ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

An Effective Quality Assessment Method for Plasma Welding Based on the Plasma Gas Flow Rates in Titanium Grade 2

Adisak Aumpiem [1*], **Asa Prateepasen** [1]

[1] *Department of Production Engineering, King Mongkut's University of Technology Thonburi, THAILAND.*
**Corresponding Author (Tel: +66-815710-128 Email: Aumpiem@Gmail.com).*

Paper ID: 12A1E

Volume 12 Issue 1

Received 04 August 2020
Received in revised form 08 October 2020
Accepted 19 October 2020
Available online 29 October 2020

Keywords:
Weld quality; Plasma gas; Titanium; Welding risk; Plasma arc welding (PAW); Heat-affected zone (HAZ).

Abstract

Most weld defects are from weld stops and starts. Plasma arc welding (PAW) is a process that it is necessary to repeat welding in the same area (start-stop area) to close a keyhole of pipe welding works in which this area obtain more heating rates than other welded areas. This study proposed a quality assessment in PAW by investigative the changing of plasma gas volume in welding a Titanium Grade 2. Weld studies involve the influent of the plasma gas led effects on "cycle start/stop" and weld zone in terms of ultimate tensile strength, hardness, welding profile, discolorations on surface welded, SEM and EDX. The results of the proposed method show that the plasma gas flow at 4.24-4.28 L/min gives the most positive results in both mechanical properties, welded profile, and discoloration of weld surface, while the hardness of weld metal and heat-affected zone (HAZ) less than the base material. Furthermore, Surface oxidation of weld zones was visual inspection is in according to standard and no negative results at 4.20-4.32 L/min and the heat repeated at the cycle of start/stop area causing coarse grain on the root welded. Such information is very useful so that appropriate welded quality assessment can be applied parameter to develop and achieve in the industry.

Disciplinary: Welding Engineering and Technology.

Cite This Article:

Aumpiem, A., Prateepasen, A. (2021). An Effective Quality Assessment Method for Plasma Welding Based on the Plasma Gas Flow Rates in Titanium Grade 2. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 12*(1), 12A1E, 1-14. http://TUENGR.COM/V12/12A1E.pdf DOI: 10.14456/ITJEMAST.2021.5

1 Introduction

The plasma arc welding (PAW) process brings the highest quality standards for titanium and titanium alloys that have been extensively used in the industry widely in the seawater systems of offshore industries and also at the same time the PAW saves time and costs including the welding quality ensuring weld and penetration welded [1]. The Titanium Gr.2 has been successfully utilized because it provides high strength, ductility, exceptional biocompatibility, and excellent corrosion resistance [2-3]. PAW produces an inner plasma gas and the outer shielding gas serving the same intention as in GTAW and many critical advantages over TIG welding [4-5]. Shielding gas of the weld pool is provided by the ionized gas by combining charge particles electron, ion, and molecules[6-7]. The energy of the density for PAW is controlled by the plasma gas flow rate and welding current. The keyhole is an important open hole melted through the workpiece which has liquid metal sides and is held open by the power applied by the plasma gas flow. A three-dimensional model was developed to periodic the heating temperature as an effected weld pool and keyhole geometry in the PAW process [8]. These outcomes in an inherently unstable mechanism during the start and stop of the weld cycle [9-10]. In the welded, it is understood throughout the welding industry that most weld defects are attributed to weld stops and starts area. When welds on pipe or curved workpiece are often rotated while the welding torch of PAW machine fixed stationary. In the start and stop area, the keyhole is the most difficult part of the keyhole in PAW when made on rotating workpiece and often welded defect or voids to be created at start and stop area on weldment.

The work aimed to study and demonstrate in welded quality assessment focused on the start and stop welded area by investigates the influence of Plasma gas flow rate affecting welded on Titanium Gr.2, thickness 3.05 mm in butt joint rotation configuration. Firstly, the value of plasma flow rate (A) has been designed to investigate in tensile and hardness tests are evaluate conducting the physical properties. The weld geometry profile, thermal temperature, and discoloration on weld surface determining in terms of welding quality assurance. Finally, SEM and EDX are studied in metallurgical systematical arcs.

2 Theory Background

Nowadays, The growing demand for energy worldwide requires that attention be given to quality and risk management to utilize products. The offshore construction project was concerned with the fabrication welding process may many more factors a delay in any one of those variables that can delay a project in varying degrees. The welding technology or technical knowledge can help mitigate the negative risk and lead the positive risk is also known as an opportunity is the enhance risk response strategy. Titanium alloys have been used widely in offshore structures of seawater systems or heat exchangers, especially in fire water and seawater coolers. Commercially pure titanium Grades 2 is a primary use. The most common method of joining titanium is Plasma welding (PAW) and Gas tungsten arc welding (GTAW) available and are capability practiced to created weld joints[11]. In the welded, it is understood throughout the welding industry that most weld defects are attributed to weld stops and starts area.

2.1 Plasma Theory and Plasma Arc Welding

Welding is a method of joining to applied the heat and/or pressure between the two workpieces. The Plasma arc welding process most high productivity used for titanium alloys. The welding joint of thin thickness at microscale was established called the micro-plasma process [12-13]. The characterization of PAW, the torch has a nozzle that creates a gas chamber encloses the tungsten electrode. The arc heats energy of the gas fed into the orifice chamber to a temperature effect where it transforms into the ionized and conducts electricity. The ionized gas is defined as plasma. Plasma is a gas that is ionized. It is considered a state of matter with an energy value of less than 10 kilo-electron volts (<10 keV). The plasma consists of both positively charged and negatively charged particles. The proportion that makes the total charge zero. These particles are quasi-neutral, which means that the electrons and ions in that area are in equal numbers and exhibit collective behavior. Plasma can be produced by providing an electric field. A large quantity to a neutral gas, when enough energy is passed through free electrons for free electrons to collide with atoms and causing electrons to escape from atoms. This process is called "the process of ionization" which occurs rapidly, dramatically increases the number of ejected electrons that break down the gas and eventually become plasma. Plasma is classified as the fourth state of matter. Plasma differs from the solid, liquid, and gaseous state with three conditions: the wavelength, number of particles, and plasma frequency. This gives the plasma a specificity that is different from the other states. Thus, the plasma arc occurred is one of the major factors when ascertaining the influence of arc plasma on the weld pool [14].

2.2 Titanium Materials

Titanium Grade 2 is a commercial pure grade with 99% minimum titanium. Commercial-grade titanium is divided into grades 1, 2, 3, and 4, in which each grade has a slight difference in chemical composition, mechanical properties, whereas corrosion resistance is similar across all four grades. Titanium is lightweight at just haft the weight of steel and the ultimate tensile strength similar to mind steel [15-17]. Titanium Gr.2 is good very corrosion resistant has been used in seawater systems such as firewater systems of an offshore platform. The most common method of joining titanium is plasma welding arc applied for specific applications. The atomic weight of titanium is 47.88. Titanium is lightweight and strong. Titanium and its alloys possess tensile strengths from 210-1380 MPa. The continuous service temperature of Titanium Gr.2 can reach up to 800°F with occasional, intermittent service at 1000°F. The pure titanium structure is a major of titanium alloys, the crystal structure at low temperature is a hexagonal close-packed(hcp) structure, called α-titanium and at high temperature is body-centered cubic(bcc) structure is stable and is referred to as β-titanium. The two different crystal structures and transformation of the temperature effected of heating is a significant basis of achieved in the properties of titanium alloys. During welding, the weld pool zone is heated to 882°C or above, developing in the transformation to the β phase. As welding cool down through the β transits, the cooling rate from the β phase field has a controlling influence on the resulting microstructure in a CP-Ti.

3 Experiments procedure

The objective of the study was set up that welding parameters are volt, ampere, arc length, and wire-speed while the plasma gas flow rate arc affects the Start/Stop area investigated respectively shown in Table 3. Before welding, Titanium specimens were cleaned from oxides and contamination on the surface by acetone.

3.1 Material and Welding Procedure

The base material used in this study was Titanium pipe, ASTM B861 Grade 2 were cut to the required dimensions of OD 88.9 mm, circumference 558 mm, thickness 3.05 mm, and length 150 mm as by abrasive cutting to prepare the joint configurations, shown in Figure 1. The welding consumable ERTi-1 for Plasma welding (PAW) was supplied by Oxfords alloy, diameter 1.2 mm.

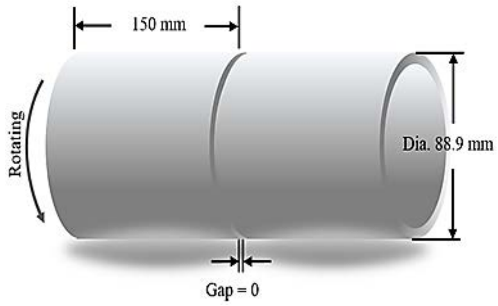


Figure 1: Joint configuration for Plasma welding

The welding consumable with the normal composition of C 0.03%, O 0.10%, H 0.008%, N 0.020%, Iron 0.20%and remainder balance Ti. The welding consumable classification of ERTi-2 with a diameter of 1.0 mm was chosen as the filler material. The chemical composition and physical properties are given in Tables 1 and 2 respectively. The micro construction of thickness section Titanium Gr.2 is shown in Figure 2.

Table 1: Chemical composition of the pure Ti pipe and filler metal (wt.%)

Composition (wt %)	Ti	Fe	C	N	H	O
Base metal	Balance	0.02	< 0.01	< 0.01	0.006	0.07
Filler metal	Balance	0.048	0.010	0.007	0.002	0.098

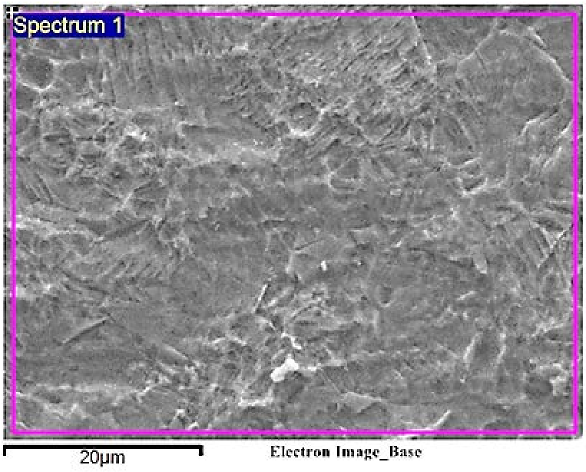


Figure 2: SEM image of base metal - Ti Gr.2

Table 2: Physical properties of Titanium Gr.2.

Material	Tensile strength, Rm, (MPa)	Yield strength, Rp 0.2, (MPa)	Elongation, A5, (%)	HRB
Base metal	436	296	37.5	84
Filler metal	345	275	20	n/a

3.2 Plasma Welding Procedure

The plasma system mainly consisted of process control, plasma controller, wire feeder, and needed accessories. The data acquisition system mainly consisted of a PC base database and a thermal camera. During the welding process the welding current, voltage, plasma gas flow into PTW300 welding gun 300 amps (duty cycle 100%) and high precision wire feeder W21 were controlled by the process control system by ESAB Aristo 5000, 500A (60% intermittence) and analog valve controlled by PLC of Plasma controller W304. The plasma arc was recorded and imaged by a Thermal camera (InfReC R550 Pro), which was set to focus on the fixed region around the nozzle of the unmovable plasma arc torch. The experimental data were displayed and recorded by a PC base database computer. The principle of the plasma welding machine in the pipe is shown in Figure 3.

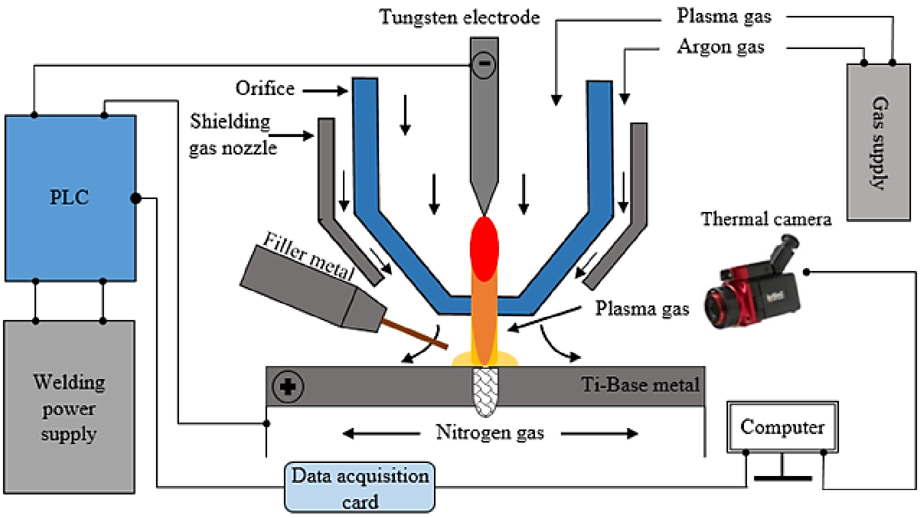


Figure 3: Schematic diagram of the experimental plasma welding system

Before welding the test specimens were ground using carbide burrs grinding size D12x25 and cleaned with acetone for at least 30 mm on each side of the weld line area. The welding parameters resulting in the keyhole of star/stop points ware arrived by trial resulting in visual good welds. The welding parameter and influence of plasma flow rate change as shown in Table3.

Table 3: PAW process parameter used in this investigation

Specimens (No.)	Current (A)	Volte (V)	Arc length (mm)	Wire-speed (Cm/min)	Plasma gas flow (L/min)	Plasma gas flow rate (%)	Tungsten setback (mm)
#1	145	23.75	8	85	4.20	-	4
#2	145	23.75	8	85	4.24	1%	4
#3	145	23.75	8	85	4.28	2%	4
#4	145	23.75	8	85	4.32	3%	4
#5	145	23.75	8	85	4.37	4%	4
#6	145	23.75	8	85	4.62	10%	4
#7	145	23.75	8	85	4.83	15%	4
#8	145	23.75	8	85	5.46	30%	4

Depicts the schematic illustration of PAW. In PAW, the molten flow by arc near the keyhole is transported backward through both sides of the keyhole and therefore produces a weld pool as shown in Figure 4(a). It is required to fill the void behind the keyhole with the molten flow for maintaining welding stability. There are two necessary conditions for welding stability: the molten flow on both sides must bridge the gap formed at the rare part by the passage of the keyhole and also, the molten flow is supported by the surface tension action on the back surface weld pool surface.

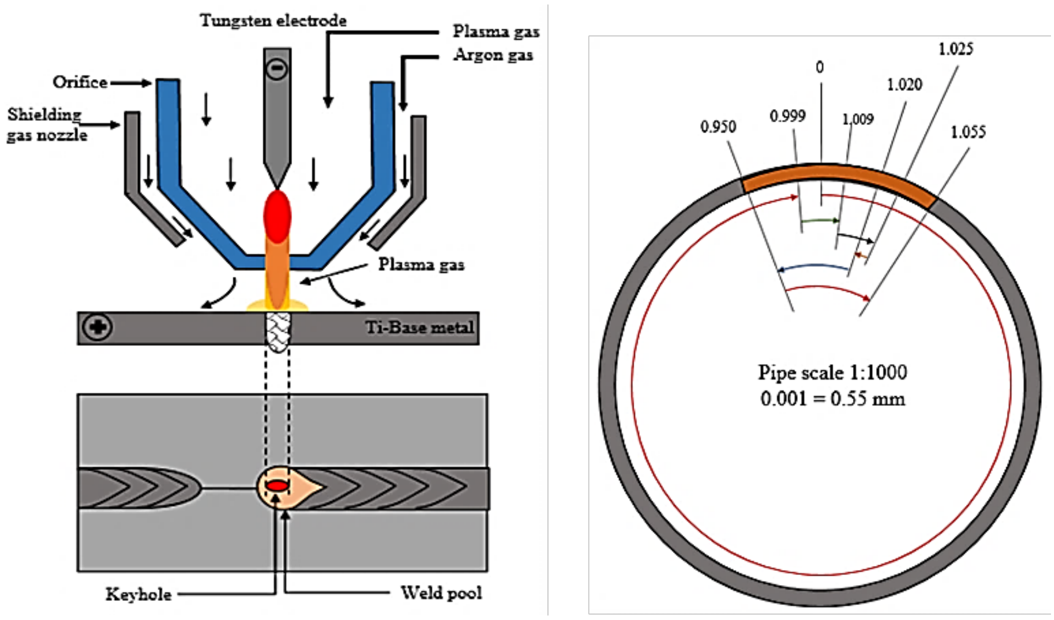


Figure 4: (a) Schematic illustration of the PAW process, (b) Cycle rotating as start/stop welded area

The welding torch over a workpiece can be rotated at a fixed speed. The workpiece is rotating and at approximately the same rotational speed and the relative of moving between the PAW torch and the workpiece is Zero until the PAW torch current and plasma temperature are at full operating levels. The welding rotation steps by each pass (root and filling passes) setup from Figure 4(b) start at sector 1 is from zero to 0.999 when the sector 2 is staring, Sector 2 starts at 0.999 and are active to 1.009 when sector 3 start, Sector 3 starts at 1.009 and are active to 1.025 when sector 4 start, Sector 4 starts at 1.025 and go backward to 1.020 when sector 5 start, Sector 5 starts at 1.020 and go backward to 0.950 when sector 6 start, Sector 6 starts at 0.950 and are active to 1.055 when sector 7 start, Sector 7 is the stop sector, the plasma welding machine stop at 1.055 respectively. The welding pass was online monitored the temperature during welding by a Thermal camera.

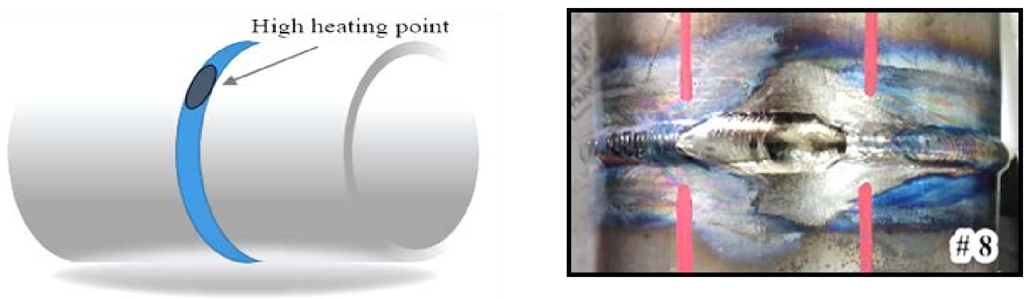


Figure 5: (a) PAW welding completed, (b) Start and stop welded of study.

After weld completed in Figure 5, The radiography test (X-ray) was confirmed the quality of weldment on the double heating area (high heating point) after welding completed. The X-ray power source 80 KV, 5mA, Source size 3.0 mm, Density 2.8-3.1, Sensitivity wire no.5, Intensifying lead screen thickness 0.027 mm, and Film Agfa D5 was applied used to confirmed weld.

4 Results

All welded specimens were cut and preparing on the double heating area of the PAW. The objective for review and identify the main course of weld poor quality which leads to the effect of quality, cost, and time.

4.1 Effect of Plasma Flow Rate on the Tensile Properties

According to the below analyses. The tensile strength of the welded specimens at different plasma gas flow rate was observed at the start/stop area is depicted in Figure 5. It can be concluded that the tensile strength of the welded joint. The average 0.2% offset yield stress and ultimate tensile strength of actual base materials were YS=465 MPa. and TS=552 MPa. The experimental resulted found that specimen#7 is the highest yield stress of were 373 MPa. The trend of high ultimate tensile strength starts from the plasma flow rate as 4.37 to 4.83 L/min and drops as a flow rate of 5.46 L/min. The specimen#5 is the highest ultimate tensile strength were 465 MPa. The stress-strain curves of all specimens shown in Figure 6 were quite different and the highest plasma flow rate not always to the higher tensile strain of the joints and observed found that the tensile strength resulted all shown that the ultimate tensile strength value is lower than the base material. The lowest percent ultimate tensile strength (31.8 %) value is seen for the specimen welded no.4 at plasma flow rate 4.32L/min when a comparison of the base material.

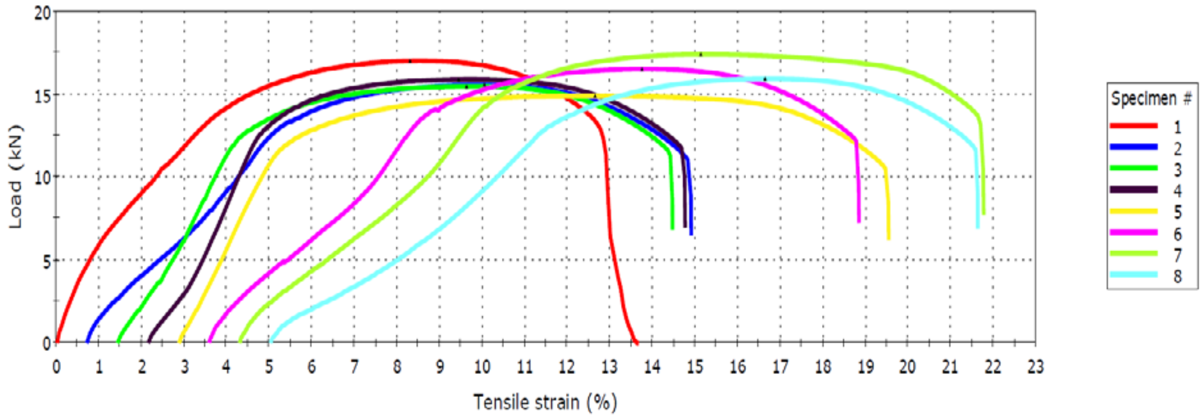


Figure 6: Tensile stress-strain curves for PAW welded in Titanium Gr.2

4.2 Thermal Temperature and Hardness Test

The plasma flow rate is effective to hardness, The micro-hardness across the weld centerline, HAZ, and the base metal result is shown in Figure 7. It can be seen that the average hardness resulted were obtained for the weld metal region is 137.56 HV and HAZ is 120.32 HV. Furthermore, The average of base material obtained is high than weld metal (155.4–146.2 HV) and HAZ region(110.2–143.4). It is clearly seen that the plasma gas flow rate to increase, the hardness affected into weld metal and HAZ region is reduced. Hardness value resulted in to increase as the plasma gas flow rate average is 4.37 to 4.83 L/min. Moreover, experimental results showed a hardness value on weld metal and HAZ less than the base material. Hardness is found to be very high in weld metal 146.2 HV as a flow rate of 4.37 L/min. while the highest hardness value on HAZ = 143.4 HV as flow rate 4.32 L/min.

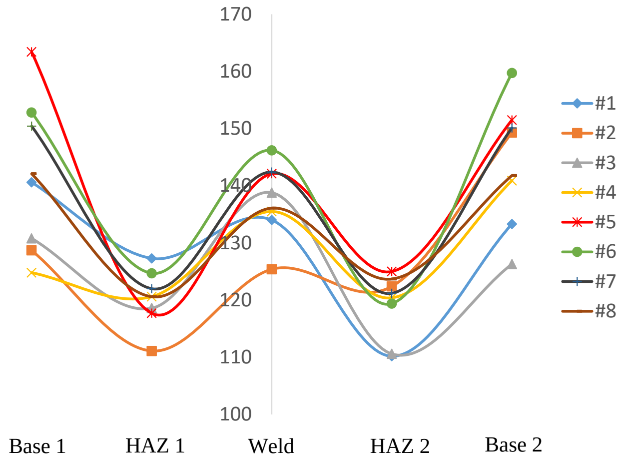


Figure 7 Schematic diagram shows the micro-hardness test along the section of welded(HV)

Thermal camera(InfReC R550 Pro) is infrared detector type Micro-bolometer, the capability for heating measuring rang up to 2000°C and accuracy ±1 °C at the room temperature 20-30°C, the resolution pixels is 640x480 pixels. The original arc image Figure 8(a) shows before effective with plasma gas. The highest temperature of the plasma flow rate at 5.46 L/min is shown in Figure 8(b). The heating temperature of plasma arc of #8 is the highest temperature, point C is 1935.7°C, A=107°C, B=226°C, D=411 °C, and E = 157°C respectively.

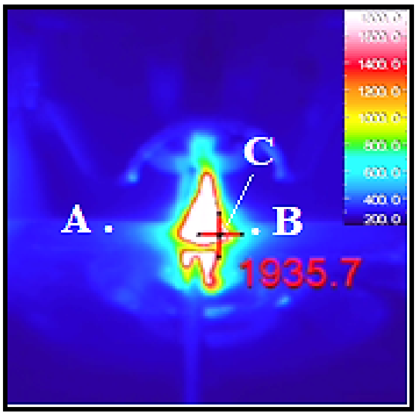


Figure 8: (a) Initial arc image; (b) Heating temperature of plasma arc

4.3 Welding Profile

The reinforcement is a factor in risk problems in welding quality controls. The higher weld reinforcement has a shorter fatigue life [15] and unacceptable such as in welding inspection standard, NORSOK M-601 is one standard were specified the acceptance criteria for visual testing the reinforcement or internal protrusion for pipe wall thickness ≤ 6 mm is 1.5 mm [18]. The welding profile results show in Figure 9, the welding profile of each plasma flow rate is different thickness which the welding profile appropriate 4.24-4.28 L/min and 4.62-4.83 L/min are suitable and comply with standard reference. Specimens#5 in Figure10. shown the highest of welding profile both Cap welded =3.22mm and root penetration welded = 0.89mm.

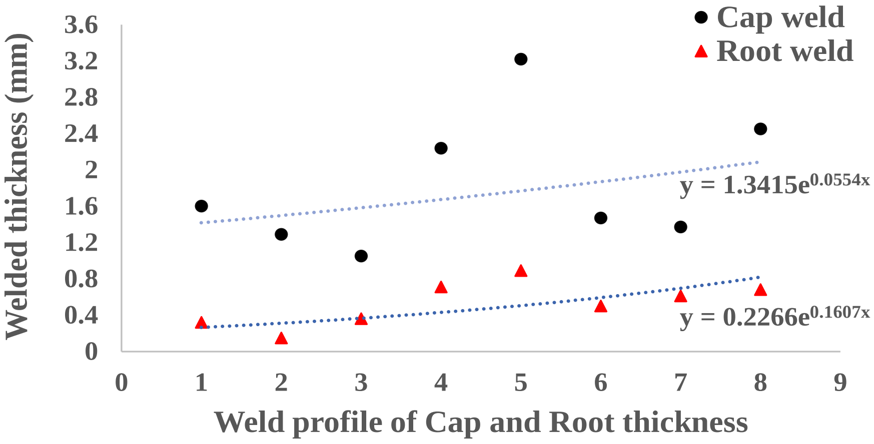


Figure 9: The welding profile of cap and root welded.

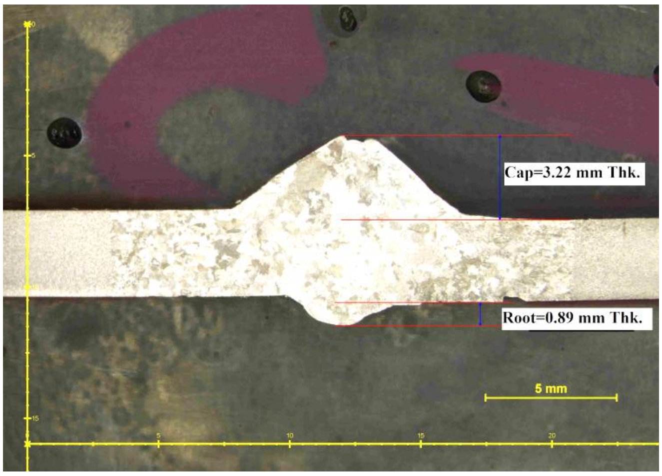


Figure 10: Welded geometric measurement of welded specimens

4.4 Determining Discoloration on the Weld Surface

In the PAW process a low level of oxygen before, during, and after welding is necessary, to achieve minimum oxygen to assess the effects of surface oxidation(discoloration). The welded color was shown the relationship of plasma gas flow rate on finish welded surface and poor indicator some surface contamination occurred during solid-state cooling at high temperature. At a temperature below 500°C a stable oxide layer of metal that provides excellent corrosion resistance. However, the oxidation resistance decreases at temperatures above 500°C, and metal becomes susceptible to embrittlement by oxygen, nitrogen, and hydrogen [19-20]. It is necessary to avoid risk when welding in a material sensitive to oxygen like Titanium or Super duplex. Due to the welding quality assurance in the piping system to determine whether the weld is of suitable quality. The color that occurred from the plasma flow rate which relates to the heating was determination and the acceptance criteria is a major point to be subject on the welded surface. The NORSOK M-601 standard was evaluated and give the accepted color on the weld metal surface: silver and straw. A narrow band of intensive color close to the limits of the gas shielding is acceptable. Darker brown, purple and blue color and grey or flaky white are not acceptable. The welding experimental resulted found that the risk range of plasma gas flow complies with NORSOK standard and acceptable are specimens no.#1-#4 while specimens no.#5-#8 are unacceptable and need improvement in the project shown in Figure11.

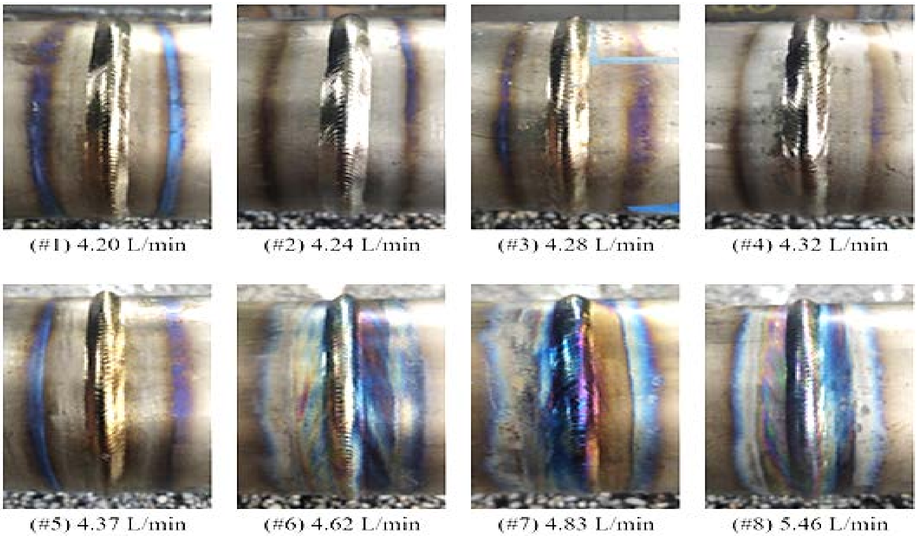


Figure 11: Effective of Plasma gas flow rate relate to coloration

4.5 SEM and EDX

The scanning electron microscope (SEM) scan a focused uses high-energy of electrons beam to generate a variety of surface specimens to create an image[19]. Energy Dispersive X-Ray Analysis (EDX) is an analytical technique used for the chemical composition of sample specimens. It relies on the interaction of some source of X-ray excitation and a sample. EDX spectroscopy confirmed that the alloy is Ti Gr.2 also known as commercially pure(CP) titanium alloy shown in Figure 12.

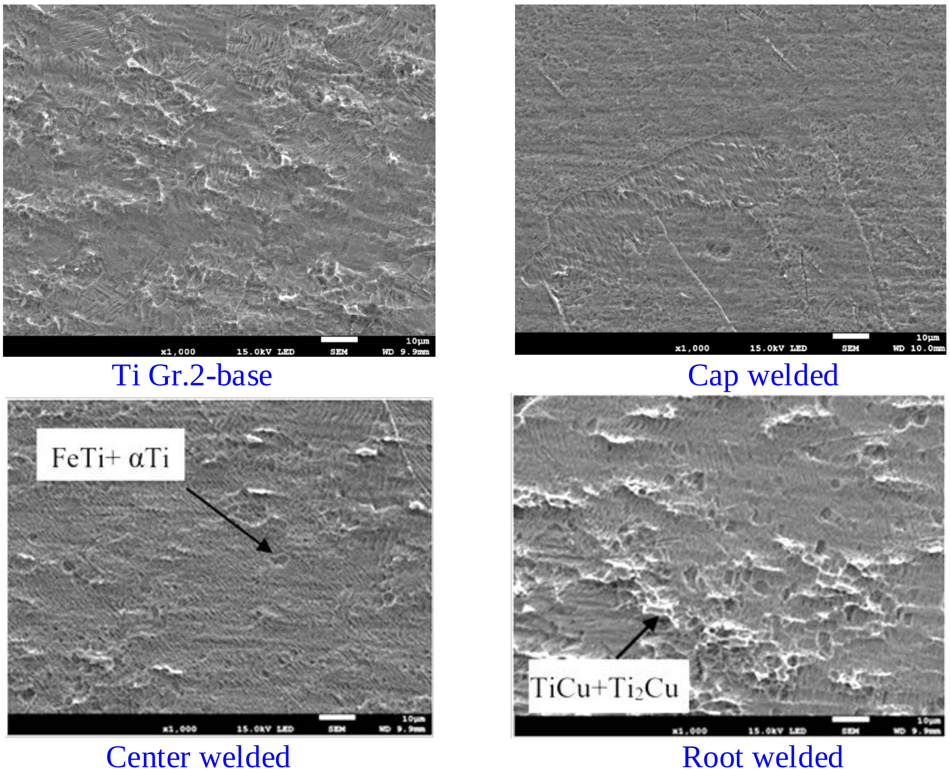
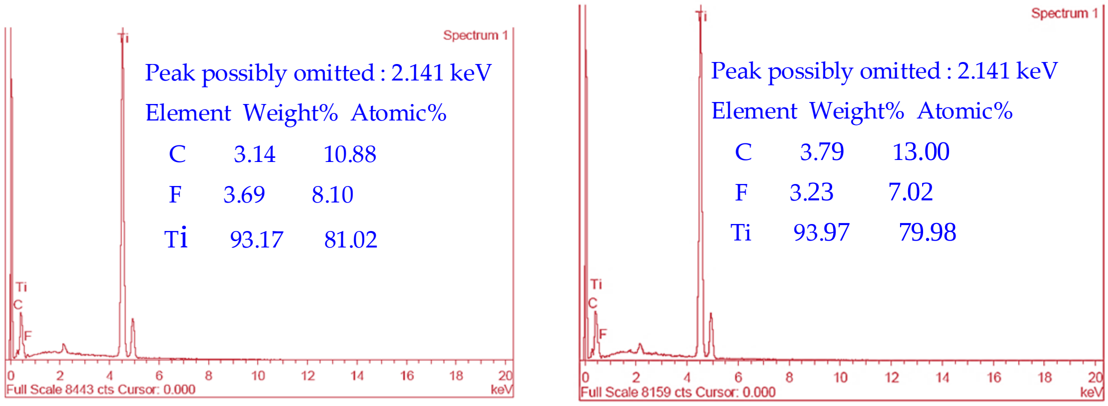


Figure 12: SEM images of Base metal, Cap, Center, and Root welded respectively

To examine the cap and root surfaces weldment of Titanium Gr.2. The fracture surfaces were investigated with SEM to determine the fracture mode. The arrows point figure shown to high-temperature beta phase boundaries (substructure in alpha cells). As the high temperature affects the mechanical properties and metallurgy of materials.

It can also be concluded that oxygen is present in the weld region which is consistent with the formation of TiO2during the plasma welding. The oxygen concentration is found to increase from 2% to 6% in the welded region with respect to the base material. The microstructure consists of fine equiaxed alpha grains and EDS showed that carbon content in the Titanium promoted improvement of the grain boundaries and characteristic of twin grain[22-24].



Cap welded Root welded

Figure 13: EDX results in the cap and root welded.

5 Discussion

These results can be recognized as acceptable industrially as the strength calculations made in the design of a fabricated structure are based on the properties of the metal being used. Titanium alloy Gr.2 were joined successfully by the plasma arc welding method at various welding plasma flow rates using on cycle start/stop welded. The effect of changing the plasma flow rate in experimental in term of welding quality is the following:

The physical properties, the start/stop welded joint strength was found to be at least as much as that of the base metal when suitable welding current was used. The highest average of tensile strength 404.8 MPa. and the ultimate tensile load 16.06 kN. The tensile strength variance was in the range of 376.0-435.4 MPa. The hardness values of the weld metal and HAZ were lower than that of the base metal. Increasing plasma gas flow rate reduced the hardness of weld metal and HAZ. The hardness samples continuously on weldment ranged from 125.4 to 146.2 HV. Welding quality for the plasma gas flow rate in Titanium Gr.2 increased, physical properties both tensile and hardness 4.37-4.83 L/min, and while continues increased both the tensile and hardness to be reduced.

Welding quality assurance to assure in quality of welds. The value of plasma gas flow increases the thermal temperature of weldment and reduced the hardness of HAZ and welded. Quality of weld, weld profile on the start/stop area highest reinforcement as 3.22 mm. The increase of plasma gas flow is the main factor affected discoloration on surface welded and reduced corrosion properties in materials. Experimental results found that flow rate at 4.20-4.37 L/min (#1-

#5) is allowed to match acceptable discoloration levels for weld and heat-affected zones while all above is unacceptable base on the standard of welding quality assurance.

Finally, Acicular alpha and twins with different sizes dominated all of the weld metal microstructures, as investigated and shown in Figure 10. The two-zone of the welded on start/stop area is now clear that the two zones in the welded joint have different microstructures due to the temperature variations during welding and cooling processes. The coarse grain observed on the root welded occurs in heat repeated as the same position of welding. The microstructure of welded depending plasma flow rate effected by acicular alpha, coarse-grained serrated alpha, and twins. The twins are the distinct microstructure found in weldment especially near the weld root. The EDX characterizations found that αTi + FeTi was displaced from the αTi + Ti2Cu phase at the highest confirmed that carbon content as the root part is increased the grain boundaries becomes improved.

6 Conclusion

This study lays the foundations for comparisons in welding quality for PAW in the effect of plasma gas flow rate on the start/stop welding by consideration in term of physical properties, quality assurance and metallurgical are following:

1. Plasma flow rate as 4.32 L/min(specimens#4) gives the lowest yields and tensile strength volumes and lower than the actual tensile strength of base material 31.8%

2. All of the Plasma flow rate range, the hardness test on welded higher than HAZ but less than the base metal. Several noteworthy results were 4.28 L/min, the hardness of base metal less than a welded(specimens#3)

3. Welding profile consideration as cap and root welded, the all suitable welding profile except the flow rate 4.37 L/min. (specimens#5)

4. Welding quality inspection for coloration on surface welded according to NORSOK standard, unacceptable were 4.62-5.46 L/min (specimens#6-8).

5. SEM and EDX confirmed that the coarse grain occurs in the region of heat repeated in the start/stop welded area and the chemical composition to help improve the ability of weldment.

The contribution of this study establishes the opportunities competitive, reduces cost and time. Moreover very useful so that appropriate welded quality assessment can be applied parameter to develop and achievement in the industry.

7 Availability of Data and Material

Information can be made available by contacting the corresponding author.

8 References

[1] M. Chithirai Pon Selvan, Nethri Rammohan, and Sampath S., Plasma Arc Welding (PAW) – A Literature Review, M. Chithirai Pon Selvan et.al, American International Journal of Research in Science, Technology, Engineering & Mathematics, 11(2), June-August, 2015, pp. 181-186

[2] Hong Zhou, Zhi Liu, and Liancong Luo, Microstructural Characterization of Shrouded Plasma-Sprayed Titanium Coatings, J. Manuf. Mater. Process, 2019, 3, 4

[3] Kavian O. Cooke and Anas M. Atieh, Current Trends in Dissimilar Diffusion Bonding of Titanium Alloys to Stainless Steels, Aluminium and Magnesium, J. Manuf. Mater. Process, 2020, 4, 39

[4] Klas Weman, Welding processes handbook, CRC Press LLC, USA, 2003

[5] N. Kahraman, M. Ta¸skın, B. G¨ulen¸c2, A. Durgutlu, An investigation into the effect of welding current on the plasma arc welding of pure titanium, Kovove Mater, 48,2010, pp. 179–184

[6] Sabah N, Nada A., Hazim I and Noha H., The Effect of Gas Flow on Plasma Parameters Induced by Microwave, Baghdad Science Journal, Vol.15(2), 2018

[7] Zu Ming, ShuangLin, Zhen Luo and ChangZhen, Plasma arc welding: Process variants and its recent developments of sensing, controlling and modeling, Journal of Manuf. Processes 23, 2016, pp. 315-327

[8] Junhua Sun, Chuan Song Wu, Yanhui Feng, Modeling the transient heat transfer for the controlled pulse key-holing process in plasma arc welding, Int. J. of Thermal Sciences 50, 2011, pp.1664-1671

[9] Z. M. Liu, Y. K. Liu, C. S. Wu, and Z. Luo, Control of Keyhole Exit Position in Plasma Arc Welding Process, Welding Journal, 2015, Vol. 94.

[10] X. R. Li, Z. Shao, and Y. M. Zhang, Double Stage Plasma Arc Pipe Welding Process, Welding Journal, 2012, Vol. 91.

[11] J. Barta, M. Maronek, B. Simekova, D. Maric, Analysis of welding joints made of titanium alloy grade2 procedure by electron beam welding, METABK 58(3-4), 2018, pp.255-258

[12] M. Baruah, S. Bag, Influence of heat input in micro-welding of titanium alloy by microplasma arc, Journal of Materials Processing Technology 231, 2016, pp. 100–112

[13] Kondapalli S. P., Chalamalasetti S. R., and Damera N. R. Optimizing pulsed current micro plasma arc welding parameters to maximize the ultimate tensile strength of Inconel625 Nickel alloy using response surface method, Int. J. Engineering, Science and Technology, Vol. 3, No. 6, 2011, pp. 226-236

[14] Ken Kimbrel, Determining acceptable levels of weld discoloration on mechanically polished and electropolished stainless steel surface, Pharmaceutical engineering ISPE, November 2011, Vol.31, no.6

[15] Shucai Y., Song Y. , Xianli L., Shuai S.and Yongzhi Z., An Investigation of the Influence of a Micro-Textured Ball End Cutter’s Different Parameters on the Surface Residual Stress of a Titanium Alloy Workpiece, J. Manuf. Mater. Process. 2019, 3, 94

[16] C. Leyens and M. Peters, Titanium and Titanium alloy, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2003

[17] Tomáš Kramár, Ivan Michalec and Pavel Kovačócy, The laser beam welding of titanium grade 2 alloy, GRANT journal, ISSN 1805-062X, 1805-0638(online), ETTN 072-11-00002-09-4, pp. 77-79

[18] Araque, Oscar & Arzola, Nelson & Hernández, Edgar, The Effect of Weld Reinforcement and Post-Welding Cooling Cycles on Fatigue Strength of Butt-Welded Joints under Cyclic Tensile Loading. Materials, 2018

[19] NORSOK standard, M-601, Welding and inspection of piping, 2016

[20] D. D. Harwig, C. Fountain, W. Ittiwattana and H. Castner, Oxygen Equivalent Effects on the Mechanical Properties of Titanium Welds, Welding Journal, November 2000, pp.305-316

[21] S. Kodama & K. Sugiura & S. Nakanishi & Y. Tsujimur & M. Tanaka & A. B. Murphy, Effect of plasma heat source characteristics on nitrogen absorption in gas tungsten arc weld metal, Weld World, 2013, 57: pp.925–932

[22] Sengottaiyan P. and John Rajan A., Structural relationships of metallurgical and mechanical properties influenced by Ni-based fillers on Gas Tungsten Arc Welded Ferritic /Austenitic SS dissimilar joints, Journal of Advanced Mechanical Design, Systems, and Manuf., Vol.13(1), 2019

[23] Zhou, H.; Liu, Z.; Luo, L., Microstructural Characterization of Shrouded Plasma-Sprayed Titanium Coatings, J. Manuf. Mater. Process. 2019, 3, 4; doi:10.3390/jmmp3010004

[24] Zhifu Wang, Andong Wang, Zhengwei Pan & Juncheng Liu, Effects of carbon and titanium on the solidification structure and properties of ferrite heat-resistant alloy, Science and Technology of Advanced Materials 2, 2011, pp. 303-307.

Professor Dr. Asa Prateepasen is Professor of the Department of Production Engineering at the King Mongkut's University of Technology Thonburi. He received his B.Eng. and an M.Eng. from the King Mongkut's University of Technology Thonburi and B.E. Ramkhamhaeng University. He got a PhD in System Engineering from Brunel University, United Kingdom. Prof. Asa's interests involve Applications of Acoustic Emission and Non-destructive Testing, Management of Project e.g. Risk Management, Quality Management.

Adisak Aumpiem received a Bachelor of Engineering (B.Eng.) degree in Welding Technology from the Mongkut's University of Technology North Bangkok (KMUTNB) and an M.Eng. degree in Welding Engineering from King Mongkut's University of Technology Thonburi (KMUTT), Thailand. He worked in the welding & NDE industry and currently is the welding coordinator in an offshore construction company. His research interests include Welding Quality Systems/Controls, Risk Management in Project.