Materials Science Forum
ISSN: 1662-9752, Vol. 904, pp 19-23
doi:10.4028/www.scientific.net/MSF.904.19

Submitted: 2017-04-05
Revised: 2017-04-20
Accepted: 2017-05-04
Online: 2017-08-22

An Investigation of Dissimilar Welding Aluminum Alloys to Stainless Steel by the Tungsten Inert Gas (TIG) Welding Process

Van Nhat Nguyen[1,a], Quoc Manh Nguyen[2,b], Dang Thi Huong Thao[2,c] and Shyh-Chour Huang[1,d]

[1]Department of Mechanical Engineering, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan

[2]Hung Yen University of Technology and Education, Khoai Chau, Hung Yen, Vietnam

[a]duynhat240685@gmail.com, [b]manhrobocon@gmail.com, [c]thaomanhutehy@gmail.com, [d]shuang@cc.kuas.edu.tw

Keywords: TIG welding, A6061 alloys, 304 stainless steel, Aluma-Steel rod.

Abstract. Welding dissimilar materials has been widely applied in industries. Some of them are considered this as a strategy to develop their future technology products. Aluminum alloy and stainless steel have differences in physical, thermal, mechanical and metallurgic properties. However, selecting a suitable welding process and welding rods can solve this problem. This research aimed to investigate the T-joint welding between A6061 aluminum alloy and SUS304 stainless steel using new welding rods, Aluma-Steel by the Tungsten Inert Gas (TIG) welding process. The mechanical properties, the characteristics of microstructure, and component analysis of the welds have been investigated by the mechanical testing, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). As a result, the fracture occurred at the adjacent area between welding seam and A6061 alloys plate. The thermal cracking appeared at central welding-seam along the base metals if high welding current. A large amount of copper elements found in the welds due to using the new welding rod, Aluma-Steel rod.

1. Introduction

Dissimilar materials welding helped the potential provided the advantages of two materials often providing for the solutions to engineering requirement order to reduce the weight and corrosion resistance of materials have been a major concern and a big challenge for researchers in recent years in the techniques and technology, dissimilar welding often use in industrial applications having complex functions but retaining stability of textures during the used process. The combinations of dissimilar materials have been widely applied for car-body construction, shipbuilding, aerospace body structures and skin panels in order to reduce the weight and decrease of the fuel consumption levels and greenhouse gas emission. This process has been widely applied mainly on the industries such as car-body construction, shipbuilding, aerospace body structures and railway transportation and skin panels. However, the process combination dissimilar materials become inevitable to hybrid structure formation between two materials by the differences in thermal-physical properties and melting temperatures of two materials and especially the formation of brittle intermetallic layer (IMCs) during welding process at high temperature [1]. Many authors have been successfully applied welding between aluminum alloys and stainless steel by bonded weld and mechanical fastening by others methods such as Laser welding [2], Metal inert gas welding [4], Friction stir welding [4], Ultrasonic welding [6], ... Using one method with the welding filler material to get the best result is always a desire of the manufacturers because it will bring them many advantages such as: reducing production cost and providing a better choice for the new welding process of aluminum to steel. Nowadays, tungsten inert gas (TIG) welding is used as a common approach to weld aluminum alloy to steel; the base and filler metals are melted by arc and welding rods will be supplied by hand throughout the process. The welding heat sources generate high temperature distributed around the welds, the molten welding pools are protected from the outside environment by an inert gas flow which can be Argon, Helium or their mixed gas. During the welding process, the brazing joint happens at the stainless steel surface plate and in aluminum alloy it is diffusion joint. The aim of this study is to investigate the weld joint properties and characteristics between A6061 aluminum alloy and SUS304 stainless steel using new filler metal (Aluma-steel welding rod) by TIG welding process. The material could be successful welded and reduced hardness and brittle of intermetallic layer in dissimilar metal welding helped weld joint better strength. This research particular was concentrated on interface microstructure characterization and microstructure welded joint.

2. Materials and Experimental Procedures

The materials used were A6061 alloys and 304 stainless steel sheets with a size of 150x70 mm and a thickness fixed of 6mm. The Aluma-Steel welding rods with the diameter of 2.4mm were chosen to be the filler metal. The chemical compositions used in this aim shown in Table 1, 2 and Table 3 was analyzed by Spectrotest and PMI - UV Plus equipment.

Table 1. Chemical composition of A6061 alloys (wt %) [6].

Material	Al	Si	Mg	Cu	Cr	Fe	Mn
A6061	Bal.	0.4-0.8	0.8-1.2	0.15-0.4	0.04-0.35	<0.7	<0.15

Table 2. Chemical composition of 304 stainless steel (wt %) [7].

Material	Fe	Ni	C	Si	Mn	Cr	P	S	O
SUS304	Bal.	8.19	0.06	0.04	0.96	18.22	0.027	0.002	0.002

Table 3. Chemical composition of Aluma-Steel welding rods (wt %).

Material	Cu	P	Al	Si	Fe	C	O	Ca
Aluma-Steel	Bal.	5.0	0.4	0.7	0.2	13.2	3.3	0.1

The aluminum alloy edge chamfered double-bevel angle at 40°, the surface of materials cleaned by the sandpapers. The gap between two sheets was 2.5-3mm. The schematic geometrical of welding between A6061 alloys and 304 stainless steel was shown in Figure 1. The equipment used in the experiment includes: TIG pulse equipment, universal testing equipment; Optical Microscopy equipment; and SEM/ESD system. The experimental process used argon shield gas is 12l/min. 2.4mm diameter tungsten electrodes were selected, the size of the gas nozzle is 6mm, the welding speed of 4mm/s, the welding voltage was 17V, and the welding current pulse of 95 and 160A.

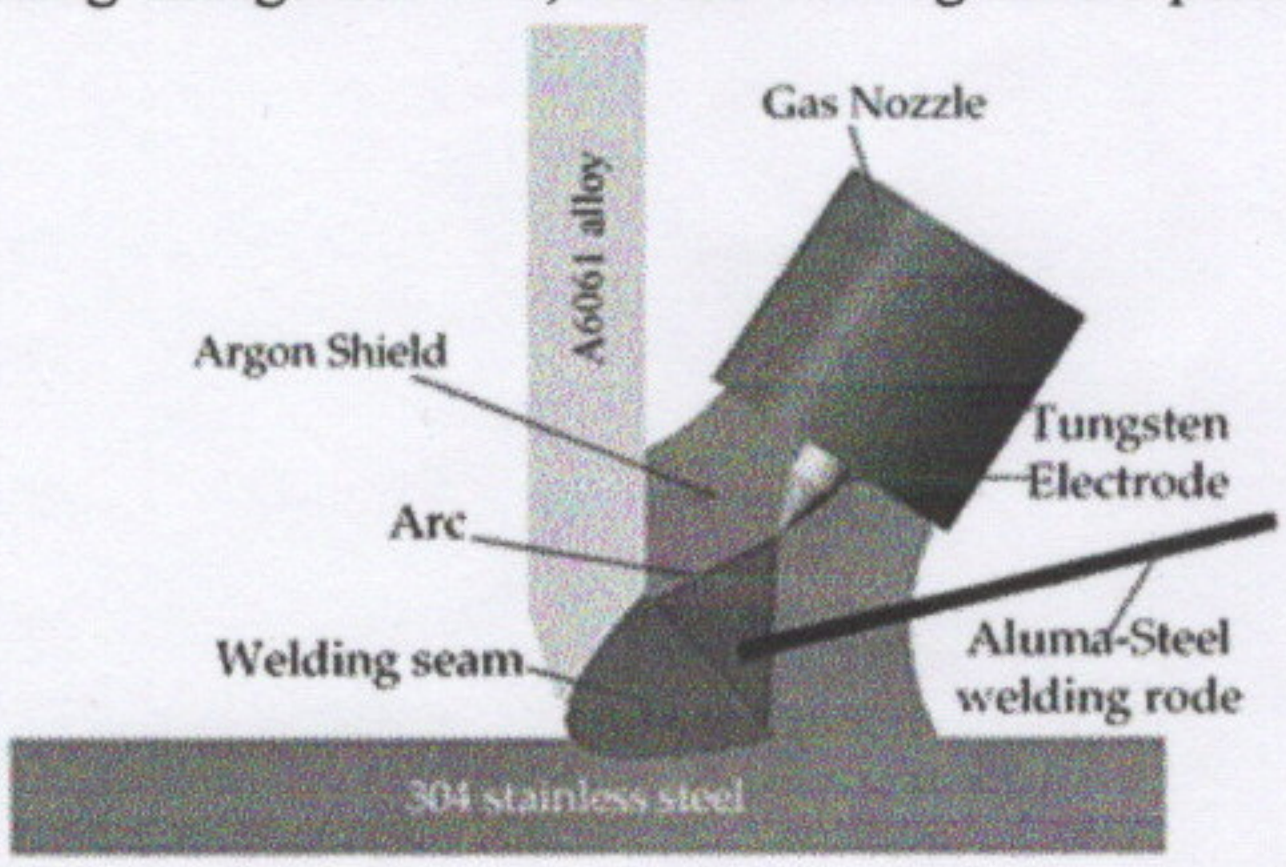

Figure 1. Schematic TIG process between A6061 alloys and 304 stainless steel.

3. Results and Discussions

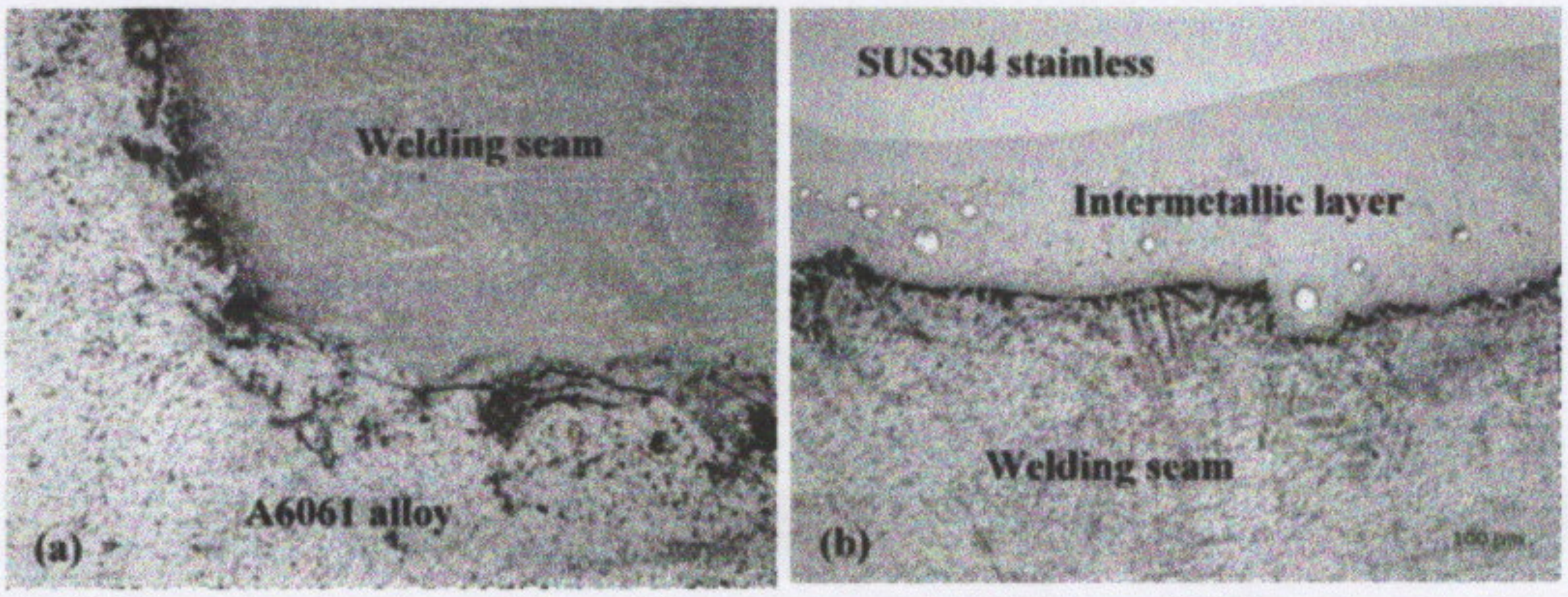

Figure 2. (a) The microstructure of the welding seam and A6061 alloy, (b) The microstructure of the SUS304 stainless steel and the welding seam.

The micro-structure of the welding-seam between A6061 alloys and 304 stainless steel using pulse welding intensity of 95A, 160A, with welding voltage of 17V, welding speed of 4mm/s were presented in figure 2. The results shown that the welds can be advantaged quality if chosen well the welding parameters. The micro-structure between welding-seam and A6061 alloys plate was shows in figure 2(a). In this area, there was a major combination of the Al atoms in the aluminum alloy sheet with Cu and P atoms in the Aluma-Steel welding rod. The structure of the welds in the area was the same as that of the normal welds. The formation of the welds was the A6061 alloy with the welding seam basing on the soluble principle and then liquid crystallization. Figure 2(b) presents the joint formation between the welding seam and SUS304 stainless steel surface stainless steel sheet area. Could see in the area, the welds were formed because of the brazing-welding because the melting temperature of the stainless steel was higher than that of the welding rod temperature. At the adjacent area between the welding seam and the stainless steel, there was a combination of Cu, P atoms in welding rod with the chemical compositions of the stainless steel such as Fe, Cr, Ni..., which created a grey intermetallic layer.

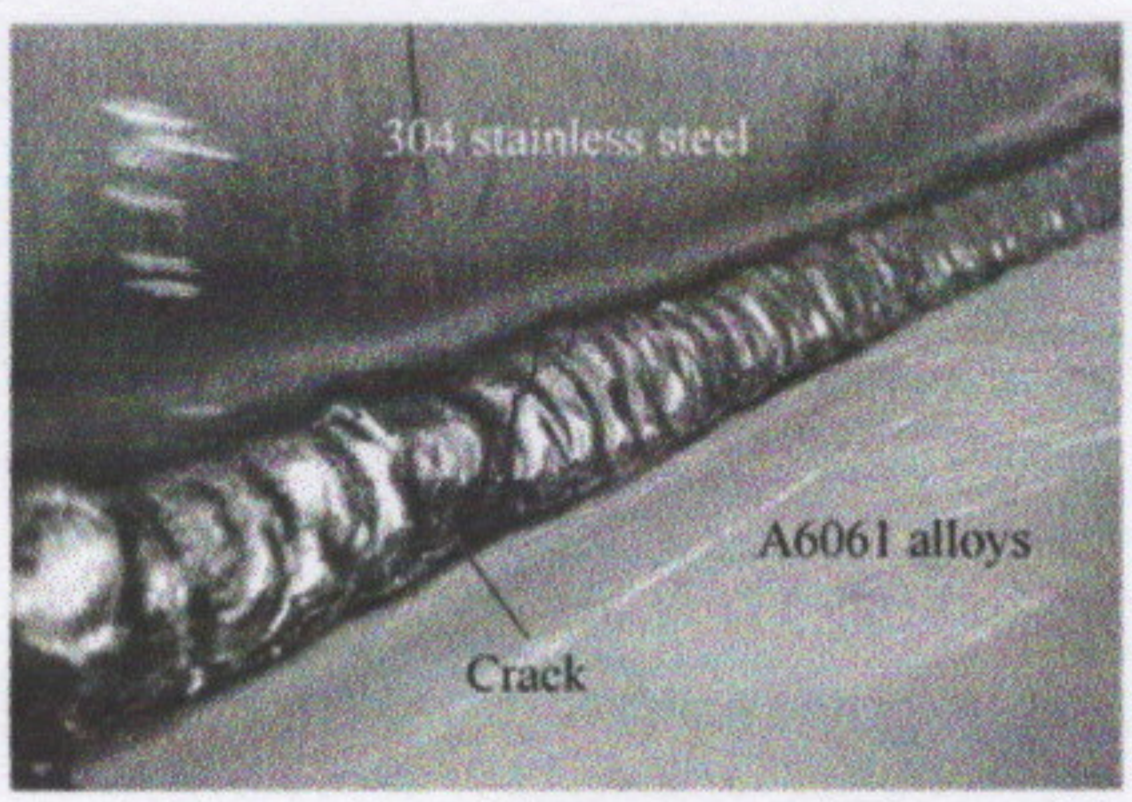

Figure 3. Thermal cracking appeared after welding.

After welding process, the thermal cracking appeared at central welding-seam along the base metals if high welding current, low welding speed and the arc directly affected the stainless steel surface were used such as figure 3. From results could see that choosing a suitable welding current has great influence on the fusion of Al base metal as well as the weldability and spreading ability of the welding-seam metals; it can also lead to the quality change of welds, and as seen, affect the formation of the continuous surface appearance.

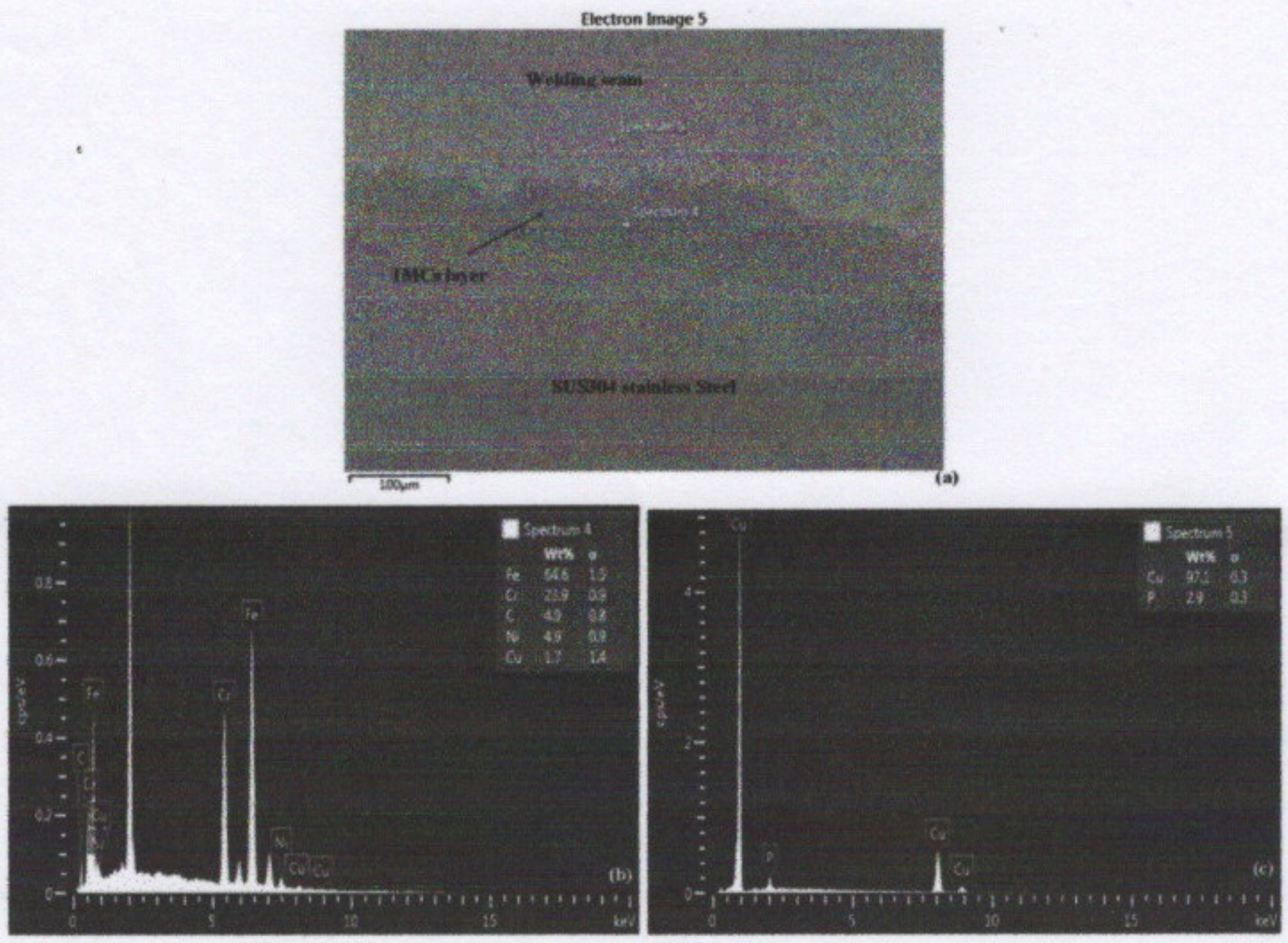

Figure 4. Energy dispersive X-ray spectrometer (EDS) analysis results between welding seam and SUS304 stainless steel (a) Analysis positions; (b) Corresponding amounts at spectrum 4; (c) Corresponding amounts at spectrum 5.

The metal chemical components on the IMCs layer zone was presents in the figure 4, spectrum-4 in the middle of the IMCs layer and spectrum-5 in the welding-seam as testing by EDS. In figure 4(b), (c) shows the results of chemical composition analysis at IMCs layer with location number 4 includes 5 composition such as: Cr=23.9%, Ni=4.9%, Cu=1.7%, C=4.9% and Fe=64.6%; and location number 5 were P=2.9% and Cu=97.1%.

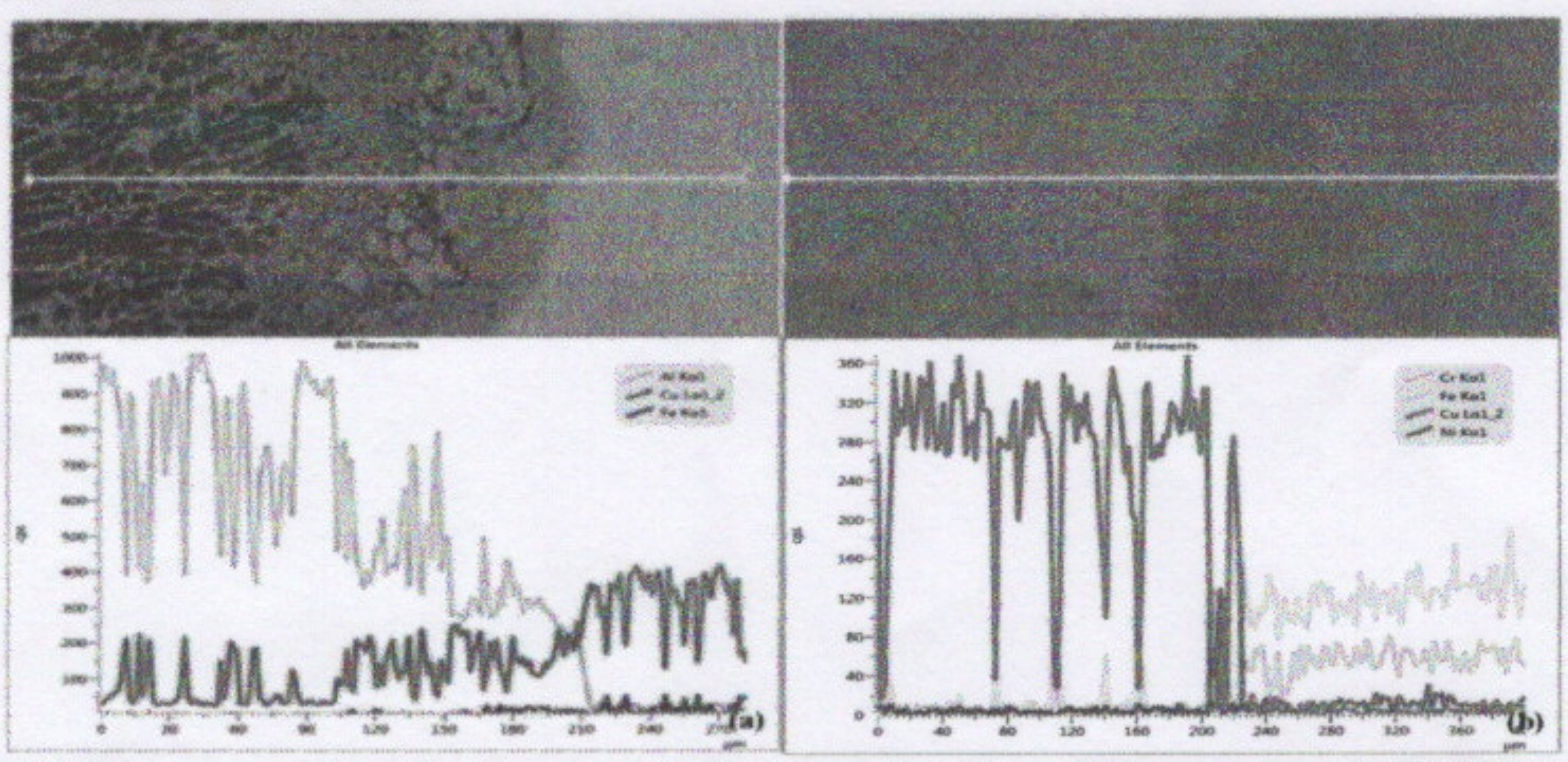

Figure 5. EDS line scanning interface results between the (a) welding seam and SUS304 stainless steel interface layer, (b) welding seam and A6061 alloys.

Figure 5(a) presents the results of the EDS line scan interface layer analysis between the 304 stainless steel and welding-seam and figure 5(b) presents the results of the EDS line scan interface layer analysis between the A6061 alloys and welding-seam. The results shows that, at the 304 stainless steel and welding-seam the atoms Al, Fe, and Cu component which appeared at the welds surface with a large copper (fewer than aluminum from base metal). And at the A6061 alloys and welding-seam the atoms Cr, Fe, Cu, and Ni component which appeared at welding seam surface with a large copper occupy a large number. This indicates the participation and diffusion of the two elements are decisive to the formation of welds at stainless steel and aluminum alloys adjacent areas.

4. Conclusions

The dissimilar joining between SUS304 stainless steel and A6061 alloys by TIG welding process using Aluma-Steel welding rods. The microstructure, and the microstructural characteristics were investigated. The major conclusions of this research should be summarized as follows:

- To make the welding process successfully, the author's should choose the appropriate filler metal and reasonable welding gaps, chosen good welding parameters and use well gas shield to protect the welding pool well during the welding process.
- The welding joints needed be cool down from 35°C – 60°C after each welding layers then the next welding layer to reduce the thermal cracking after welding.
- In addition, the copper atoms was found between the A6061 alloys plate and welding-seam, as well as between the 304 stainless steel plate and welding-seams showed that the diffusion of this atom contributes greatly to the successfully of the welding process of the materials A6061 alloy to 304 stainless steel in this research.

Acknowledgments

The authors acknowledge and thank the Ministry of Science and Technology of the Republic of China for their partial financial support of this study under Contract Number MOST 105-2221-E-151-016.

References

[1] K.J. Lee, S. Kumai, N. Kawamura, N. Ishikawa, K. Furuya. - Growth manner of intermetallic compounds at the weld interface of steel/aluminum alloy lap joint fabricated by a defocused laser beam, Materials Transactions, 48 (2007) 1396–1405.

[2] S. Yana, Z. Hong, T. Watanabe, T. Jingguo. - CW/PW dual-beam YAG laser welding of steel/aluminum alloy sheets, Optics and Lasers in Engineering, 48 (2010) 732–736.

[3] Q. M. Nguyen, S. C. Huang. - Investigation of the Microstructure of an Intermetallic Layer in Welding Aluminum Alloys to Steel by MIG Process, Materials, 8 (2015) 8246–8254.

[4] Y.F. Sun, H. Fujii, N. Takaki, Y. Okitsu. - Microstructure and mechanical properties of dissimilar Al alloy/steel joints prepared by a flat spot friction stir welding technique, Materials and Design, 47 (2013) 350-357.

[5] T. Watanabe, H. Sakuyama, A. Yanagisawa. - Ultrasonic welding between mild steel sheet and [6] C.M. Chen, R. Kovacevic. - Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding, International Journal of Machine Tools & Manufacture, 44 (2004) 1205-1214.

[7] S. Lu, H. Fujii, K. Nogi. - Arc ignitability, bead protection and weld shape variations for He-Ar-O2 shielded GTA welding on SUS304 stainless steel, Journal of Materials Processing Technology, 209 (2009) 1231-1239.Al–Mg alloy sheet, Journal of Materials Processing Technology, 209 (2009) 5475–5480.