SPECTROSCOPIC MEASUREMENT DURING A-TIG WELDING OF AUSTENITIC STAINLESS STEEL

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Abstract. *Despite the effort of the scientific and technological community to provide a better understanding of the governing mechanisms that take place during A-TIG welding (Active Flux TIG), a consensus of the importance of each mechanism has not been reached. The mechanisms proposed so far embrace the arc constriction due to the presence of electronegative elements, the Marangoni Effect (weld pool flows inwards due to the presence of surface active elements), the concentration of the arc root as flux acts as an insulator, the increase in the electromagnetic force, the change in the anode spot mode and even the increase in the arc efficiency. Thus, it is proposed here to use the Optical Emission Spectroscopy (OES) in an attempt to characterise the electric arc and, therefore, contribute to the investigation and understanding of the mechanisms behind the penetration enhancement of the A-TIG process. Different runs were carried out in SUS304 austenitic stainless steel with the flux being applied on the surface with a coating thickness of 8±1 microns and welding with autogeneous argon TIG process at 150 A. The results show the presence of flux elements on the arc with lower ionisation potential than argon. This could lead to an arc constriction in terms of its electrical radius and, therefore, increasing the current density and the electromagnetic force (since the current is kept constant). By its turn, the increase in the electromagnetic force leads to an increase in the plasma jet, finally increasing the penetration.*

Keywords: *Welding, Emission Spectroscopy, Active Flux.*

1. INTRODUCTION

It is well-established in the welding community the suitability of TIG process for operations requiring considerable precision, high weld joint quality and the versatility of decoupling the arc power with the filler addition rate. However, these advantages are offset by limited thickness that can be welded in single pass and by the lower productivity compared to other processes.

Different approaches have been proposed to cope with these overcomes, such as adding a very small quantity of oxidant gas to the inert one, increase the gas flow and use of external magnetic fields. One specific technique has been shown affordable, robust and efficient: the use of active flux over the workpiece prior welding and carrying the arc over it (A-TIG – Active Flux Tungsten Inert Gas) or aside it (FBTIG – Flux Bonded Tungsten Inert Gas).

The A-TIG welding has been successfully shown as an efficient process variant for penetration enhancement, the mechanism or mechanisms behind this observed penetration increase has (or have) not been put together in a consensual theory. Since consensus has not been reached so far in literature, it is propose to initially investigate it by using the emission spectroscopy. Besides the inherent scientific contribution, it is also expect that, from a better understand of the mechanisms involved in the A-TIG process, it could lead to further development in the flux composition, application technique, specific flux for different materials and robustness.

1.1. A-TIG

The initial idea of employing elements for penetration increase starts with the simple question of which elements/compounds should be on the flux. According to ASM (1993), elements such as S, O, Se and Te increase penetration, whereas Ca, Al, Ce, La, Si and Ti decrease penetration.

Many authors affirm that the flux has the role of surface elements. For instance, Paskell et al. (1997) provides some values for elements such S, O and Ca. In the work of Dong & Katayama (2004), two different SUS304 austenitic stainless steels are used, which have lower and higher sulphur contents. Zhao et al. (2006) also presents some contents for S and O, which beyond a point (200 ppm for O and 80 ppm for S) their content no longer presents appreciable influence. The idea of surface-active element comes from the fundamental work of Heiple & Roper (1982).

Some authors consider only the oxygen content is the significant one (Zhao et al., 2006). Therefore, one can concluded that any type of silicate could be used. However, it has been proved that different silicates generates different weld pool profiles and penetration levels (width/penetration ratio as well).

Furthermore, some elements used in the covered electrodes is also considered as potential candidates for the A-TIG flux, like rutile (TiO_2) and potassium salts for arc stabilization and silica (SiO_2), fluorites (CaF_2, LiF, BaF_2) and chlorides (LiCl) for slag formation.

Also, different elements may have influence on the arc formation (Middel & de Ouden, 2006). For instance, K and Na produce a higher degree of ionisation at lower temperatures if compared to argon. This characteristic could lead to the arc temperature reduction, constricting it and, therefore, increasing the current density.

Another important issue is how to apply the flux. Different methods/techniques have been used to apply/spread the flux over the workpiece surface. For instance, Lucas & Howse (1996) state the flux can be manually applied by using a brush or a dispenser (such as a spray). Also, very little flux is required to affect the arc so that a thin coating painted on to the surface of the component will suffice. Zamkov & Prilutsky (2004) cites other authors for stating that the depth of penetration depends on the quantity of the flux.

The painted/brushed technique was used by Niagaj (2006), although the resulting thickness is not mentioned, and by Paskell et al. (1997), where the final thickness is neither mentioned, but it is stated that it should be less than 0.127 mm. It is also stated that the flux “was applied manually with a brush in a layer thick enough to prevent visual observation of the base metal”.

In the work of Marya (2004) and Rückert & Huneau (2004), it is presented an average thickness value of 40-70 microns for brushed flux. The use of water and acetone (forms a colloid) is briefly discussed. In the work of Parshin (2006), the obtained thickness is not mentioned, but 0.1 mm of thickness for covering the melting wire for surface tension and electrical properties determination.

It is suggested that the most suitable technique, which guarantees both thickness uniformity and rapid dry time is by spraying the flux. Other forms presented in scientific literature and even in commercial forms are spray cans and crayons.

Looking specifically into the layer thickness, according to Rückert & Huneau (2004), for A-TIG the penetration increases with flux thickness until ~50 microns of thickness and after decreases. For FBTIG, the penetration increases until this values remains constant afterwards. It must be pointed out that each of these references employed different fluxes.

1.2. Proposed Mechanisms

Arc/anode constriction was initially proposed in the E O Paton Welding Institute (Simonik et al., 1976; Ostrovskii et al., 1977 and Mechev, 1993) and further used to explain the mechanism by different authors (Lucas, 2000), with some analytical demonstration (Paton et al., 2000).

The arc constriction and the Marangoni effect are the most cited mechanisms behind the penetration increase. However, there is no consensus of their significance and even presence, since some authors consider one or other and not both as the mechanism. Dong & Katayama (2004) tried to prove Marangoni effect with X-ray transmission system with a trace element (tungsten) and filming with a high-speed camera at 500 fps.

Even numerical results do not seem to be in agreement. For instance, Yushenko et al. (2008) state that the Lorentz force plays the major role, followed by the buoyancy and after Marangoni forces. On the other hand, Tanaka and Lowke (Tanaka & Lowke, 2007) present results showing that the drag force plays the major role and the Lorentz force is only third in the importance ranking behind Marangoni, which places in second.

Some authors consider that the increase in voltage could lead to a higher heat input (Middel & de Ouden, 2006). However, the change is voltage depends on the material, and in some cases, the flux can even reduce the voltage fall (Middel, 2000). Besides, even an increase in the voltage (current is kept constant) does not assures increase in the heat input, because the process efficiency could be lower.

According to Ohji et al. (1990), the anode size on arc weld pool is sensitive to the minor element in base metal (however, in the experiments the arc is affect, before the spot size reaches the flux). This means that the electromagnetic force is one of the important factors for the minor element effect in arc weld pool. In another work from the same authors (Ohji & Inoue, 1991), it is stated that the weld pool vaporizations plays an important role, where the Sulphur depresses the metal vaporization and it is suggested that a surface tensional gradient on molten pool surface due to the evaporation of surface active element (S) is important as the mechanisms of the inward flow on pool surface. As a conclusion of both papers, the authors state that the minor element influences the anode size on molten pool surface and it causes the change of fluid flow mode in molten pool, because the convective flow by electromagnetic force is directly dependent on the anode size.

The presence of active elements is not necessarily required to be on the workpiece. The AA-TIG (Advanced A-TIG) embraces the use of oxidant gases in small ppm of CO2 or O2 in the flux (Lu et al., 2004 and Fujii, 2005).

Although the Oxygen presence seems to be consolidated by literature (Rodrigues & Loureiro, 2005), it is suggested that the Oxygen content may not play such an important role in the definition of the weld bead geometry. In the same work, it is shown that the penetration enhancement is reduced when, in the shielding gas, H_2 is added to the Ar.

Finally, from this wide range of proposed mechanisms, the aim of the present work is to assess the electric arc by using the emission spectroscopy and, therefore, contribute to the discussion about the mechanism(s) involved in the A-TIG process.

2. EXPERIMENTAL APPROACH

2.1. Material and Workpiece

Austenitic stainless steel SUS304 was selected and plate dimension of 125 x 38 x 4.7 mm was cut by guillotine, considering both heat flow and availability. The plate size is important because it could influence the bead geometry. Bigger plates promote fast cooling rates, which could emphasize the A-TIG effect (more localized heat).

The 150-A current was selected from preliminary tests where full penetration was achieved while on flux and partial penetration when out of it. Therefore, it reduces costs on macroanalyses to guarantee the flux increases penetration.

The flux used in this work consists of a mixture of silicate salts that has been employed technologically at The Welding Insitute - TWI (Howse & Lucas, 1997).

A spray gun (model 250-3 Airbrush from Badger) was used for spraying the flux over the plate. The air pressure was kept constant and the air quality is considered as a standard industrial line at 3 bar. The distance from the plate to the spray nozzle was kept constant at 100 mm and the travel speed at ~50 mm/s (manual application).

The thickness of the coating after the flux is dried was measured by a coating thickness gauge PosiTestDFT (2004), which has a range of 0-1000 microns and accuracy of ±2 microns + 3%.

These approaches lead to a consistent and repeatable 7-9 microns coating thickness. Since the flux was kept at the same composition, the amount of flux can be considered as the same.

It must be pointed out that the proposed approach led to satisfactory results, since the accuracy of the gage is higher than the deviation standard of the measured thicknesses.

2.2. Equipments

The experimental rig consists of an inverter power source (data plate is shown in Fig. 1) was used with a TIG torch water cooled, electrode W+2%Th (diameter 2.4 mm) and an arc length of 3 mm. The nozzle inner diameter is 10 mm and the electrode stick-out is 10 mm. In fact, this is the maximum recommend in practical literature (equal to the nozzle diameter). Commercial pure Argon at 12 l/min was used. The travel speed was set as 10 cm/min. The acquisition system was set at 1 kHz per channel for voltage and current record.

To perform the measurement of the optical emission spectroscopy, the HR4000 spectrometer was using for acquiring spectrum in the range of 250 to 950 nm, with a resolution of 0.3 nm. Each spectrum consists of 5 averages and they are acquired at a rate of 5 Hz. Three runs were carried out, which flux applied on different regions and thicknesses (Fig. 2): flux in a middle stripe (run Spec01), two flux stripes (run Spec02) and increasing thickness coating with 8, 18, 27 and 45 microns (run Spec03).

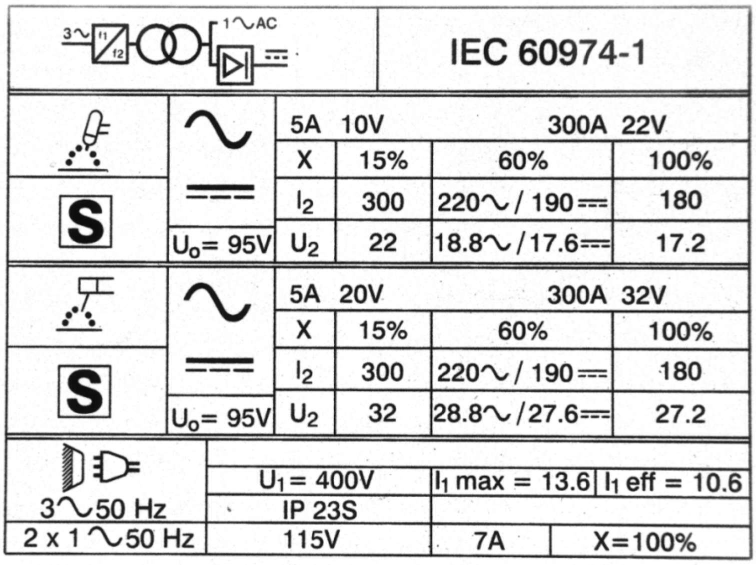
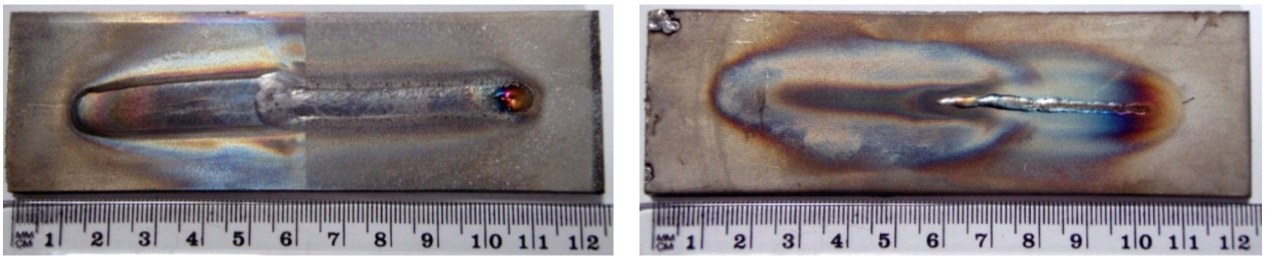


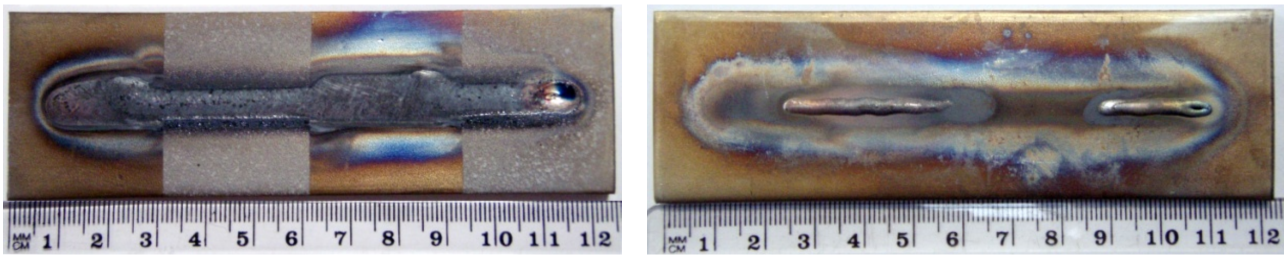
Figure 1. Data for the power source according to IEC 60974-1.

3. RESULTS AND DISCUSSION

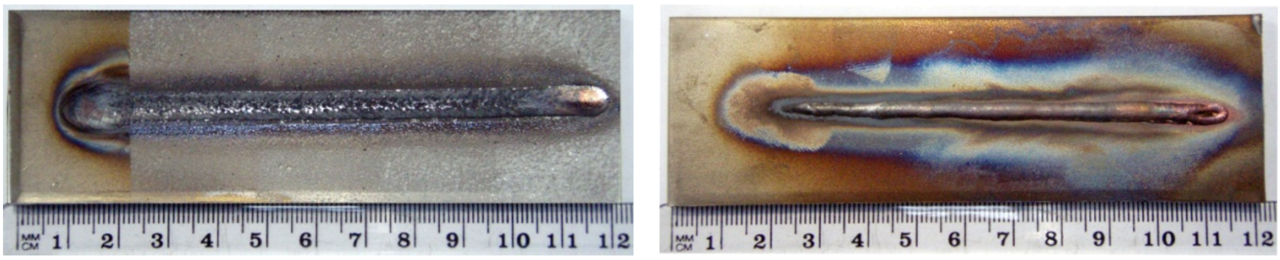
The obtained welds are shown in Fig. 2, where both face and root pictures are shown for the tree runs. The electrical signals are shown in Fig. 3 and mean/rms values for current and voltage were calculated and displayed in Tab. 1. The whole spectra are shown in Figs. 4, 5 and 6, respectively for each run.



Run Spec01



Run Spec02



Run Spec03

Figure 2. Bead face (left) and root (right) appearance (rough superficial aspect of the bead face is where the flux is) (Copyright © TWI Ltd).

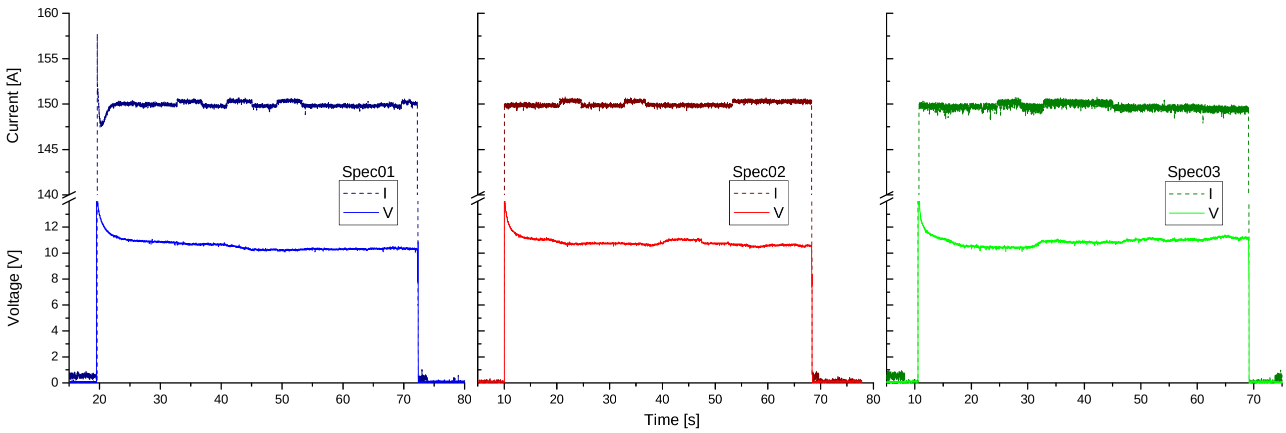


Figure 3. Electrical signals acquired during runs for spectroscopic study (Copyright © TWI Ltd).

Table 1. Measured voltage and current levels.

Run	Mean Voltage [V]	Rms Voltage [V]	Mean Current [A]	Rms Current [A]
Spec01	10.6	10.6	150	150
Spec02	10.8	10.8	150	150
Spec03	10.9	10.9	150	150

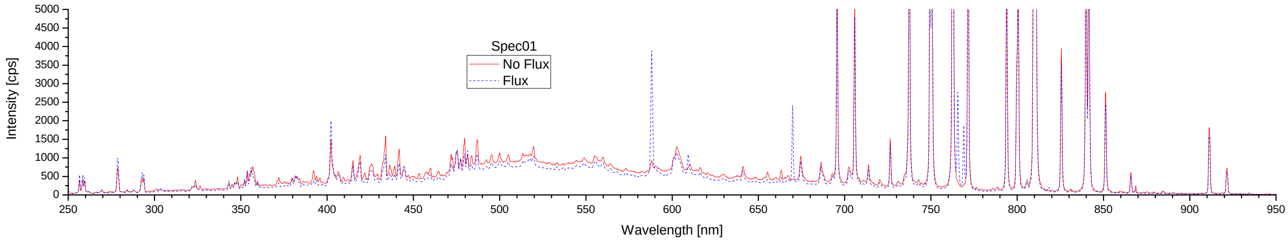


Figure 4. Spectra for Spec01 run (Copyright © TWI Ltd).

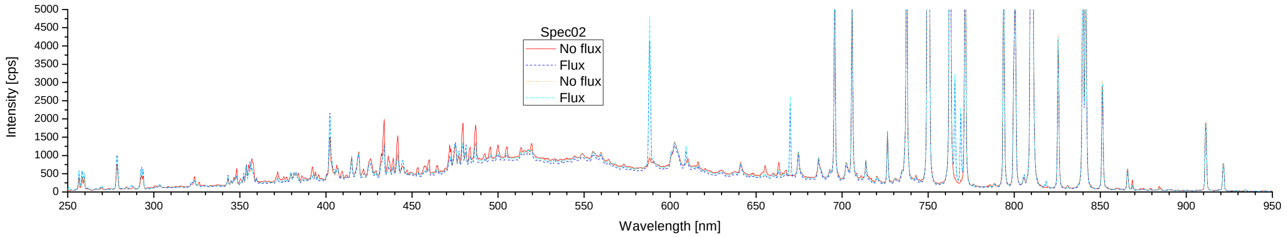


Figure 5. Spectra for Spec02 run (Copyright © TWI Ltd).

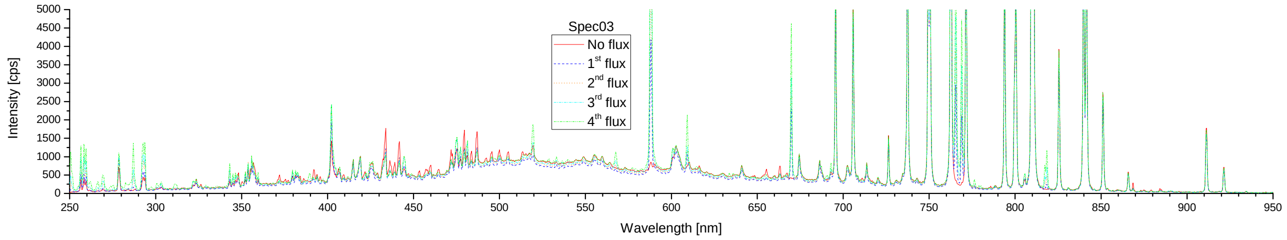


Figure 6. Spectra for Spec03 run (Copyright © TWI Ltd).

The black body radiation was measured (Fig. 7), i.e, the full energy level was taken into account. It shows a reduction in the total arc radiation, especially for Run Spec01, which indicates the total arc-volume reduction, i.e., the arc contraction. This is a strong indicative of the Lorentz force increase and, therefore, penetration enhancement.

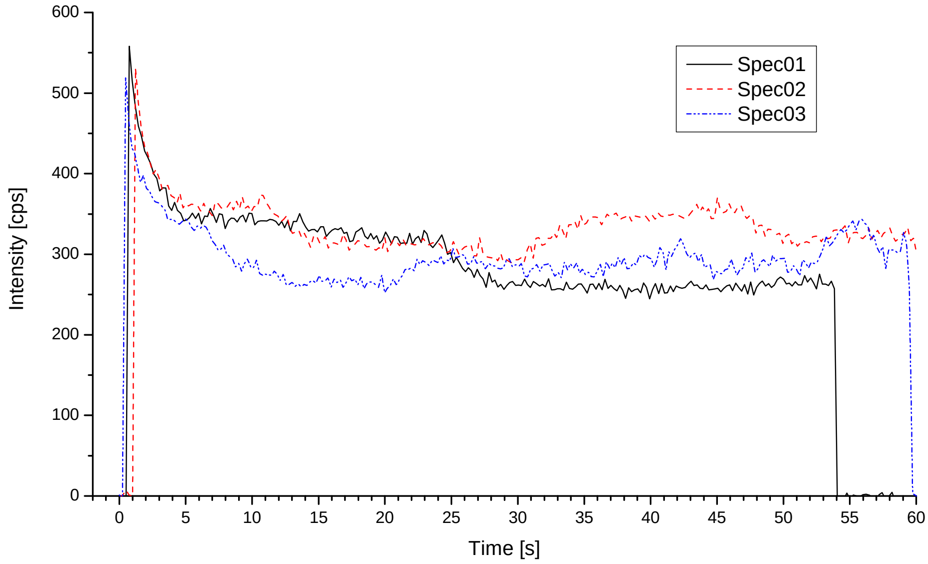


Figure 7. Intensity variation of black body radiation (Copyright © TWI Ltd).

From the spectra, different lines were selected and are shown in Tab. 2. These lines were automatically identified from the spectra and its trend during the experiment were record (i.e., along the time) and their trend will be followed discussed and analysed.

From Fig. 8, the Mn I lines present an increase. This means that more Mn was melted, i.e., or increased the melting efficiency or increased the temperature of the weld pool. Also the lower level after leaving the flux (Spec02 run around 30 s) represents a drop in the Mn content in the arc, meaning less fusion in the pool. Form the observation of the bead (Fig. 2), it can be inferred that the pool tends to spread over the plate, increasing its area and therefore reducing the current density, which led to the lower fusion and lower Mn levels.

From Fig. 9, Ar I lines slow reduction could indicate a temperature increase or decrease. Therefore, Ar II levels must be checked. If they increase, the temperature increases. On the other hand, if Ar II levels decrease, therefore the arc temperature decreased.

From Fig. 10, O I line intensity remains approximately constant. However, when great quantity of flux is added (Spec03 after 35 s), there is an increase in the O lines, which corroborates to the electronegative elements presence.

From Fig. 11 (Ar II and H I lines), there is also a decay in Ar II lines. This was checked to guarantee that the arc temperature does not increase. It could be a population inversion between the excited (I) and ionized lines (II) meaning that, although the Ar I lines decay, the Ar II levels increase due to temperature increase. This did not happen. Therefore, the arc temperature is lower.

As same as pointed to OI lines, there is an increase for thicker coatings, such after 50 s in Spec 03. It could represent a change in the mechanism for thicker coatings. However, it is not investigated since the thinner the coating, less slag on the bead and the better.

Moreover, in Fig. 12 the lines of the elements present in the flux are shown: Na I, K I and Li I. This picture clearly present a trend of the thicker the flux layer, more elements are injected into de arc. These elements have lower ionisation potential and cause change in the arc column. It is assumed here, that lower the ionisation level means lower the maximum temperature reached. This could lead to the arc reduction and, therefore, increase the current density and finally the penetration.

Table 2. Observed lines.

Wavelength [nm]	Element	Trend
279.482	Mn I	Increase since the beginning
403.076	Mn I	Increase since the beginning
415.859	Ar I	Slow reduction
420.067	Ar I	Slow reduction
434.806	Ar II	Fast initial reduction and after slow reduction
480.602	Ar II	Fast initial reduction and after slow reduction
487.986	Ar II	Fast initial reduction and after slow reduction
588.995	Na I	Increase
610.354	Li I	Increase
656.285	H I	Fast initial reduction and after slow reduction
670.776	Li I	Increase
696.543	Ar I	Slow reduction
706.722	Ar I	Slow reduction
766.49	K I	Increase
769.896	K I	Increase
777.194	O I	Remains approximately constant
818.326	Na I	Increase
819.482	Na I	Increase

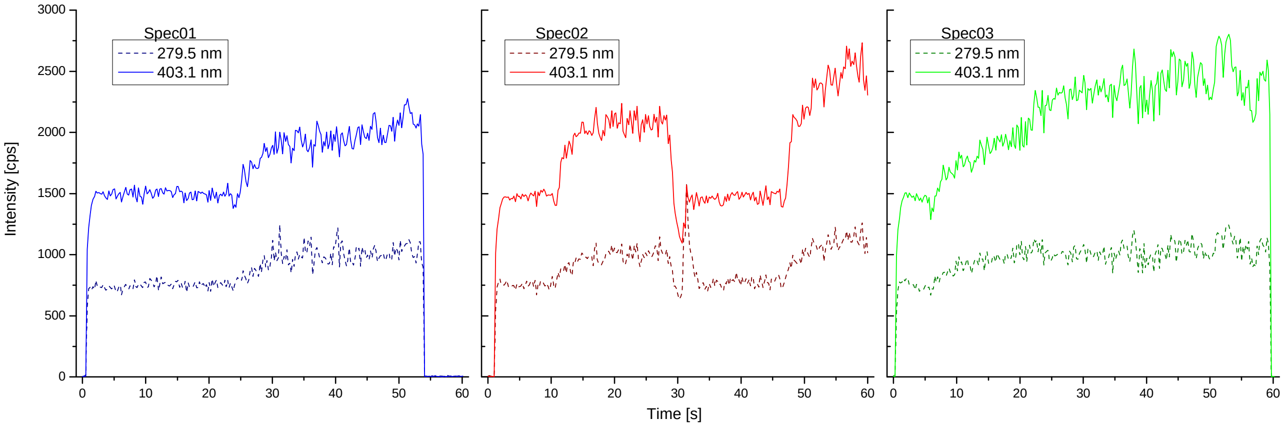


Figure 8. Intensity variation of Mn I lines (Copyright © TWI Ltd).

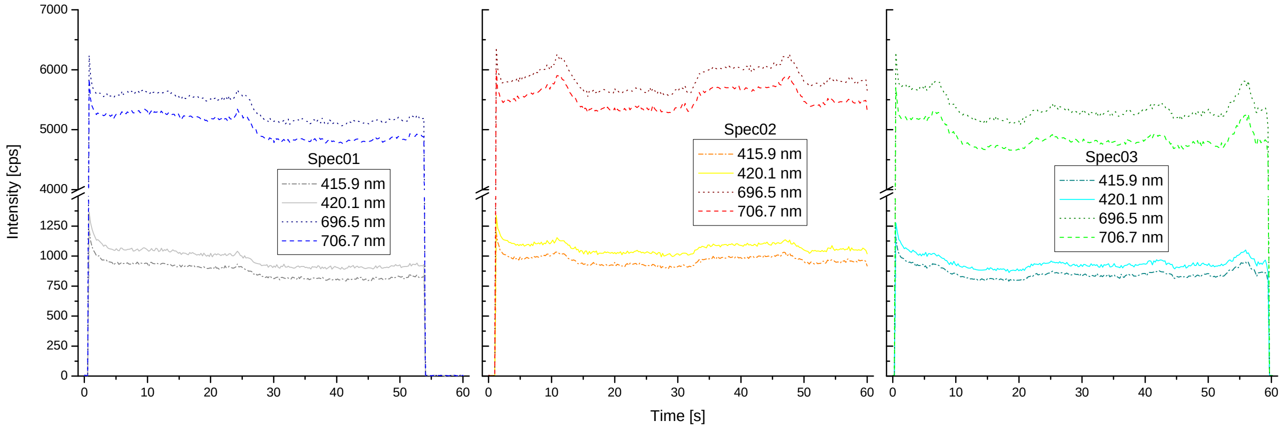


Figure 9. Intensity variation of Ar I lines (Copyright © TWI Ltd).

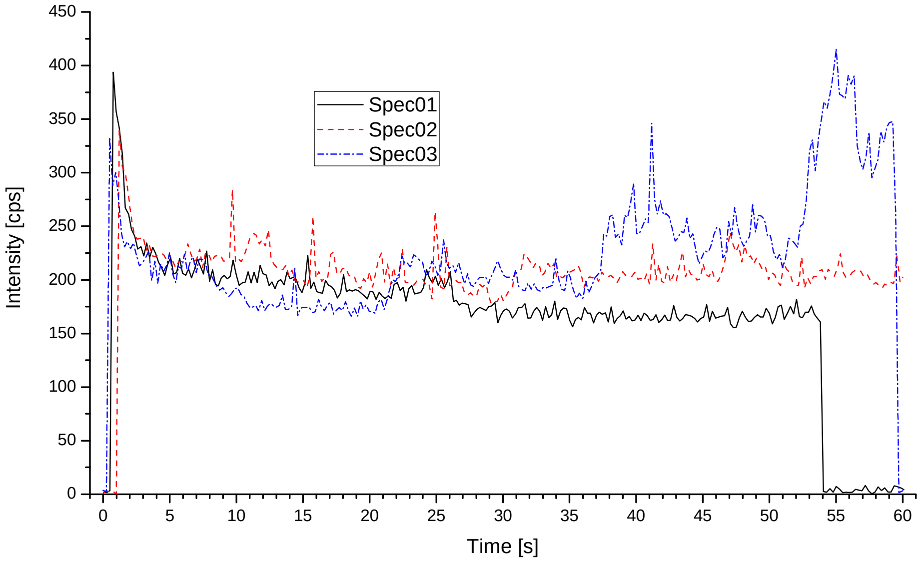


Figure 10. Intensity variation of O I lines (Copyright © TWI Ltd).

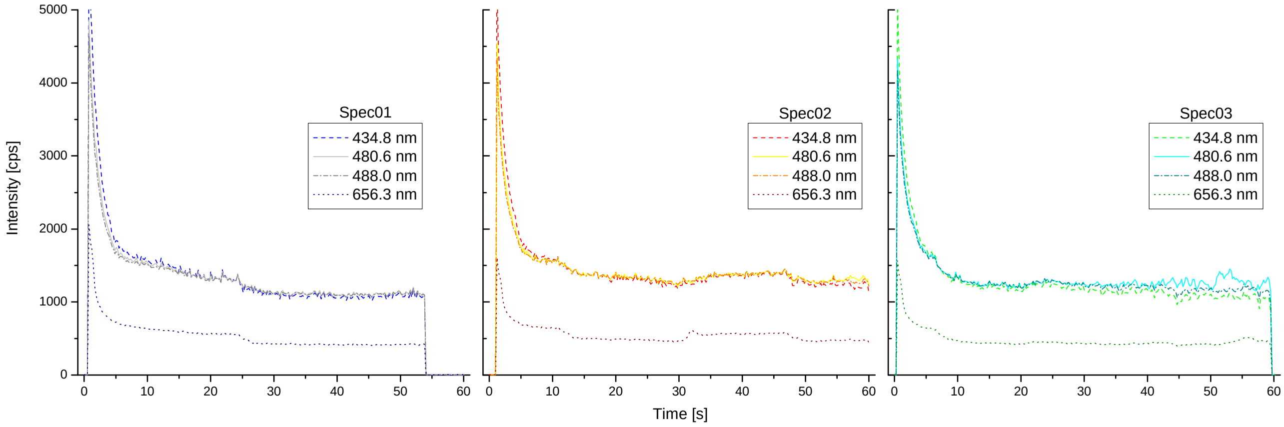


Figure 11. Intensity variation of Ar II and H I lines (Copyright © TWI Ltd).

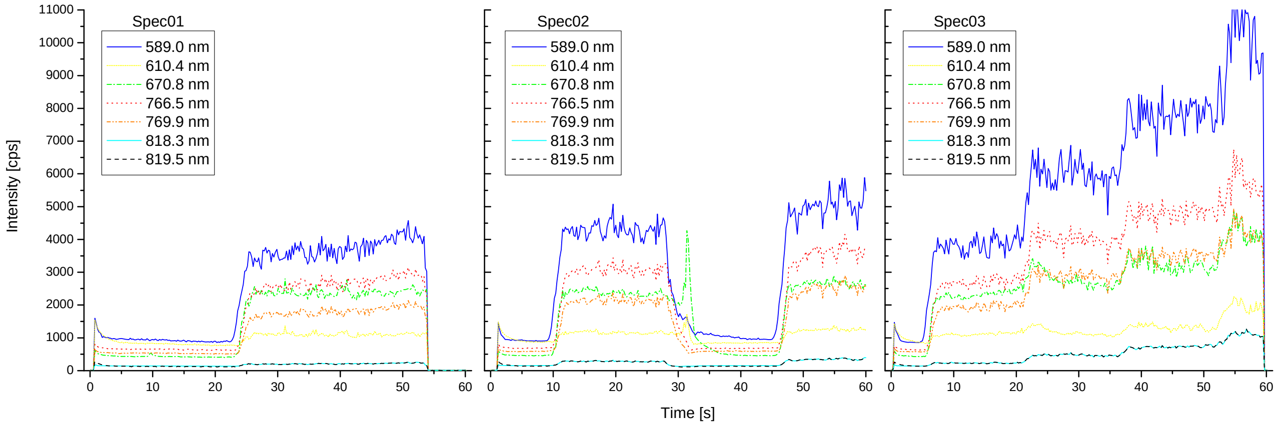


Figure 12. Intensity variation of Na I, K I and Li I lines (Copyright © TWI Ltd).

4. CONCLUSION

The main conclusion from the optical emission spectroscopic measurement refers that the arc contraction in the flux presence plays a very important role in the penetration enhancement obtained by the A-TIG process. It must be pointed out that the other mechanisms proposed by literature cannot be ignored, since no experiment was carried out to investigate them. However, the current density increase is very strong candidate to be one of the mechanisms.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

ASM, 1993. “ASM Handbook: Vol. 6 Welding, Brazing and Soldering”. 58p.
Dong, C. and S. Katayama, 2004. “Basic Understanding of A-TIG Welding Process”, IIW Doc: 12.
Fujii, H..2005. "Mechanism of A-TIG and AA-TIG.advanced A-TIG", Welding International 19(12): 934-939.
Heiple, C. R. and J. R. Roper, 1982. "Mechanism for Minor Element Effect on GTA Fusion Zone Geometry." Welding Journal(April): 97s-102s.
Howse, D. S., W. Lucas, et al., 1997. “An Investigation into the Mechanisms of Active Fluxes for TIG (A-TIG) Welding”, The Welding Institute Repot: 50.
Lu, S., H. Fujii, et al., 2004. “Effects of Welding Parameters on the Weld Shape in Ar-O2 and Ar-CO2 Shielded GTA Welding”, IIW Doc: 8.
Lucas, W., 2000. "Activating Flux - Improving the Performance of the TIG Process." Welding & Metal Fabrication February: 7-10.

Lucas, W. and D. Howse, 1996. "Activating Flux - Increasing the Performance and Productivity of the TIG and Plasma Processes." Welding & Metal Fabrication January: 11-17.

Marya, S., 2004. “Enhancing GTAW Performance Through Flux Coatings: Theoretical Background And Industrial Applications”, IIW Doc: 9.

Mechev, V. S., 1993. "Mechanism of Contraction of the Welding Arc in the Presence of Electronegative Particles." Welding International 7(2): 154-156.

Middel, W.. 2000. “Additives in GTA Welding”, PhD Thesis, Delft University of Technology: 153.

Middel, W. and G. d. Ouden., 2006. "Follow the Track." Retrieved 01/03, 2006, from http://www.delftoutlook.tudelft.nl/info/fullimage4bc3.html?ImageID=682.

Niagaj, J., 2006. "Use of A-TIG Method for Welding of Titanium, Nickel, their Alloys and Austenitic Steels." Welding International 20(7): 516-520.

Ohji, T. and e. al., 1990. "Minor Element Effect on Weld Penetration." Q. J. Japan Welding Soc. 8(1): 54-58.

Ohji, T., H. Inoue, et al.. 1991. "Metal Flow in Molten Pool by Defocused Electron Beam." Q. J. Japan Welding Soc. 9(4): 501-506.

Ostrovskii, O. E. and e. al., 1977. "The Effect of Activating Fluxes on the Penetration Capability of the Welding Arc and the Energy Concentration in the Anode Spot." Svar. Proiz.(3): 3-4.

Parshin, S. G., 2006. "Properties of Slag Films of Activating Fluxes in Argon-Arc Welding." Welding International 20(1): 45-48.

Paskell, T., C. Lundin, et al., 1997. "GTAW Flux Increases Weld Joint Penetration." Welding Journal April: 57-62.

Paton, B. E., V. N. Zamkov, et al., 2000. "Contraction of the Welding Arc Caused by the Flux in Tungsten-Electrode Argon-Arc Welding." The Paton Welding Journal: 5-11.

PosiTestDFT, C, 2004. “Coating Thickness Gage - Instruction Manual ver. 1.0.Combo -measures on all metals)”, USA, p. 1.

Rodrigues, A. and A. Loureiro, 2005. "Effect of Shielding Gas and Activating Flux on Weld Bead Geometry in Tungsten Inert Gas Welding of Austenitic Stainless Steels." Science and Technology of Welding and Joining 10(6): 760-765.

Rückert, G., B. Huneau, et al., 2004. “Optimization of flux coatings on ATIG welding performance: Case study of silica on stainless steels”, IIW Doc.

Simonik, A. G. and e. al., 1976. "The Effect of Contraction of the Arc Discharge upon the Introduction of Electro-Negative Elements." Svar. Proiz.(3): 49-51.

Tanaka, M. and J. J. Lowke., 2007. "Predictions of Weld Pool Profiles using Plasma Physics." J. Phys. D: Appl. Phys. 40: R1-R23.

Yushchenko, K. A., D. V. Kovalenko, et al., 2008. “Experimental Studies and Mathematical Modelling of Metal Penetration in TIG and A-TIG Stationary Arc Welding”. Graz, Austria, IIW Doc: 28.

Zamkov, V. N. and V. P. Prilutsky, 2004. "Theory and Practice of TIG-F (A-TIG) Welding (Review)." The Paton Welding Journal 9: 11-14.

Zhao, Y., Y. Shi, et al., 2006. "The Study of Surface-Active Element Oxygen on Flow Patterns and Penetration in A-TIG Welding." Metallurgical and Materials Transactions B 37B(3): 485-493.

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