%.

other hand, it can be seen that increasing the pulse correction led to a decrease and the fragmentation of acicular Si (see Fig. 7c).

As mentioned in previous research, presence of this acicular Si and IMC layer in weld made are main factors in high level of distribution in tensile strength results [6]. As seen in Figs. 5a and 8, there is a different zone in weld toe. The EDS analysis was used to detect the composition of this zone. The EDS result agreed with the presence of zinc in it (see Fig. 8). Qin et al. [9] observed that zinc-rich zones region including high concentration residual zinc formed at the weld toe. It is obvious that high concentration residual zinc formed at the weld toe leading to a weak joint. Figure 9 shows line scanning analysis of the aluminum-seam-steel interface layer. As it is seen, some amount of inter-diffusion occurred during this work. From the Al side to the steel side, the content of Al in the IMC layer decreased. Furthermore, it is clear that more content diffusion of Si atoms into aluminum occurred.

Figure 10 depicts the appearance of the welds made as a function of pulse corrections. As indicated, unlike the wire feed speed [6], the pulse corrections had a negligible effect on the appearances of joints. Considering the aforementioned discussion, the pulse correction during the GMAW-CMT process played the significant role in the micro and macrostructure and also the thickness of IMC layer. On the contrary, the pulse correction had minor role on the appearances of the joints under different conditions. In brief, pulse correction result in even better welding outcomes. This can be attributed to the penetration stabilizer and the

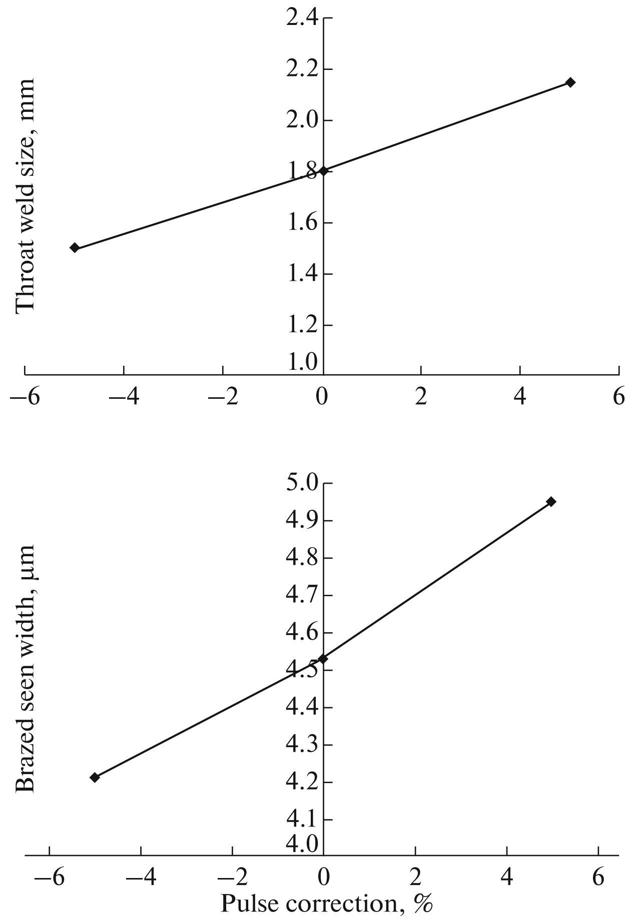

Fig. 6. Variation of throat weld size and brazed seam width versus pulse correction.

arc length stabilizer during welding. Figure 11 shows the metallographic images of fusion zone (weld metal) structure. As is clear in figure, there are homogeneous fusion zone during GMAW-CMT.

3.2. Tensile Strength of the Joints and Microhardness Distribution

To investigate the effect of the pulse correction on the mechanical strength of the weld acquired, the tensile test of the joints were performed. The relationship between the tensile strength and the pulse corrections is shown in Fig. 12. As is clear in Fig. 12 and as it was expected, the maximum tensile strength was obtained by the +5 pulse correction whereas minimum tensile strength was obtained by –5 pulse correction. The tensile strength of the as-welded joint by –5 and +5 pulse correction reaches 156 and 209 N/mm^2, respectively. The reason behind this behavior originated from the increase of brazed seam width and throat weld size. As mentioned previously, increasing the pulse correction led to increase of flow in the filler wire and in fact raising of brazed seam width and throat weld size. This result agreed with the thickness of IMC layer results. According to the results, there was a direct correlation between the pulse correction and the strength of the joints. In addition, this is largely because of presence the acicular Si. In high cooling rates, solubility of Si element in the aluminum was restricted and subsequently resulted in formation of the acicular silicon phase. Su et al. [10] and also Milani et al. [6] reported that the IMC layer thickness was significant factor for determining the strength of the joints. Eventually, it can be said that pulse correction improves the joint tensile strength to around 220 N/mm^2 by stabling of arc and raise of filler metal flow in the joint. Vickers microhardness along the joint was measured to evaluate the influence of the pulse correction on the hardness profile of different regions.

Figures 13a and 13b display the OM images showing vickers microhardness distribution in different regions during the GMAW-C. Obviously, it is clear that the hardness in the fusion zone is lower than that of galvanized steel whereas it in the fusion zone was more than that of aluminum. Also, it can be seen that

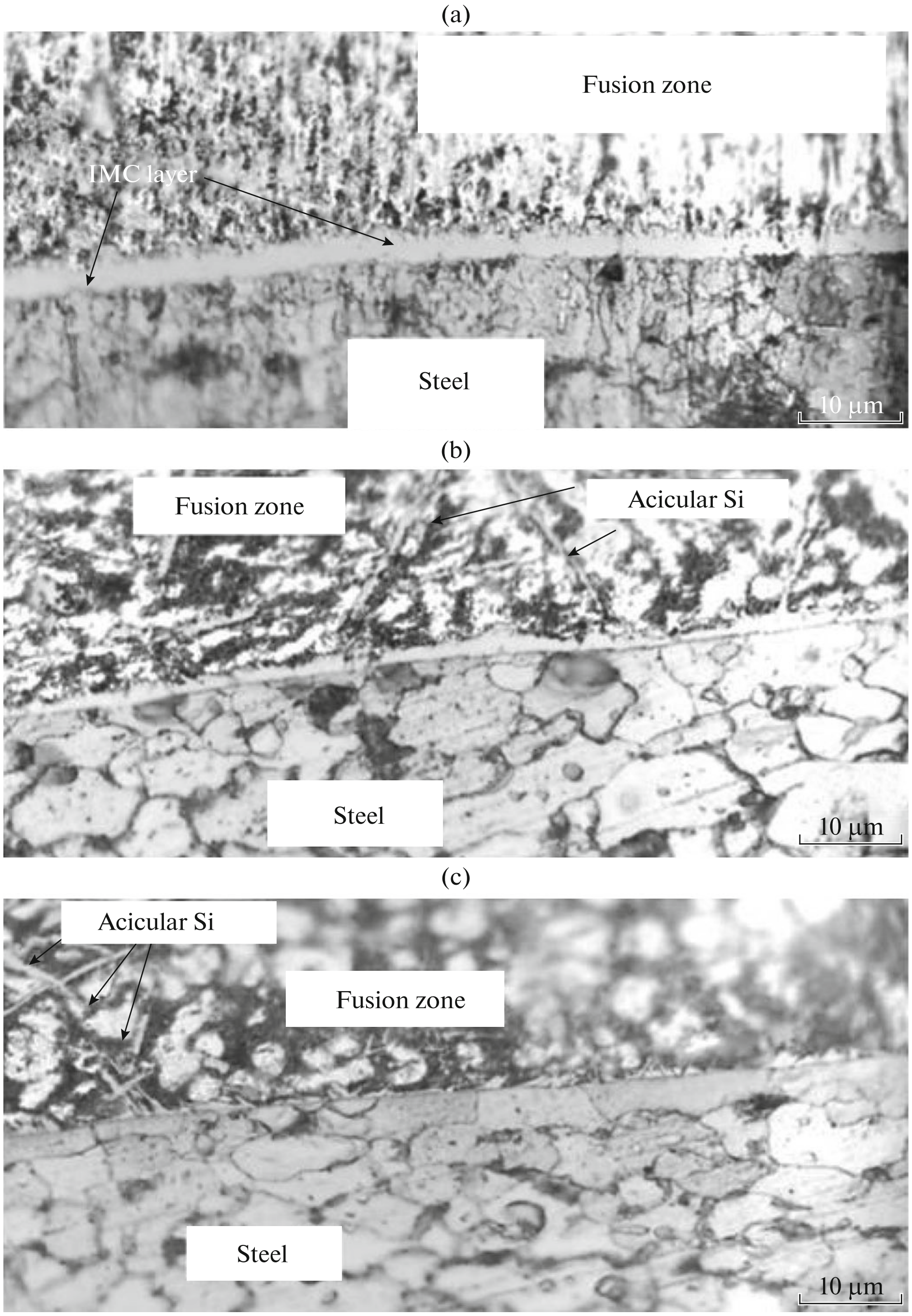

Fig. 7. Cross sectional microstructure of the interface region of steel/fusion zone produced as a function of pulse correction: (a) –5%, (b) 0% and (c) +5%.

the joint's hardness distribution was uniform in both conditions (+5 and –5% pulse correction). In other word, regardless of the pulse correction value, the hardness slightly increases with the increase of pulse correction. As seen, the maximum microhardness attained near the galvanized steel. It should be pointed out that the microhardness value decreased while getting away from the fusion zone.

4. CONCLUSIONS

Gas metal arc welding cold metal transfer (GMAW-CMT) method with $AlSi_3Mn$ filler wire was performed on welding of the 5754 aluminum alloy with thickness of 3 mm to the galvanized steel with thickness of 2 mm aluminum alloy to investigate the effect of pulse correction on structure and mechanical

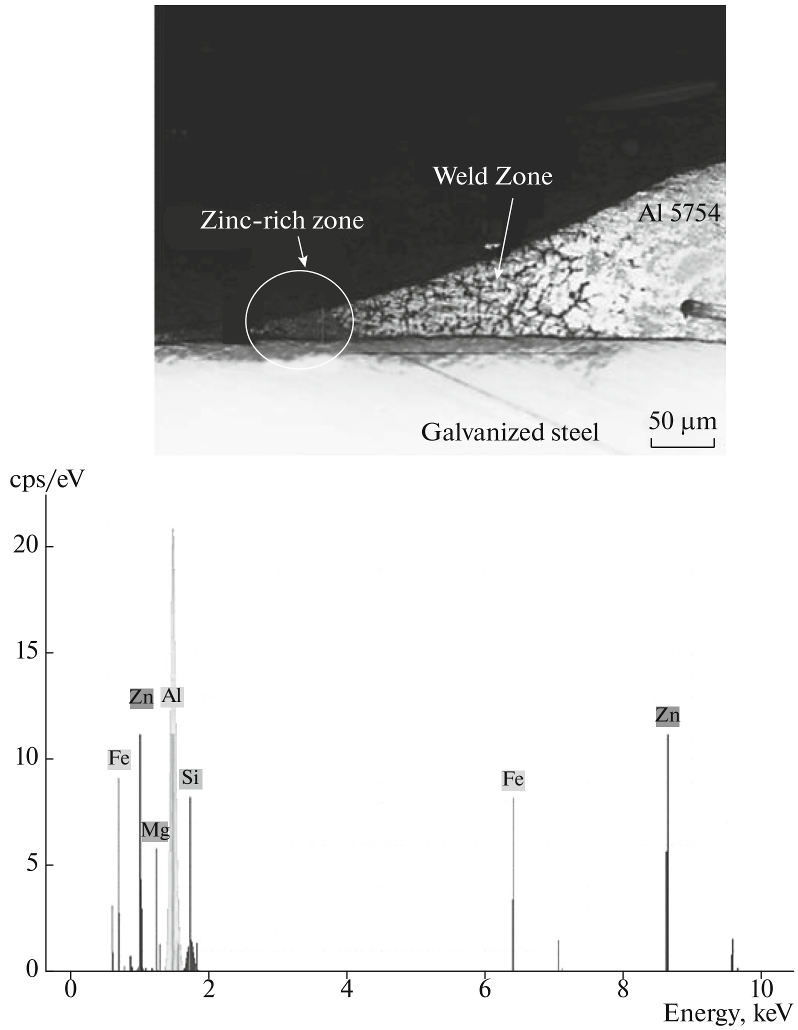

Fig. 8. Zinc-rich zone in weld toe along with the result of the EDS analysis of the location marked in figure.

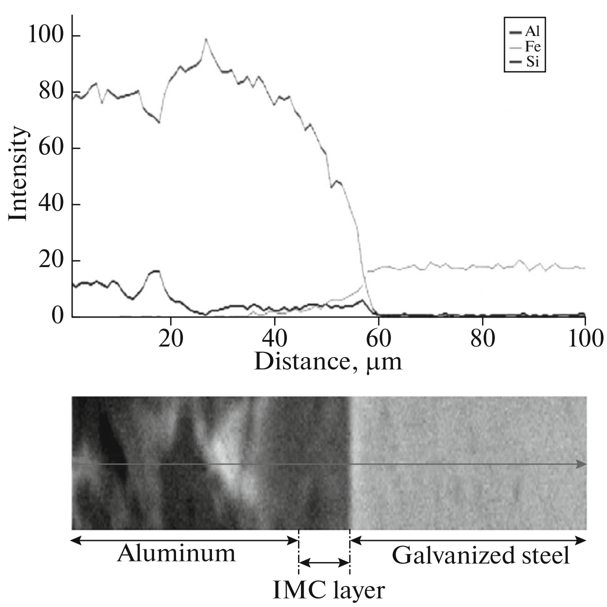

Fig. 9. Line scanning analysis of the aluminum-seam-steel interface layer.

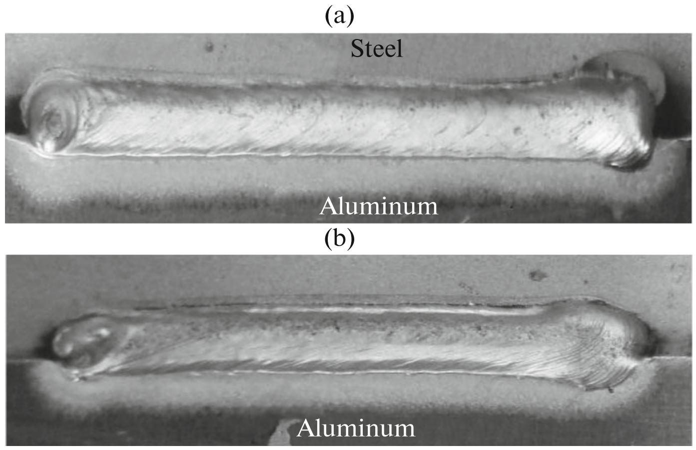

Fig. 10. Appearances of the joints under different pulse corrections: (a) –5% and (b) +5%.

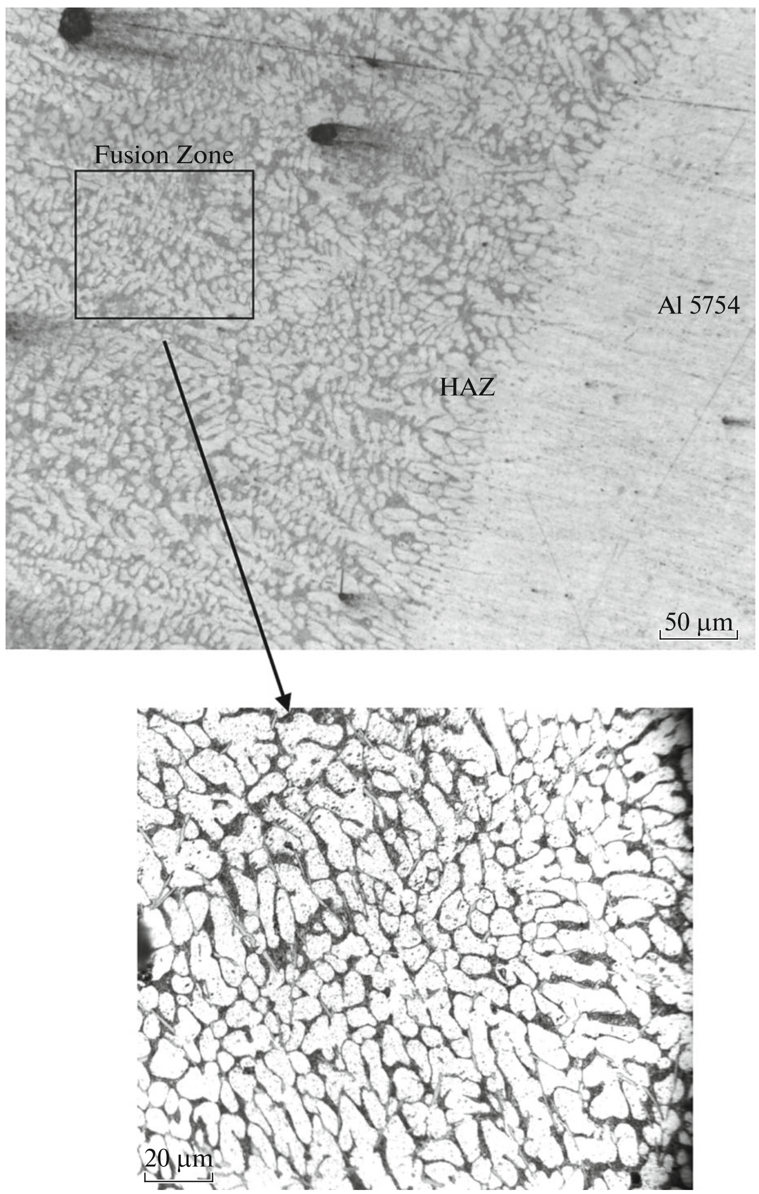

Fig. 11. The metallographic images of fusion zone (weld metal) structure.

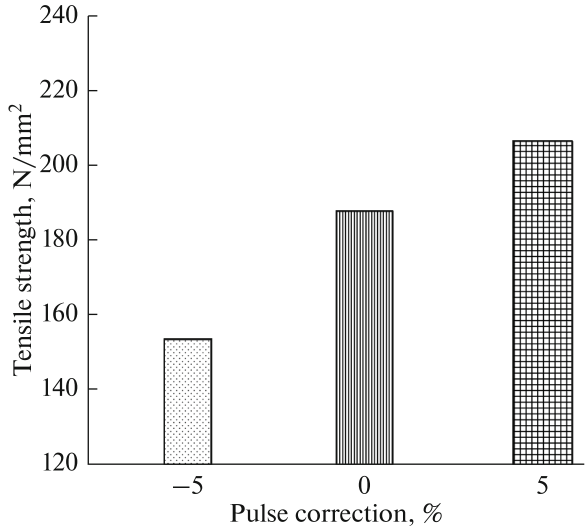

Fig. 12. Variation of the tensile strength versus pulse correction.

(a)

(b)

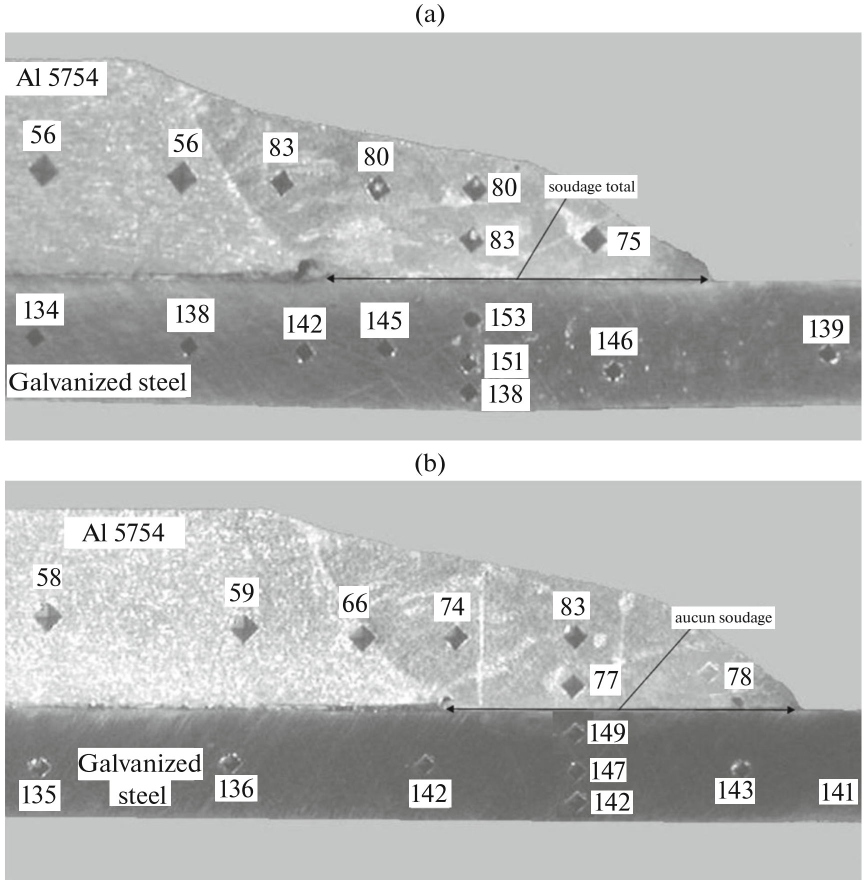

Fig. 13. OM images showing Vickers microhardness distribution in different regions during the GMAW-CMT: (a) +5% and (b) –5%.

properties of welded samples. Based on the experiments and results, it has been observed that:

(1) Increasing the pulse correction led to increase of flow in the filler wire and in fact increasing of brazed seam width and also throat weld size.

(2) The main effect of pulse correction was on the on IMC layer thickness and subsequently on the tensile strength. However, the best mechanical properties are obtained at higher pulse correction presumably due to the occurrence of thinner IMC layer thickness.

(3) It was found that, weld zone hardness is increasing as compared to the parent metal, but the hardness slightly increases with the increase of pulse correction. The maximum microhardness attained near the galvanized steel side (153 Hv).

(4) Pulse correction was a factor which had a major role on welded joints and with increasing the pulse correction, wetting angle on the surface of the steel sheet about 23% was decreased. In addition, zinc-rich zone region formed in the toe weld regardless of the pulse correction.

(5) In order to have a weld with good appearances and strength, in addition of filler wire and wire feed speed, also the pulse correction should be controlled.

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