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Environment effect on microstructure properties of gas tungsten arc welding for titanium and aluminium alloy joints

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Many engineering applications are in need of high strength and low weight alloys; titanium and aluminium alloys are used in several engineering applications to reduce weight. In this study, investigate effect of environment conditions on microstructure properties of gas tungsten arc welded assisted with brazing of titanium alloy Ti-6Al-4v and aluminium alloy Al7075 has been carried out. Alloys are made joined together in natural environment and at shielded argon gas environment conditions. Mechanical properties have been arrived, tensile tests have been conducted to examine the strength of weld and results have been achieved 92.3 Mpa and 356 MPa in regular and argon environment, respectively. Vicker's hardness value of 103.4 Hv and 183.1 Hv has been attained in respective environment condition. Fatigue properties have been elevated and fracture surface of the specimens analyzed in respective mechanisms. Welding speed, arc voltage and welding current parameters are considered to join the dissimilar alloys in both environments and identified the most influencing parameters. SEM and XRD techniques have been used to weigh up the microstructures of weld interface. The outcomes confirmed that argon gas, as a joining environment, has a substantial blow on properties of mechanical and microstructure of the weld joint.

Keywords: Environment effect, Microstructure, Dissimilar, Titanium alloy, Aluminium alloy

1 Introduction

In present days, several manufacturing industries like automobile, aerospace and structural industriesare involving in build up the new materials as high strength to weight ratio to improve their quality of performance. The study has been performed about developing the different kind of welding process to enhance high strength and low weight alloys. Titanium alloys and aluminium alloys are presently used in various industrial applications due to the physical properties like weight, strength and corrosion of these alloys. Titanium and aluminium alloy joint is made by gas tungsten arc welding and interface is analyzed through electron probe micro-analyzer (EPMA) and X-Ray Diffraction (XRD) techniques[1]. Laser welding is employed to make dissimilar joints of titanium and aluminium alloys[2,3], fusion welded joints between titanium and aluminium alloys can be carried out through electron beam welding which provides coarse β at heat affected zone of titanium 17 alloy side[4]. To improve the strength of mechanical properties, the inter-metallic composite thickness has to be reduced. Titanium is one of the most significant nonferrous metals. Pulsed current single pass gas tungsten arc welding of titanium thin sections was accomplished found to be greater to conservative constant current process in provisions of grain improvement in the fusion zone[5]. Few studies are carried out in micro structural and mechanical properties through friction stir welding, laser welding and assisted with gas tungsten arc welding (GTAW)[6-9]. The intermetallic elements like TiAl, $TiAl_2$ and Ti_3Al at the interface of dissimilar joint of titanium and aluminium alloy can be easily formed in laser beam welding, friction stir welding[10,11]. Fatigue properties were analyzed, final rupture region, the surface is described by indentations illuminating ductile behavior[12]. In this study, titanium (Ti-6Al-4V) and aluminium (Al7075) dissimilar material has been joint using pulsed current gas tungsten arc welding in open environment and closed chamber environment. The mechanical and fatigue properties are calculated for welded samples to evaluate the tensile, hardness and fatigue strength of the weld joints. Majorly three factors are considered as parameters to attain the maximum result in mechanical properties and intermetallic compounds. Parameters are welding current, Arc voltage and Welding speed. The microstructural examination is carried out to discover the refinement of particle structure and bonding

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connection between the dissimilar materials of titanium and aluminium in the weld interface which varies from the base metal. Energy dispersive X-Ray (EDX) and scanning electron microscope (SEM) examination is prepared to inspect the materials composition and investigate the fracture surface of the material.

2 Method of Experiment

2.1 Selection of Material

Gas tungsten arc welding process is considered to conduct this research worktitaniumand aluminium alloys are considered as parent material and the chemical properties of the parent materials are listed in Table 1 and Table 2. The chemical elements of the filler material are listed in Table 3.

2.2 Work Piece Design and Welding Parameters

GTAW, the specimen dimensions for both titanium alloy and aluminium alloy are measured about 100 mm in width, 200 mm in length and 3 mm thickness. Titanium alloy specimens are made with 40˚ bevel angle whereas aluminium specimens are remains same dimensions, because melting temperature between the titanium (Ti-6Al-4v) and aluminium alloy (Al7075) is varies a lot nearly twice. Titanium Specimen is machined with 1 mm root face and placed with standard condition. Titanium and aluminium specimen placed on the copper backup plate is shown in Fig.1.

Pulsed current gas tungsten arc welding equipment is used to join the dissimilar materials of titanium and aluminium alloys. The joining process is carried out in two conditions; process carried out with an open environment and the same process is conducted in closed environmental setup. For making controlled environment argon gas is used as a medium, argon gas is acting as a resisting layer between the environment and welding setup. Copper plate with holes is used as a backup plate to control the temperature distribution along the specimen and expand the flow of filler. Closed chamber is developed with four holes and a window; tubes are inserted through the hole for supplying argon gas to the chamber as well as through the copper backup plate. Window is provided for welder to view the fusion area on the specimen. Specimen surface is developed by cleaning the top surface with Silicon Carbide paper and acetone previous to the experiment initiate. Figure 2 illustrate the open environment setup, Fig. 3 shows the closed environment setup. In

Table 1 — Element composition of titanium alloy (Ti-6Al-4V).

Elements	Al	Ti	Cr	Cu	V	Fe	Si	Zn	Mg	Mn	Zr
Parent material – 1 Ti6Al4V (wt. %)	6.2	89.7	-	-	3.8	0.1	0.1	-	-	-	0.1

Table 2 — Element composition of aluminium alloy (AA7075).

Elements	Al	Ti	Cr	Cu	V	Fe	Si	Zn	Mg	Mn	Zr
Parent material – 2 Al 7075 (wt. %)	89.5	0.1	0.2	1.5	-	0.3	0.25	5.4	2.6	0.15	-

Table 3 — Element composition of aluminium filler rod (AA 4047).

Elements	Al	Ti	Cr	Cu	V	Fe	Si	Zn	Mg	Mn	Zr
Filler material AA 4047 (wt. %)	86.25	-	-	0.3	0.15	0.4	12.3	0.2	0.1	0.1	0.2

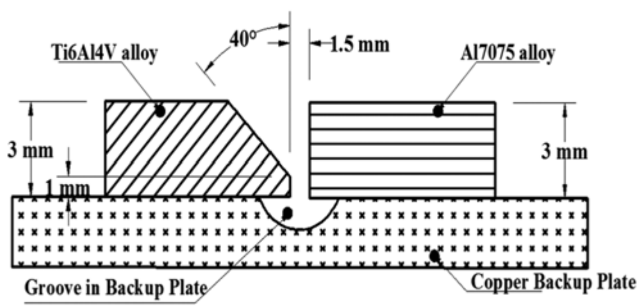

Fig. 1 — Work piece design setup diagram.

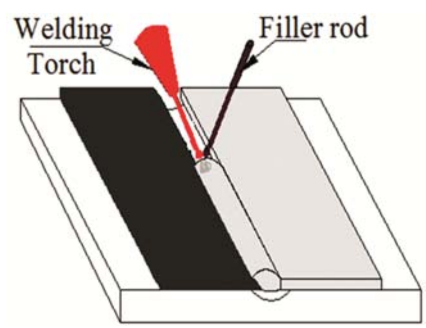

Fig. 2 — Setup diagram for an open environment .

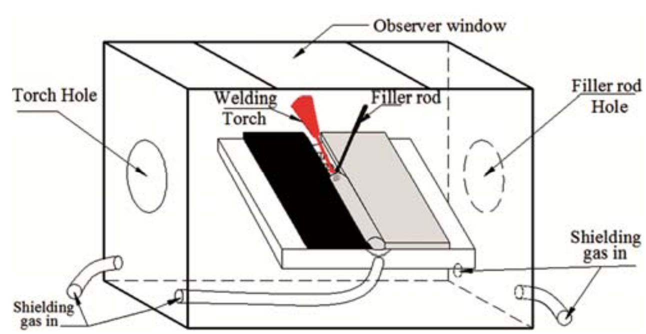

Fig. 3 — Closed chamber setup for pulsed GTAW process.

gas tungsten welding process, many parameters are influencing the quality of welds like welding current, welding speed, arc voltage, gas flow rate, electrode and filler wire diameter. In this work the major affecting parameters are considered and manually select the values for joining these dissimilar materials. The parameters are welding current (70-110A), Welding speed (50-100 mm/min) and arc voltage (12-18 Volts) other parameters considered as uniform because contribution percentage is very low. Parameters are listed in Table.4. Titanium alloy and aluminium alloy were joined using pulsed current gas tungsten arc welding process Tensile test is experienced to determine the uniqueness of the materials and bonding strength for five samples with different parameters. Universal testing machine (1000) TUF CN – Servo was used to conduct the tensile test. The tensile test is conducted to determine the parameters affecting the tensile properties of the fused dissimilar materials aluminium alloy and titanium alloy and confirmed that grain size, formation of new arrangements between them and cooling rate of the welded specimens are the main reasons in presenting the better joint strength and excellence of the welded samples[13]. Figure 4 illustrates the standard tensile test specimen.

Fatigue investigation were carried out with SPRANKTRONICS Multi axial fatigue testing machine, ASTM-E606 standard is considered to develop the specimen and manufactured using electro discharge machining. Ultimate tensile test report is used for fatigue load and is applied as the basic load by percentage basis on sample to calculate greatest fatigue properties like no of cycles and fatigue load[14,15]. In order to evaluate the understanding of the optimal fatigue strength fashioned between titanium and aluminium alloy using aluminium filler with 12% Si, fractography examination was accomplished to monitor the changes encouraged in the fracture zone. Schematic diagram of fatigue test specimen is shown in Fig. 5.

The fused samples are focused to micro structural inspection to discover the material aspects at the fused zone. Optical electron microscopy is used to examine the both samples from open environment and closed chamber environment. Microstructure of specimens of the welded joint are observed using SEM also in this study energy-dispersive X-ray spectrometer (EDS) is used to observe the microstructure of the welded joint operational with for analyzing the chemical constitution[16]. VEGA 3 TESCAN machine is used to carry out the micro structure study and the software engaged in this equipment is to scan the welded specimen along the welding boundary zone and beam plotting to attain the X-ray cartography or absorption of profile by elements correspondingly.

Table 4 — Parameters range of pulsed GTAW.

PARAMETERS	RANGE	
	Low	High
Welding current (A)	70	110
Welding speed (mm/min)	50	100
Arc voltage (V)	12	18

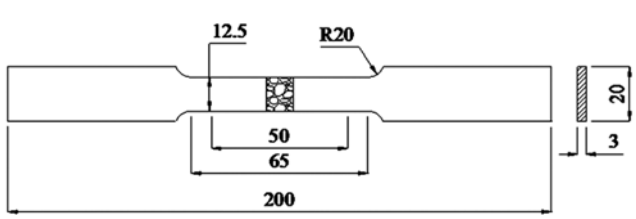

Fig.4 — Schematic diagram of tensile test specimen.

3 Results and Discussion

3.1 Tensile and Hardness Test

The tensile test is conducted to estimate the ultimate tensile strength for titanium-aluminium alloy welded samples under different loading order, where specimen is mixed in nature acquiring both the weld metal and base metal. The specimen size of about 12.5 mm in width and 200 mm in length is developed with EDM method in proportion to ASTM-E8 standards. Figure 6 shows the specimen before the tensile test[17]. The highest tensile strength obtained is 356 MPa in closed environment specimen and value is obtained for the parameters about welding speed 65 mm/min, welding current 95 A and arc voltage 16V, whereas tensile strength value achieved is 92.3 MPa for normal environment specimens. This result indicates that slower speed of welding operation gives maximum strength and higher welding current generates the maximum strength of the weld joint. The hardness value is computed to organize the

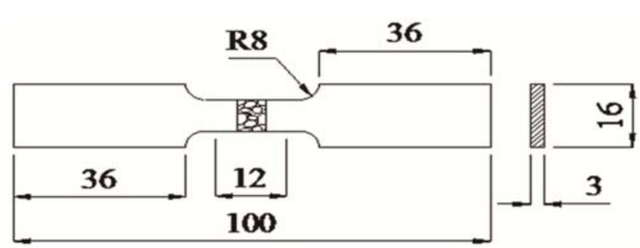

Fig.5 — Schematic diagram of fatigue test specimen.

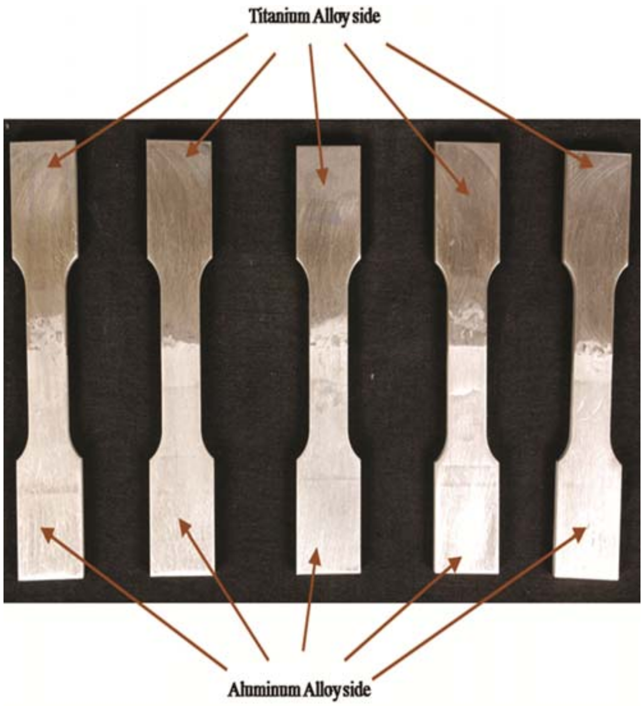

Fig.6 — photograph of tensile test specimens.

alteration of mechanical property in the fused specimen. The Vickers's hardness testing machine is made use of to evaluate the hardness value of the specimens with a loading time of 15s and a load of 0.5 Kg for every specimen. The highest value of hardness for the closed environment welded specimen is achieved of about 183.1 Hv and for normal environment hardness value obtained is 103.4 Hv.

3.2 Fatigue Test

Fatigue analysis of dissimilar joints of Ti6Al4V and Al7075 is performed to examine the dynamic strength in cyclic stresses; most of the structures are subjected to cyclic loading and bumpy loading in application of aerospace. Specimens were prepared as per the standard of ASTM-E606 like tensile. Multi axis fatigue testing machine was used to observe the fatigue strength of the welded work pieces. Figure 7 shows the machine used to conduct the experiment and Fig. 8 illustrates the location of the specimen in machine. Fatigue performance is investigated using the fundamental load of ultimate tensile test and the fatigue is acquired from the ultimate stress in incremental basis of five percentage to attain maximum number of cycles and greatest fatigue strength. Greatest fatigue strength is attained as 99.74 MPa in the best parameters as welding current 95 A, welding speed 65 mm/s and Arc voltage of 16 V.

Fig.7 — Multi axial fatigue testing machine.

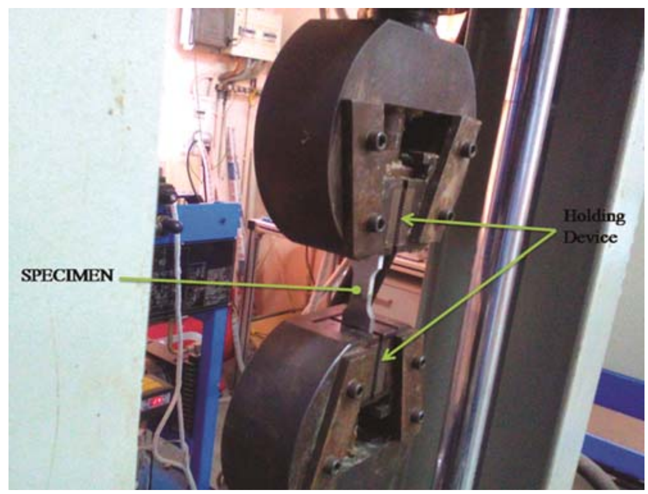

Fig.8 — Specimen attached in multi axial fatigue testing machine.

Number of cycles for the respective load is slight lesser afterward to examination the maximum number of cycles in least amount load, 70 MPa is prearranged to inspect the maximum number of cycles of 106 as high fatigue cycle. At the load of 99.74 MPa test shows the low fatigue cycle, from the learning it exposes that, reasonable welding current and lowest amount of welding speed attain the highest strength of fatigue[18-20].

3.3 Microstructure and Fractography

Microstructures of weld zone, base metal and weld interface are examined with Scanning Electron Microscope and Optical microscopy. Compared with the heat affected zone and weld interface microstructure is almost unchanged, in this examine microstructure analysis is carried out in optical microscope to know the structure of heat affected zone, and interface between the weld zone with aluminiumalloy and titanium alloy. Figure 9 illustrates the structure reveals that Si layer is formed between titanium alloy and weld zone, weld zone shows the non-defective surface and heat affected zone is almost closely structure of the base metal because of the copper backup plate is used to assist to transfer the heat through heat affected zone is even. Scanning electron microscope is used to analyze the interface zone; it shows that arrangement of these elements posses appropriate interfacial bonding with no cracking in the aluminium alloys. Open environment welds microstructure analysis examined reveals that few cracks and voids formation at interface also in weld zone[21]. SEM image of weld interface is shown in Fig.10a. Figure 10b illustrates the SEM image of weld interface in open environment, Fig.10 c shows the void formation in weld area. Titanium alloy side interface is spiky and other parent alloy of aluminium side is totally nonlinearity, the weld pool is irregularity due to aluminium melting temperature and aluminium alloy base material dissolving taking place a superior amount of material. From the microstructure analysis, weld interface between the alloys shows better bonding and no fractures and pores. Fractography study is performed to know the morphology of the fractured surface, fracture initiates at flaw area of weld and crack promulgated along the intermetallic part of brittle phase. scanning electron microscopy is used to examine the fractured area, the same representations listed in Fig.11, Fig.12 and Fig.13. Fractured image observable in Fig.11 is brittle fracture area at cracked location; the image is captured nearer to the interface of titanium and weld zone. Due to the presence of silicon element interface turned into brittle phase, even though silicon is necessary to control the titanium alloy reactions with the aluminium alloy. Image of lack of fusion at intermetallic zone is captured and clearly observable in Fig.12. Lack of fusion area is visible due to variation of parameters which has observed very less value of fatigue strength. Figure 13 shows that the strained fracture area, material stream in a specific welding speed and welding current is generated and influenced by the parameters. From the fracture surface analysis, it clearly reveals that joint interface area is formed as brittle in characteristics. Due to the presence of silicon element the interface formed brittle structure.

Fig.9 — Interface microstructure of aluminium and weld zone.

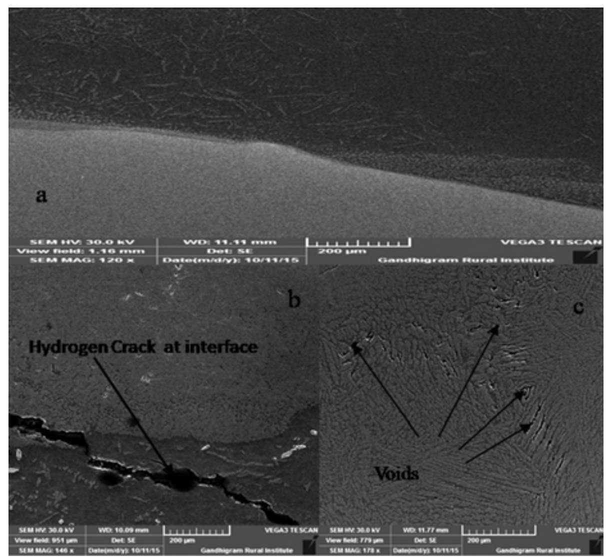

Fig.10 — (a) SEM image at interface of weld joint, (b) SEM image at interface for open environment welded joint and (c) SEM Image at welded area for open environment welded joint.

Fig.11 — SEM image of fracture surface in fatigue.

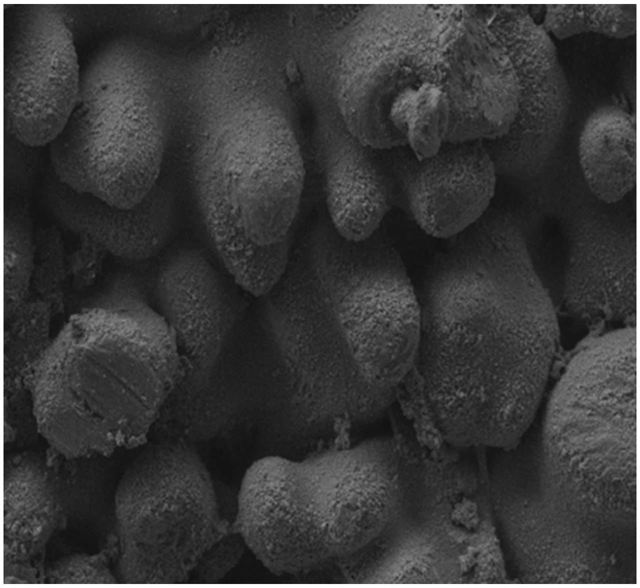

Fig.12 — SEM image of fracture surface for lower most fatigue strength specimen.

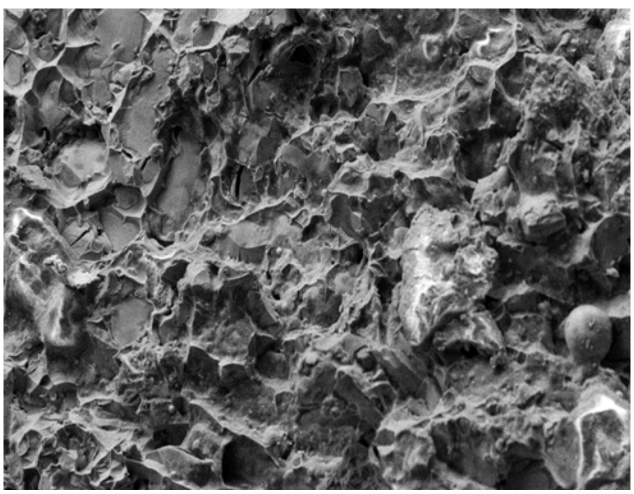

Fig.13 — Fracture surface image of superior strained specimen.

3.4 Energy Dispersive X-Ray (EDAX)

Energy dispersive X-ray (EDAX) is employed to examine the distribution of dissimilar elements across weld interface and element distribution in different part. This examination is conducted for the dissimilar material titanium alloy and aluminium alloy. In the interface of weld, precipitation exits of about two third of the chemical elements engaged by aluminium alloy and one third of elements is titanium alloy[22,23]. EDAX result of titanium alloy is shown in Fig. 14a. Figure 14b illustrates the EDAX image of weld interface in open environment, Fig.14 c shows the image of aluminium alloy side in weld area. The composition ratio among aluminium and titanium

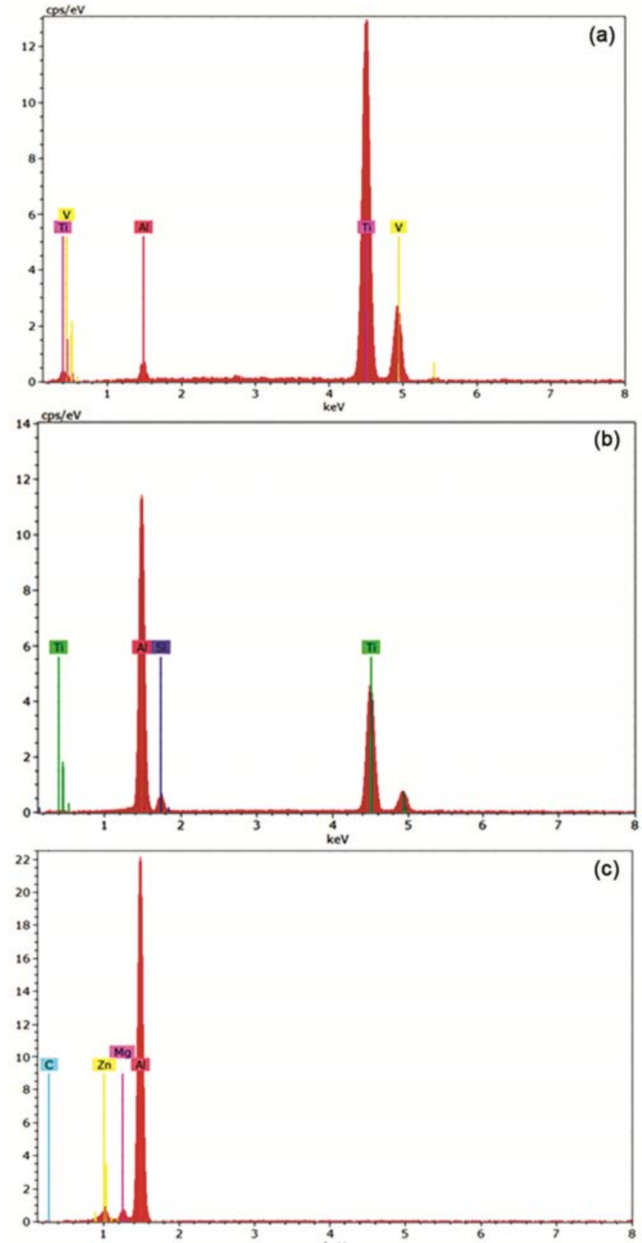

Fig.14 — (a) EDAX Result for titanium alloy (Ti-6Al-4V), (b) EDAX result for weld interface and (c) EDX result for aluminium alloy (Al 7075).

alloy would in the proportion of 3:1. The precipitation is principally filled with double inter-metallic $TiAl_3$, presence of Si in filler material aluminium AA 4047. At the time of welding process, at prominent temperature the formation of Si layer is found in the weld interface. This operates as a barricade between Ti/Al alloys. This EDX examination proves that the composition of substance over the weld face of these segment acquire Ti-Al, $TiAl_3$, Al and Si elements.

4 Conclusions

Titanium and aluminium alloy are successfully joint using pulsed current gas tungsten arc welding (PCGTAW) process. Aluminium alloy filler with 12% Si is employed to develop the dissimilar joints. Process is carried out in open environment and closed chamber environment to achieve better weldments and strength. Bevel angle on titanium alloy is assisted to elongated time gap to dissolve as the aluminium gets melt fast throughout the welding process. Tensile test is examined for both the stage, open environment specimen attained 92.3 MPa and closed chamber specimen is achieved 356 MPa because in open environment few voids are present and hydrogen cracking initiates in the weld interface. The maximum hardness is obtained in open environment specimen is 183.1 Hv along the weld interface; value is nearest to the aluminium base alloy. All the maximum value is obtained about the parameters of welding current 95 A, welding speed 65 mm/min and arc voltage 16 V. Microstructure examination is conducted using optical microscope and scanning electron microscope, it reveals that joint is successfully made without any flaw in closed chamber environment and few voids and hydrogen crack formation is occurs in open environment welding process. Argon gas is acted as resist layer in closed chamber environment between the process and environment. Further the parameters to be evaluated through mathematical model techniques to increase the weld strength and better microstructure properties.

References

1 Sambasiva Rao A, Madhusudhan Reddy G & Satya Prasad K, *Mater Sci Technol*, 27 (2011) 65.
2 Chu C Y, Hsieh C T & Tsay L W, *Mater Des*, 63 (2014)14.
3 Grevey D, Vignal V, Bendaoud I, Erazmus Vignal P, Tomashchuk I, Daloz D & Sallamand P, *Mater Des*, 87 (2015) 974.
4 Wang S Q, Liu J H, Lu Z X & Chen D L, *Mater Sci Eng A*, 598 (2014) 122.
5 Hui J Y, Yong J L & Kwang O L, *Acta Metall Sin (Engl Lett)*, 28 (2015) 684.
6 Han S B, Hee S B, Hyun J S & Sung M J, *Mater Des*, 51 (2013) 544.
7 Shusen Z, Gang Y, Xiuli H & Yaowu H, *J Mater Process Technol*, 212 (2012) 1520.
8 ChenY C & Nakata K, *Mater Des*, 30 (2009) 469.
9 Xiu Y F & Jian X Z, *Int J Adv Manuf Technol*, 85 (2016) 337.
10 Su J L, Makoto T, Yousuke K & Seiji K, *Int J Precis Eng Manuf,* 10 (2015) 2121.
11 Dorbane A, Mansoor B, Ayoub G, Shunmugasamy V C & Imad A, *Mater Sci Eng A*, 651 (2016) 720.
12 Zhou L, Li Z Y, Nakata K, Feng J C, Huang Y X & Liao J S, *J Mater Eng Perform*, 25 (2016) 2403.
13 Yazdipour A & Heidarzadeh A, *J Alloys Compounds*, 680 (2016) 595.
14 Plaine A H, Suhuddin U F H, Alcântara N G & Dos Santos J F, *Int J Fatigue*, 91 (2016) 149.
15 Johansingh P, Achar D R G, Guha B & Hans Nordberg, *Int J Fatigue*, 25 (2003) 1.
16 Moataz M, Michael P , Chatri B, Axel S, John E D, Darren J H, Christopher D & Gavin J, *Metall Mater Transac A*, 43A (2012) 3149.
17 Jung G L, Lee J K, Hong S M, Lee M K & Rhee C K, *J Mater Sci*, 45 (2010) 6837.
18 Wen G D, MaT J , Li W Y, Wang S Q, Guo H Z & Chen D L, *Mater Sci Eng A*, 612 (2014) 80.
19 Rao H M, Jordon J B, Ghaffari B, Su X, Khosrovaneh A K, Barkey M E, Yuan W & Guo M, *Int J Fatigue*, 82 (2015) 737.
20 Wang S Q, LiW Y, ZhouY, Li X & Chen D L, *Mater Sci Eng A,* 649 (2016) 146.
21 Kaio N C, Leonardo C C, Luciano B, Jorge F D S & Claudemiro B, *Mater Des*, 56 (2014) 139.
22 Chatterjee S, AbinandananT A & Chattopadhyay K, *J Mater Sci*, 41 (2006) 643.
23 Shuhai C, Mingxin Z, Jihua H, Chengji C, Hua Z & Xingke Z, *Mater Des*, 53 (2014) 504.