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Pulsed DC Robotic MIG Welding of Non Heat Treatable Aluminum Alloys

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In this study, 5754 aluminum alloy sheets were joined at different welding speeds through the pulsed DC Robotic MIG welding method. The study includes microstructural and mechanical properties of welded joints. Tensile and three point bending tests were implemented in order to determine the mechanical properties of welded joints. The characteristics of the macrostructure and microstructure were examined via a stereo-microscope, an optical microscope. The hardness of the welded samples were measured on the cross section. As a result of the study conducted here, it was determined that mechanical properties are improved as welding speed increases. The porosities observed in the macrostructure did not have a significant reducing effect on mechanical strength.

Keywords: GMAW, Pulsed current, Aluminum alloy, Microstructure, Mechanical properties

1. INTRODUCTION

Today, one of the welding methods that are used most commonly in aluminum constructions is the MIG (Metal Inert Gas) welding technique which is implemented with a melting electrode in an atmosphere of a shielding gas or shielding gas mixture. MIG welding which is performed with a melting electrode has a very wide area of use. In comparison to other welding methods, MIG welding has many advantages through its economy, easy assembly, capacity to be mechanized, fast operation, compatibility for robotic use, ease of use in highly complex welding constructions, capacity to be used in every position and enable the welding of all commercial metals such as carbon steel, stainless steel, aluminum, copper, titanium and their alloys [1, 2, 3].

As it is known, gas metal arc welding (GMAW) stands out among other welding methods due its compatibility with automation. After the development of robotics, it was thought that the process could be carried out with robots and the implementation was started when it became possible to manufacture equipment which is compatible with robots [4]. Robots are able to carry out the welding process as precisely as a human [5]. Robots are mostly used with the CO_2, MIG, MAG, TIG and laser welding methods.

Ability to avoid mistakes arising from the welding operator have become factors which increase the feasibility and reliability of the MIG welding method when it is implemented with a robot [6]. Sectors such as the automobile industry, where the requirement for numbers and quality is high, responded very quickly to this development and a large number of robots started to be used in production within a short time. With the usage of the welding robot, production efficiency increased, the status of a welder changed and the stable welding quality required for automation was achieved [7]. At the same time, the number of robots used in the sectors of domestic appliances, general machinery and metals is on the increase as well. Robotic MIG welding is particularly common in automobile industry and its supporting industries, heavy industry fields, off-road vehicle production, machinery manufacture, shipyards and production facilities for trucks, rigs, trailers and truck beds.

When magnesium is used as the major alloying element or combined with manganese, the result is a moderate to high-strength, non-heat-treatable alloy. Alloys in this series are readily weldable and have excellent resistance to corrosion, even in marine applications. 5xxx series aluminum alloys are desirable for the automotive industry due to their excellent high-strength to weight ratio, corrosion resistance, very good thermal and electrical conductivity, weldability [8,9]. The excellent corrosion resistance of aluminum originates from the tightly bonded passive oxide film formed on the surface when it is exposed to air or water [10]. The corrosion resistance of metals depends upon the solid-state characteristics of the passive oxide film [11].

In this study, 5754 H-22 aluminum sheets were joined with the pulsed current robotic MIG welding method at different welding speeds parameters. The effects of the heat input which varies in accordance with the welding speed on mechanical strength and microstructural changes were examined.

2. EXPERIMENTAL PROCEDURE

In this study, 5754 H-22 aluminum alloy sheets of 2 mm thickness were used. Table 1 demonstrates the chemical composition of the materials used in the experiment while Table 2 contains the mechanical properties of the material. The chemical composition of the welding wire is given in Table 3 and the mechanical properties of the welding wire are provided in Table 4.

The welded joint process was carried out with an OTC brand A II-B4L (Long Reach) 6-axis welding robot in horizontal butt welding position at pulsed DC setting (pulsed current + pole) after the surfaces of the samples with the dimensions of 150 x 300 x 2 mm were cleaned with alcohol. The welding parameters used in the experiment are shown in Table 5.

Table 1. The chemical composition of AA 5754 H-22 wt%

Material	Fe	Si	Cu	Mn	Mg	Zn	Al
AA5754	0.311	0.22	0.025	0.35	3.2	0.164	Balance

Table 2. The mechanical properties of AA 5754 H-22

Tensile strength (MPa)	Yield strength (MPa)	Elongation %	Hardness (HV)
215	170	10.3	76

Table 3. The chemical composition of welding wire wt%

welding wire AlMg5	Si	Fe	Mn	Mg	Al
	0.25	0.4	0.3	5	Balance

Table 4. The mechanical properties of welding wire

welding wire AlMg5	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
	110	240	17

Table 5. The welding parameters

Samples	Current (A)	Welding speed (cm/min)	Voltage (V)	Shielding gas	Gas flow rate (lt/min)	Heat input (kJ/mm)
Z-1	90	75	17	Ar	20	0.097
Z-2	90	77	17	Ar	20	0.095
Z-3	90	79	17	Ar	20	0.092

Selection of pulsed DC for the welding process was made due to the knowledge that the usage of this setting leads to improvements in the mechanical properties of both the HAZ and the weld metal. This occurs because the pulsed DC feature generates low heat input in the weld zone and provides a high weld metal deposition rate [12,13]. Weld parameters are the most important factors of the MIG welding method which affect the cost, quality and efficiency of welded joints [14-16]. In order to determine the mechanical properties of the welded joints, three tensile test samples were prepared for each weld speed. The tensile test was conducted in a Testometric brand Micro 500 tensile testing device at 5 mm/min speed and the process was continued until breakage. Three test samples were prepared for each weld speed of the bending test as well. For examination of the microstructure and the macrostructure, the samples were polished respectively with 60-2000 mesh sandpapers and 1μ of diamond paste. After the polished samples were etched with Keller's reagent, the macrostructure was examined with Nikon brand L150A optical microscope and the macrostructure was examined with Nikon brand SMZ8000 stereo-microscope. The hardness measurements of the samples were conducted with a Matsuzawa brand MHT-2 microhardness device with the application of a 200 g load (HV0.2 kg) at 1 mm intervals with a depth of 0.5 mm from the surface.

3. RESULTS AND DISCUSSION

3.1 Tensile test

A tensile test was applied in order to determine the mechanical properties of samples joined with different welding speeds and the results can be seen in Table 6. Figure 1 demonstrates the tensile test samples.

Table 6. The tensile test results of samples

Samples	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
Base metal	131	215	13
Z-1	155	219	6.6
Z-2	159	224	6.8
Z-3	164	230	7.1

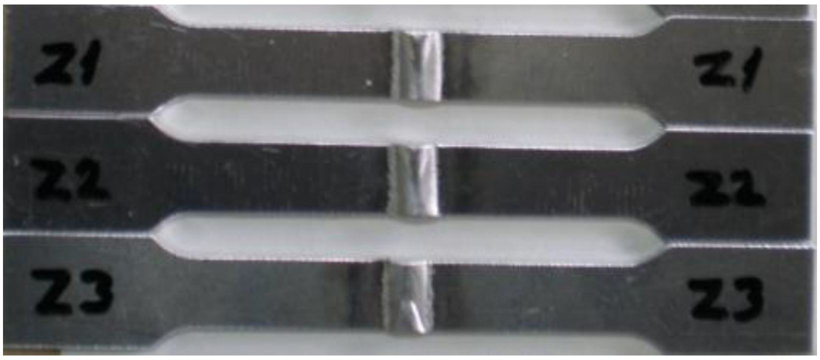

Figure 1. Macro image of the Robotic MIG welded samples

When the test results are examined, it is seen that the tensile strengths of the welded samples are slightly higher than that of the main material. According to the tensile strength results, it can be said that the welding speeds chosen for the tests yield acceptable weldability and strength values. The study also produced the result that it is possible to achieve sufficient tensile strengths for the welded joints of 5000 series (Al-Mg) aluminum alloys [17]. It is understood from the results of the study that an increase in welding speed or, in other words, a decrease in transfer of heat input to the weld zone improves tensile strength, even if by a small amount. During the tensile tests, none of the samples was fractured in the weld metal and the breakages of each sample occurred in areas close to the HAZ. It was determined according to the percentage elongation results of the welded samples that the said percentages decreased by a small amount in relation to the main material. The fact that the percentage elongation values of the welded samples were revealed to be lower than that of the main material can be said to cause the most of the deformation to occur in the HAZ and the area surrounding it. It can also be said that the welding current and the shielding argon gas have an effect on percentage elongation as well. Additionally, formation of a fine-grained structure in the weld metal through the effect of a low heat input caused the ductility of the welded samples to be lower in comparison to that of the main material. The temperature differences due to the heating and cooling in the weld zone which arise from the fact that the thermal expansion coefficients of aluminum and its alloys are high lead to severe internal stresses and distortions. In consideration of this adverse circumstance and as stated before, the test samples were joined with the pulsed direct current arc welding method. This method enabled the application of a strong pinch effect on every area of work that is desired, which in turn provided a suitable work environment via administration of a small heat input to the work piece without causing a short circuit. It also made it possible for molten metal drops of the desired number and size to be transferred to the work piece via adjustment of the frequency, which yielded a positive effect in enhancing the mechanical properties of the weld metal. In addition, the welding wire chosen for the study (AlMg5) is thought to have had a positive effect on the enhancement of the mechanical properties of the weld metal as well.

3.2 Bending test

The formability of the test samples was determined via the three point bending test. During the test process, the samples were folded with 180^0 angle. The controls carried out after the test revealed that there were no cracks in the welded joints. These results implicate that welded joints created with the method of robotic MIG can be easily given form under service conditions.

3.3 Microhardness examinations

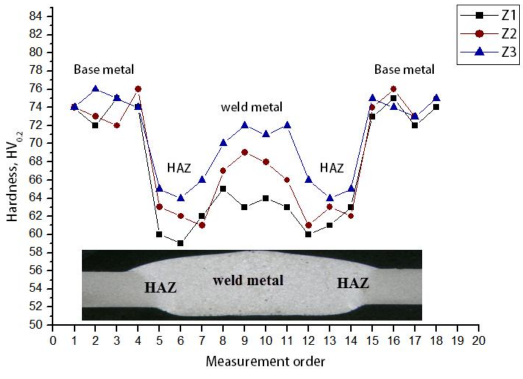

Figure 2. Microhardness distributions in the welded joint

The hardness distributions of the welded test samples were identified and shown in a graph in Figure 2.

The results demonstrated in Figure 2 indicates that the hardness values are similar to each other. In general, it was observed that the hardness value decreased by a small amount in the HAZ and increased by a small amount in the main material. It was also observed that, as the heat input increased, the hardness in the weld metal and the HAZ decreased in comparison to the main material. The reason behind the decrease of hardness in the weld metal is thought to arise from the recrystallization in the area. In addition, the fact that the HAZ structure is constituted of coarser grains in relation to the weld metal led to an even higher decrease in hardness value. The small amount of heat input-sourced hardness decrease in the HAZ indicates that there will also be a small amount of decrease in the mechanical strength in comparison to the weld metal. This is because hardness is one of the factors that affect mechanical strength in welding of aluminum alloys, in the same way as it is with iron alloys. Increase of the hardness value enables the strength to increase as well [18]. Additionally, the dendritic structures formed in the weld metal also constitute factors which affect and increase weld metal hardness. It should also be stressed here that chemical composition (i.e. increase or decrease of magnesium for non-heat-treatable aluminum alloys) and microstructure changes which may occur in the weld pool during solidification of the weld seam will also affect the changes in weld metal and HAZ hardness changes during the welding process of aluminum alloys.

3.4 Microstructure examinations

The main material, HAZ and weld metal areas of the samples joined at varying speeds were examined and the optical microscope images of these samples can be seen in Figure 3. When the microstructure images of the samples are inspected, it can be clearly seen that there are differences in microstructure and grain structure of the main material and the HAZ and the weld metal due to the heat input supplied to the HAZ and the weld metal. The microstructure images indicate that the distribution in the main material is homogenous while the structure in the HAZ is more irregular; it is also observed that the HAZ did not expand to cover a very wide area. The size of the HAZ defines the area in which the structural transformations in the weld zone occurred [19]. These structural transformations usually have an adverse effect on the mechanical properties of the material. During the welding process, the narrower the area to which the heat input is restricted, the narrower becomes the area in which the weld pool solidifies; as a result, the HAZ is limited to a narrower area as well. In the weld metal zone, a dendritic structure of equiaxed fine grains is seen; usage of pulsed current has a significant role in acquisition of this fine grained structure [11]. The dendrites observed in the weld metal were formed during the cooling period of the weld seam and these dendrites were also observed to show differences in size on the basis of the cooling rate. It is thought for one of the reasons of the lack of cracks in the weld metal to be the fact that this dendritic structure is also a fine structure. As a result of this dendritic and fine structure, the toughness and corrosion behavior of the weld metal is also expected to improvement. Coarsened grains distribution from base metal toward HAZ and weld metal might trigger the galvanic effects [20]. The compositional and microstructural changes across the welded joint may also deteriorate the corrosion resistance of the aluminum alloy. Loss of magnesium results in weak of the corrosion behavior and occurs hot crack susceptibility of non heat treatable aluminum alloys. it can be clearly seen in Figure 3, Figure 4 and Figure 5, is dependent on welded samples' chemical composition, hot cracks has not been occurred. It is considered that the existence of hot cracks in weld metal and HAZ plays an important role in the desired corrosion behavior. In addition, it should be noted that an increase in heat input can increase the sensivity to corrosion, and this corrosion behavior can be reduced by low heat inputs.

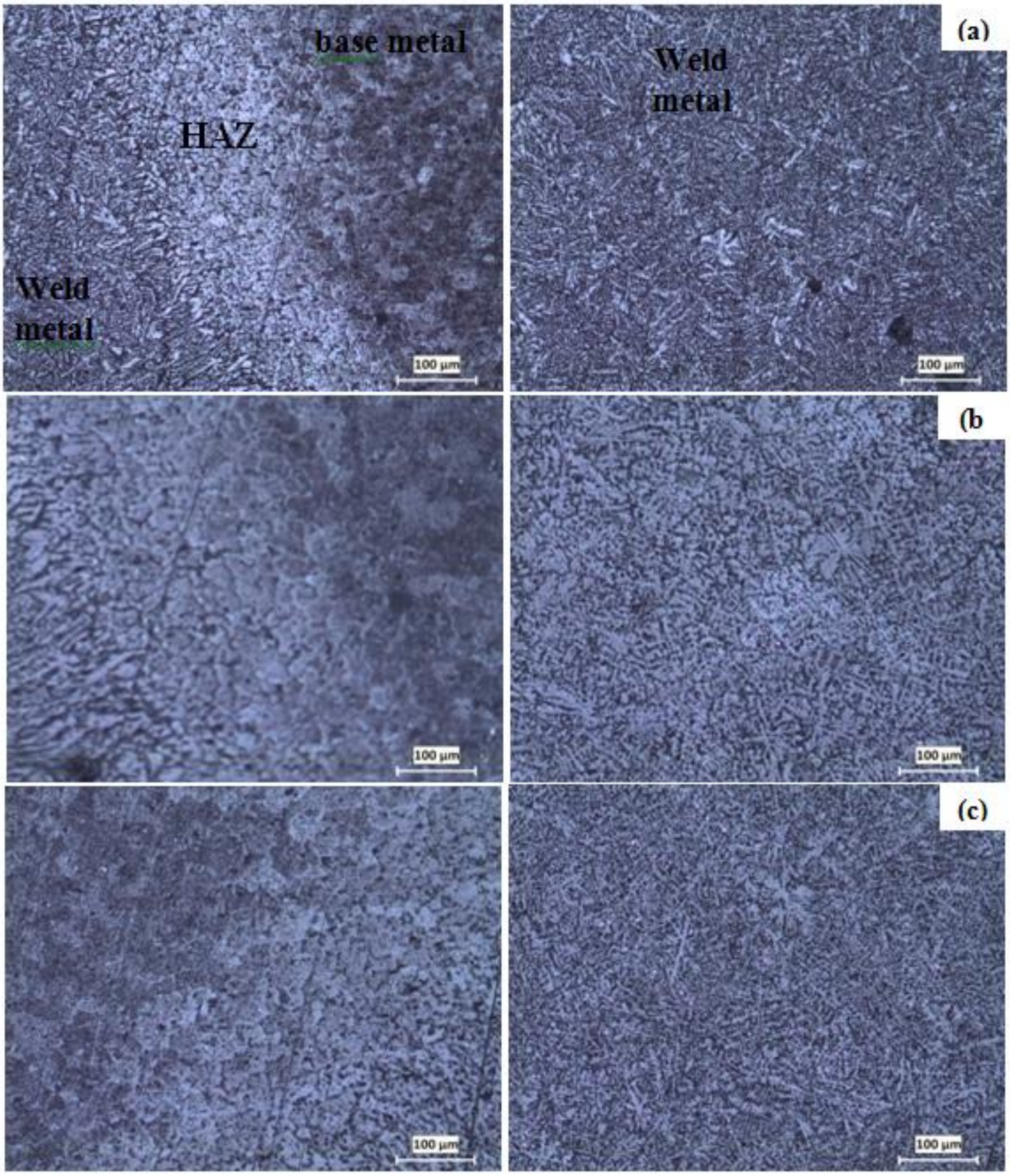

Figure 3. Microstructure image of welded samples, (a) Z-1, (b) Z-2, (c) Z-3

3.5. Macrostructure examinations

The macro images of the weld cross sections of the test samples are provided in Figure 4. Since the solubility of hydrogen is much higher when it is in liquid state rather than solid state, porosity occurs when the hydrogen which enters the weld seam during the welding process emerges as gas during the solidification phase [21].

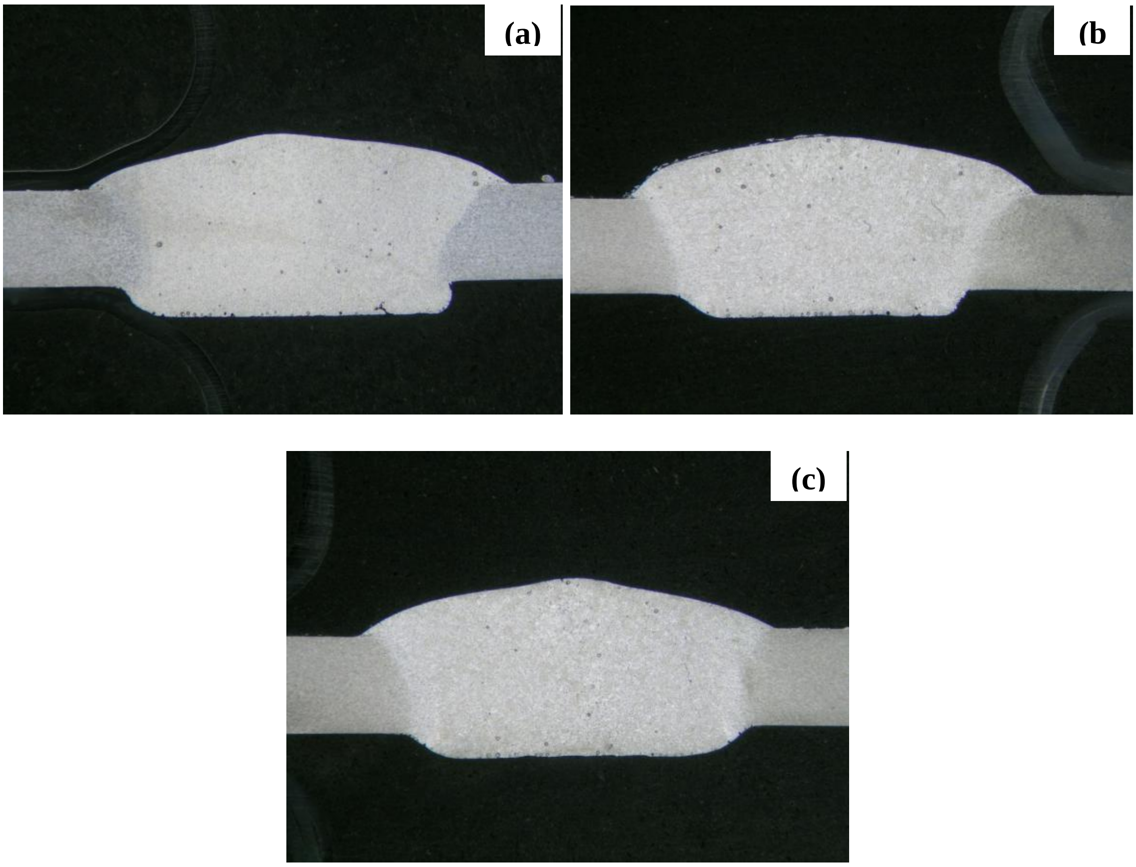

Figure 4. Macro image of welded samples, (a) Z-1, (b) Z-2, (c) Z-3

The porosity observed in the weld metal in macrostructure images is a normal condition that can be caused by the welding wire and shielding gas used during the welding of aluminum and its alloys; the size and number of the pores are at acceptable levels, which is also supported by the data derived from the results of the mechanical test. Since each welded sample was joined at the most suitable parameters, there were no lack of penetration defects and the fact that the test samples were joined with full penetration was proven by the macrostructure images. Additionally, usage of pure argon gas in the welding process enabled spray arc transfer due to low thermal conductivity of this gas. The spray arc provided a sound penetration in medium and high welding currents by forming a droplet diameter which is smaller than the welding wire diameter [22]. Usage of argon gas in welding of aluminum and its alloys helps in achieving a stable and controllable weld arc [23] and thus facilitates acquisition of the mechanical strength expected from welded joints.

The macrostructure photographs of the weld bead geometries of the welded samples can fully illustrate the suitability of the welding parameters and penetration status, as well as weld bead form and geometry. As it can be understood from the macrostructure images in Figure 5, it was observed that metal deposition rate increases as welding speed increases, which in turn leads to an increase in the weld bead geometry on an area basis.

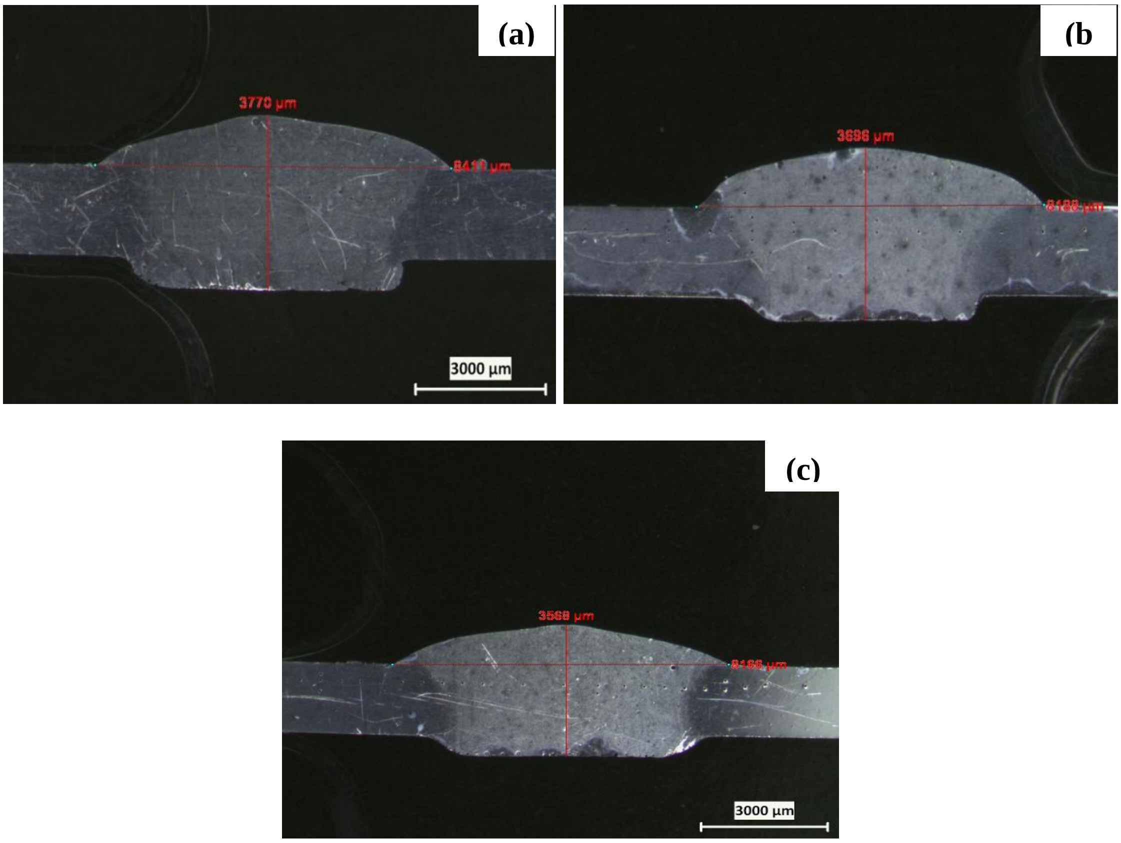

Figure 5. Image of weld bead geometry, (a) Z-1, (b) Z-2, (c) Z-3 samples

4. CONCLUSIONS

1. During the tensile tests, none of the welded samples was fractured in the weld metal and the breakages of each sample occurred in areas close to the HAZ.
2. The mean values derived from the results of the hardness measurements yielded the main material area as the hardest, followed by the weld metal with the closest value, and finally, the HAZ.
3. Usage of pulsed DC in the welded joints provided a low heat input and thus prevented distortions, found to be beneficial to improve the microstructure of welded joint (such as equiaxed fine grains, narrow HAZ) as well as facilitating acquisition of sufficient mechanical strength.

4. On the basis of above macrostructure and microstructural investigation results, existence of hot cracks in the weld regions can be concluded plays an important role in the desired corrosion behavior of samples.

5. Due to its speed and high melting rate, the robotic MIG weld method ensures for welded joints to be made swiftly and weld seams to be achieved with high quality.

6. The evaluation of the weld bead form, mechanical properties and microstructural characteristics obtained via welded joints yielded sufficient data for many industries.

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References

1. C. Köse, Z. Tatlı, *NWSA: Technol. Appl. Sci.*, 10 (2015) 12
2. N.J. Pires, A. Loureiro, T. Godinho, P. Ferreira, B. Fernando, J. Morgado, *IEEE Robotics & Automation Magazine*, 10 (2003) 55
3. T. Ueyama, T. Ohnawa, K. Yamazaki, M. Tanaka, M. Ushio, K. Nakata K, *Transactions of JWRI*, 34 (2005) 18
4. G.V. Gök, Ç. Afyon, Ç, TMMOB: Congress of Welding Technologies, 1999
5. P. Dahlen, G. Bolmsjö, *Int. J. of Human Factors in Manufacturing*, 6 (1996) 162
6. S. Yumurtacı, T. Mert, *TMMOB: Engineers & Machineries*, 50, (2009) 6
7. S.B. Chen, T. Qiu, *Intelligent Technologies for Robotic Welding, Robotic Welding, Intelligence and Automation, LNCIS 299*, 2004
8. S. Toros, F. Ozturk, I. Kacar, *Journal of Materials Processing Technology*, 1-3 (2008) 12
9. D. Wang, D. Yang, D. Zhang, K. Li, L. Gao, T. Lin, *Applied Surface Science*, 357 (2015) 2183
10. E. Romhanji, M. Popovic, *Association of Metallurgical Engineers of Serbia AMES*, 12 (2006) 307
11. J. Gandra, R.M. Miranda, P. Vilaça, *Materials Science and Engineering: A*, 528 (2011) 5599
12. H.J. Park, D.C. Kim, D.C, *Journal of Achievements in Materials and Manufacturing Engineering*, 27, (2008) 86
13. H.R. Ghazvinloo, A.H. Raouf, *Indian Journal of Science and Technology*, 3 (2010) 162
14. P.K. Ghosh, L. Dorn, M. Hübner, V.K. Goyal, *Journal of Materials Processing Technology*, 194 (2007) 175
15. L. Anna, T. Xinhua, L. Fenggui, *Materials & Design*, 50 (2013) 155
16. P.K. Ghosh, V. Sherma, *Materials Transactions, JIM*, 32 (1991) 150
17. L.O. Larsson, N. Palmquist, *Svetsaren*, 2/2000 (2000) 50
18. D.W. Moon, E.A. Metzbower, *AWS, Welding Journal*, 62 (1983) 53
19. M.K. Külekçi, A. Şık, A, TMMOB: Congress of Welding Technologies, 2003
20. M.B. Hariri, S.G. Shiri, Y. Yaghoubinezhad, M.M. Rahvard, *Materials & Design*, 50 (2013) 634
21. G. ÇAM, *TMMOB: Engineers & Machineries*, 46 (2005) 39
22. F. Wang, W.K. Hou, *Journal of Physics D: Applied Physics*, 36 (2003) 1152
23. PLC Air Products, *Welder's Handbook, Gas shield welding, oxy fual cutting and plasma cutting*, Air Product PLC, 1999