SUCCESSFUL HIGH-PRODUCTIVITY WELDING WITH A-TIG PROCESS

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Abstract. *It is well-established by 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 shortfalls, such as adding a very small quantity of oxidant gas to the inert one, increasing the gas flow, use of external magnetic fields, increasing the electrode emissivity and optimisation of the electrode-tip configuration. Although these approaches enhanced the arc characteristics and improved the penetration pattern, the achieved productivity improvements were marginal. An increase in productivity can be achieved by increasing the penetration depth, as it helps reducing the number of welding passes. Activated TIG welding process, known as A-TIG, can be beneficial in this respect. A-TIG welding process involves a method of increasing the penetration capability of the arc in TIG welding. This is achieved through the application of a thin coating of activating flux material onto the work piece surface prior to welding. Therefore, this work explores A-TIG welding process employing a developed flux for improving the penetration depth and productivity for stainless steel tube materials and also applied on bead-on-plate welds for mild steel, ferritic stainless steel and aluminium. Four different applications are presented, described and discussed. It was found that the consistency in quality, reduced need for edge preparation, reduced distortion and the improved productivity could make A-TIG welding process more attractive than the conventional TIG process in tube welding.*

Keywords*: Welding, A-TIG, Productivity, Flux.*

1. INTRODUCTION

The A-TIG welding process involves a method of increasing the penetration capability of the arc in TIG welding. This is achieved through the application of a thin coating of activating flux material onto the joint surface prior to welding. The effect of flux is believed to constrict the arc which increases the current density at the anode and the arc force action on the weld pool. The constricted appearance of the A-TIG arc is compared with the characteristic diffuse appearance of the conventional TIG arc in Fig.1.

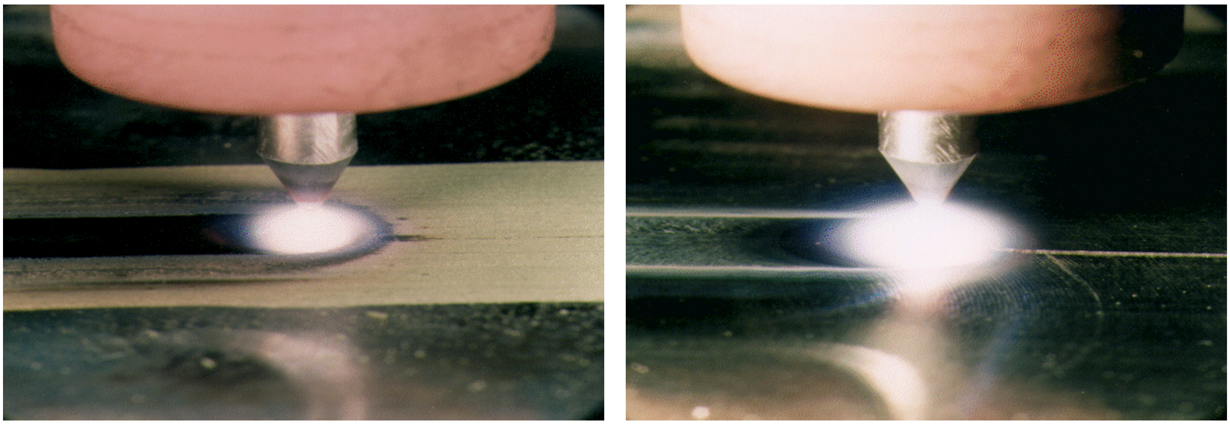

Figure 1. Comparison of conventional TIG and A-TIG welding arc (Copyright © TWI Ltd).

The use of activating fluxes for TIG welding was first reported by the EO Paton Institute of Electric Welding in the former Soviet Union in the 1950's. More recently activating fluxes have become commercially available from several sources. These fluxes claim to be suitable for the welding of a range of materials, including C-Mn steel, Cr-Mo steels, stainless steels and nickel-based alloys. The fluxes are generally available in the form of either an aerosol or as a paste (powdered flux mixed with a suitable solvent) which is applied onto the surface with a brush. The activating fluxes can be applied in both manual and mechanised welding, although it is more difficult to control in the former mode of operation. Although different theories has been published through the years (Gurevich et al, 1965; Makara et al, 1968; Simonik 1976; Ostrovskii et al, 1977; Heiple & Roper, 1982; Voropai & Lebedeva, 1989 and Howse et al, 1997), the mechanism or mechanisms behind the A-TIG process is/are not fully understood.

The specific advantages claimed for the A-TIG process compared with conventional TIG include:

- Increased productivity due to greater depth of penetration, i.e., up to 8 mm in stainless steel compared to 3mm for conventional TIG welding. Increased productivity is derived through a reduction in welding time and/or a reduction in the number of welding passes.
- Reduced distortion, i.e., the use of a square edge closed butt joint preparation reduces weld shrinkage compared with a conventional multipass V butt joint.
- Problems of inconsistent weld penetration associated with cast-to-cast material variations can be eliminated. For example, deep penetration welds can be made in low sulphur stainless steel (~0.002%), which would otherwise show a shallow, wide weld bead in conventional TIG welding.

Despite the productivity benefits of A-TIG welding, industry to date has been slow to exploit the process. This is because the use of the flux is seen as an additional cost and its application an additional operation. Furthermore, the commercial fluxes tend to produce an inferior surface finish compared to conventional TIG welding and produce a surface slag residue, which is required to be removed. In order to mitigate these disadvantages, TWI has developed a new activating flux with the following characteristics which have been demonstrated in several experiments:

- It comprises a relatively simple, readily available flux ingredient.
- The flux ingredient is non-toxic. It contains no halides or fluorides.
- Flux performance, including depth of weld penetration in stainless steel, is similar to alternative commercial fluxes.
- It produces a satisfactory weld deposit surface appearance with minimal slag residue.

This work explores A-TIG welding process employing TWI's flux, which consists of a mixture of silicates (Howse et al., 1997), for improving the penetration depth and productivity for stainless steel tube materials and bead-on-plate beads in other materials (mild steel, ferritic stainless steel and aluminium). It was found that the consistency in quality, reduced need for edge preparation, reduced distortion and the improved productivity could make A-TIG welding process more attractive than the conventional TIG process in tube welding.

2. EXPERIMENTAL PROGRAMME

The experimental methodology and results consists of a series of four (4) case studies, which are aimed at illustrating the benefits of employing A-TIG welding for stainless steel tube welding and for different materials (mild steel, ferritic stainless steel and aluminium) in bead-on-plate situation.

2.1. Case Study 1: Experiments on stainless steel tube material of different wall thickness

Orbital welding of stainless steel tube is often difficult due to several problems including the capacity limitation with the welding head, heat build-up in the tube material, weld sagging, and the deflection of the arc from the seam at locations corresponding to the long seam joint resulting in lack of penetration. A-TIG welding process can offer solution to many of these problems. In this case study A-TIG welding of 304L grade stainless steel of different sizes were investigated.

Orbital welding was carried out using a Swagelok M100 or Arc Machines Inc 227 welding systems depending on the diameter of the tube, together with the appropriate weld head. The flux was applied as water based paste using a painting brush. The thickness of the flux coating was ~ 40 microns. Welding trials were carried out on tube materials of the following dimensions:

- Seamless 304L stainless steel tube 48mm OD, 4mm WT.
- 304L stainless steel laser seam welded tube 29mm OD, 1.6mm WT. These tube materials had previously shown a susceptibility to arc deflections during conventional TIG welding. Welding trials were carried out to determine whether the use of an activating flux eliminated this problem.
- 304L stainless steel tube, 6mm OD 1.6mm WT. A series of welds were carried out to compare the production duty cycles possible with conventional TIG and A-TIG welding. The welds were performed as full penetration melt runs to identify the effect of heat buildup in the tube material.

In comparison to conventional TIG welding, all the A-TIG weld procedures showed significant reduction in arc energy together with much narrower weld bead profile (Fig. 2-4). This could help increase production duty cycles for applications where heat buildup was a limiting factor. This was demonstrated for the thin wall stainless steel tube. Compared to conventional TIG welding, the operating duty cycle of the orbital TIG weld head could be extended by 50% as a result of the lower heat input required by the A-TIG procedure.

The flux was also effective in eliminating arc deflection when welding laser seam welded tube thus avoiding the possibility of lack of penetration defects which may occur in conventional TIG welding (Fig. 5).

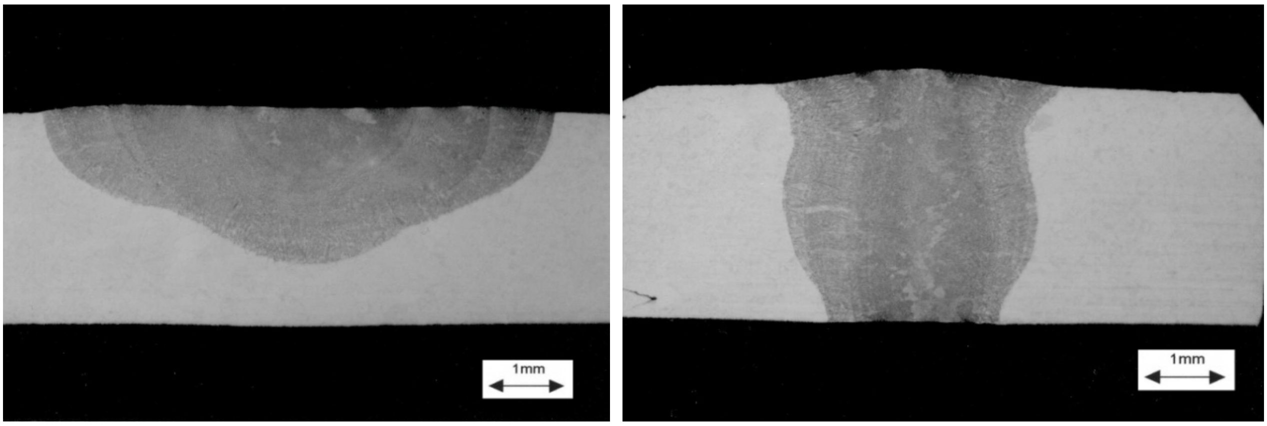

Figure 2. Transverse weld section of A-TIG and conventional TIG welds in 48mm OD, 4mmWT 304L stainless tube (Copyright © TWI Ltd).

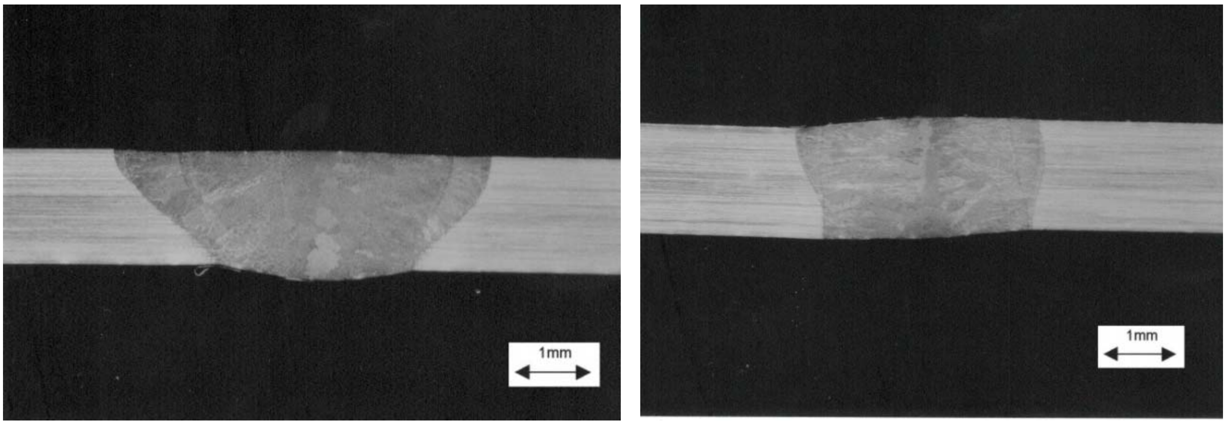

Figure 3. Transverse weld sections of Conventional TIG and A-TIG welds in 29mm OD 1.6mm WT laser seam weld 304L tube (Copyright © TWI Ltd).

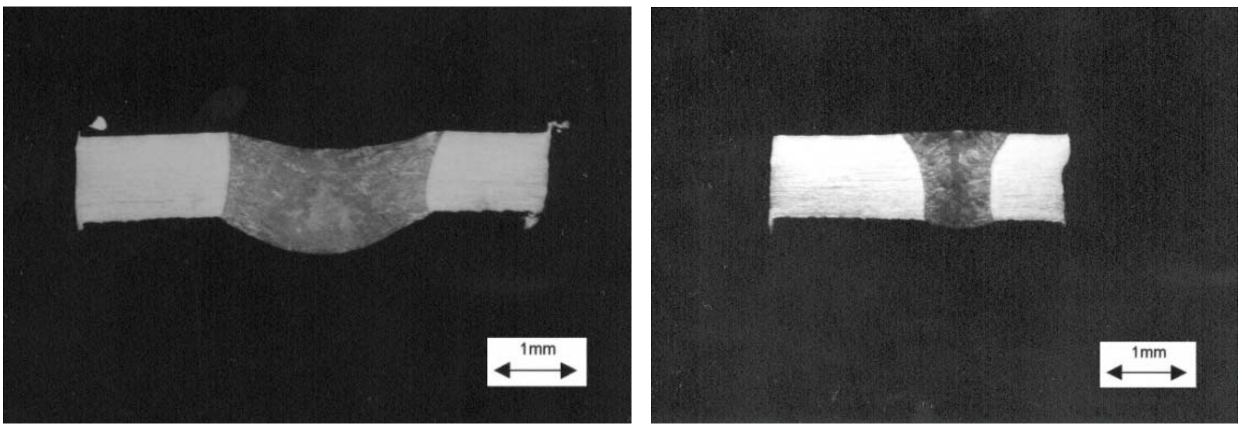

Figure 4. Transverse weld sections of A-TIG and conventional TIG welds in 6mm OD, 1.0 WT 304 L stainless tubes (Copyright © TWI Ltd).

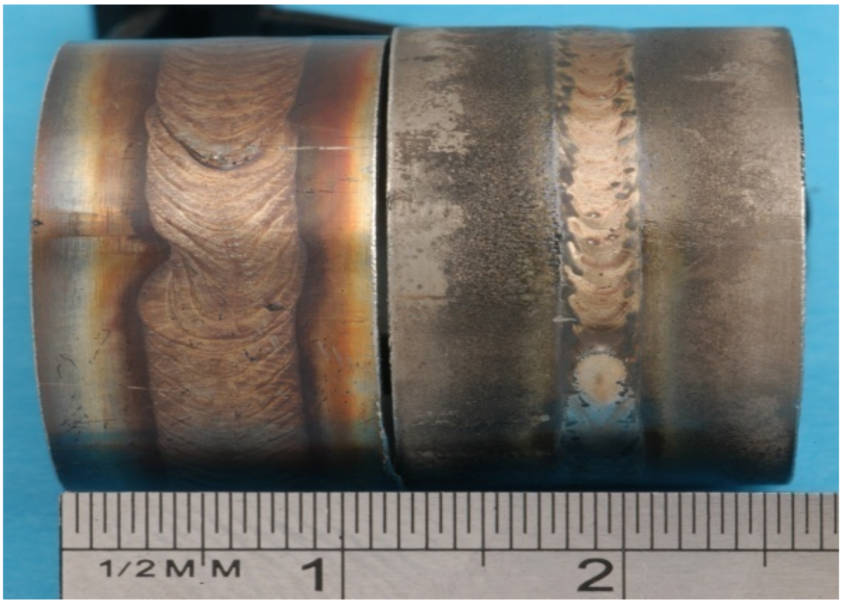

Figure 5. Conventional TIG and A-TIG welds in 29mm OD 1.6mm WT laser seam welded 304L tube showing a deflected weld bead in the conventional TIG weld (Copyright © TWI Ltd).

The main conclusions at this point can be summarized as: The use of an activating flux enables autogenous orbital TIG welding equipment to be used for the butt welding of 4mm thick 304L stainless steel tube; The use of activating flux eliminates the problem of arc deflection which can occur with orbital TIG welding of laser seam welded tube; Compared to conventional orbital TIG welding, the arc energy is reduced by 25 – 30% for A-TIG, resulting in a narrow weld profile and reduced thermal build up, as a result the operating duty cycles for the weld head can be increased by up to 50% for welding small diameter, thin wall stainless steel tube.

2.2. Case Study 2: Welding of thick pipes in stainless steel material

The objective of this investigation was to produce a weld penetration in excess of 5mm on AISI 316L grade stainless steel tubes of size 70mm OD X 22mm WT using square butt joint configuration keeping the welding current within 150A as limited by the capacity of the welding torch.

Experiments were carried out in the 2G position. Initial bead-on-tube welding trials were carried out by moving the tube relative to the torch at constant speed by holding and rotating it with a chuck. The axis of the pipe was vertical. The torch was mounted on an Arc Voltage Controller (AVC) which accommodated any variations in torch height coming from the eccentricity of the tube rotation and hence kept the arc voltage constant. The welding power source was OTC make AccuTIG 300P AC/DC TIG welding machine, which had a maximum current capacity of 300A.

The flux was applied manually onto the joint by a painting brush and the thickness of the flux coating was measured with a PosiTestDFT (2004) coating thickness gauge. The measured thickness of the flux coating was in the range 37-45 microns, with an error of ± 2 microns.

Initial bead-on-tube experiments with the application of flux revealed significant constriction of the arc by the flux coating. The weld sagging was only about 0.35mm. Photomacrographs of typical transverse macrosections of selected welds are given in Fig. 6. There was no significant difference in penetration depths between the weld produced on tubes and the weld produced on a butt joint with the application of the flux. Photomacrographs clearly show flow lines from the outer region towards the centre and down the weld.

The major conclusions of this section were: Single pass weld providing a depth of penetration in excess of 5mm can be produced on 22mm thick stainless steel tubes by the A-TIG process in 2G position welding at a welding current less than 150A; Flux coating thickness in the range 37-45 microns was adequate to provide sufficient arc constriction and the required minimum penetration depth; Close control of flux coating procedure and hence the coating thickness is necessary in achieving uniform arc weld geometry along the circumference.

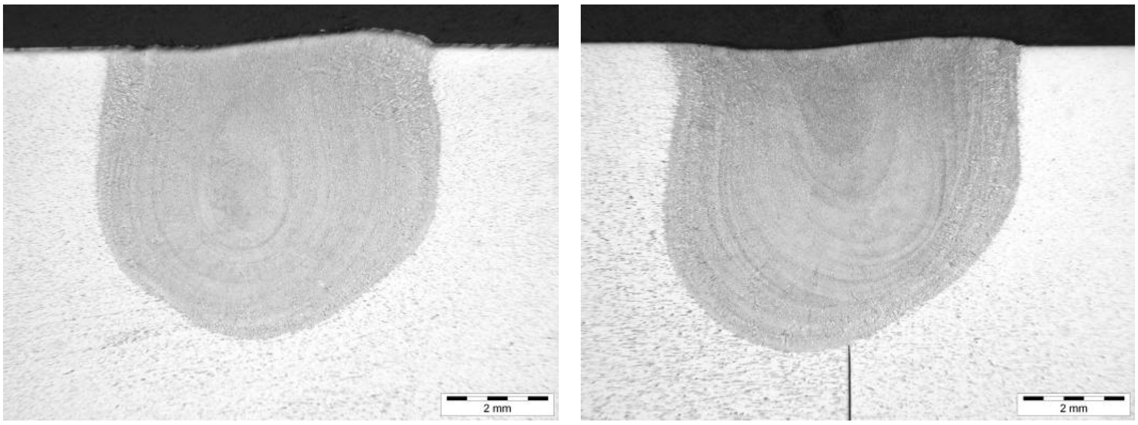

Figure 6. Photomacrographs of typical transverse sections of the A-TIG weld at 150A: bead-on- plate and butt welds (Copyright © TWI Ltd).

2.3. Case Study 3: Full penetration weld in low sulphur containing stainless steel

Welding experiments were carried out on 316L grade stainless steel with sulphur content less than 0.002% in the 2G position. A Miller Maxstar 300 DC TIG/ STICK inverter power source was used with 300A water cooled machine torch. The welding machine had settings for controlling the pre gas shielding time, the base current, the current slope-up time, the peak current, the current slope-down time and the post gas shielding time. TWI developed flux was used in the investigation. The components for welding were initially de-greased with acetone. The flux was applied directly onto the weld seam manually using a two stroke brush action giving a flux covering to a width of about 10mm on either side of the seam. The thickness of the flux coating was measured with a PosiTestDFT coating thickness gauge and the thickness was 35-50 microns with an error of ± 2 microns.

Photomacrograph of the transverse section of the welds obtained in conventional TIG and A-TIG are shown in Fig. 7. The weld produced with A-TIG process was narrower and with little or no sagging compared to the one produced with conventional TIG welding which was shallow with significant sagging.

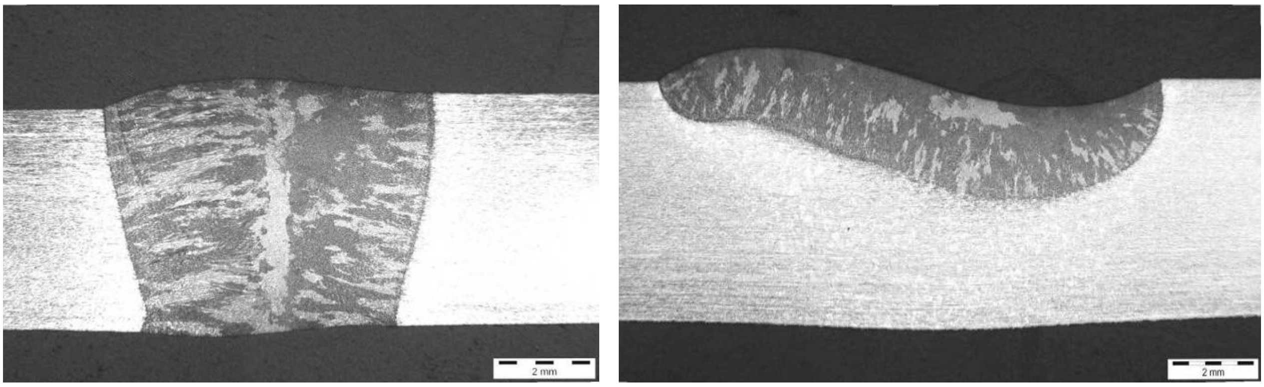

Figure 7. Photomicrographs of transverse macro sections of weld on 316L grade steel produced at 180A welding current and 85mm/min welding speed with A-TIG and conventional TIG welding (Copyright © TWI Ltd).

The major conclusions of this study were: TWI developed A-TIG flux was found to be effective in constricting the arc and increasing penetration on low sulphur containing 316L grade stainless steel; Flux coating thickness in the range 37-45 microns was adequate to provide sufficient arc constriction and the required minimum penetration depth; A productivity improvement of about 3 times can be achieved by A-TIG welding process employing TWI flux.

2.4. Case Study 4: Bead-on-plate weldments with different materials

Bead-on-plate weldments were carried out in flat position on a workpiece of 125 x 38 x 5.0 mm for three different materials: mild steel (SAE 1020), ferritic stainless steel (chemical composition is shown in Tab. 1) and aluminium (AA 5052).

TWI's flux (Howse et al., 1997) was sprayed over half of the plate, providing a coating thickness of 8±2 microns (PosiTestDFT, 2004). The welding current was set at 150A which produced full penetration on the flux coated section and only partial penetration on the uncoated section. The other welding parameters were:

- Travel speed: 100 mm/min
- Shielding gas: argon at 12 l/min
- Nozzle diameter: 10 mm
- Electrode W+2%Th, diameter of 2.4 mm, with a stick-out of 10 mm.
- The arc length of 3 mm.

Table 1. Chemical composition for the employed ferritic stainless steel.

Elem.	**C**	**Cr**	**Mn**	**N**	**Nb**	**Ni**	**P**	**S**	**Si**	**V**	**Ti**
%	0,0095	17,1284	0,1434	0,0075	0,2009	0,1777	0,0234	0,0027	0,4032	0,0507	0,1984

The obtained results are shown in Fig. 8. It clearly shows the effect of penetration enhancement on the root side for all the three materials. This assures the employability of the flux over a wide range of engineering materials. Since the welding current was kept constant, it is possible to state that, in order to keep the same penetration, the travels speed can be increased and therefore, increasing the process productivity.

3. CONCLUSIONS

The main conclusions that outcome from the experiments are:

- Transverse macro sections of A-TIG weld show inward flow lines even in low sulphur containing stainless steel.
- Strong electromagnetic force from the constructed arc is believed to reverse the flow pattern overcoming the effect of TCST in A-TIG welding.
- Case studies show significantly higher productivity with A-TIG welding compared to conventional TIG welding.
- The flux can be successfully applied over a range of materials.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

Gurevich SM et al. 1965. "Improving the penetration of titanium alloys when they are welded by argon tungsten arc process", Automatic Welding**,** 9**,** pp l-4.

Heiple CR and Roper JR, 1982. "Mechanism for minor element effect on GTA fusion zone geometry", Welding Journal**,** 61 (4), pp. 97s-102s.

Howse D, Lucas W and Russell JD, 1997. "An investigation into the mechanisms of active fluxes for TIG (A-TIG) welding", TWI Members report 604, 1997.

Makara AM et al, 1968. "'High-tensile martensitic steels welded by argon tungsten arc process using flux". Automatic Welding**,** 7**,** 1968, pp. 78-79.

Ostrovskii OE et al. 1977. "The effect of activating fluxes on the penetration capability of the welding arc and the energy concentration in the anode spot", Welding Production, 3, 1977, pp. 3-4**.**

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

Simonik AG, 1976. "The effect of contraction of the arc discharge upon the introduction of electro-negative elements", Welding Production**,** 1976, 3**,** pp 49-51.

Voropai NM and Lebedeva, 1989. "Physical properties of welding fluxes based on TiO, formed in melting activated wires", Automatic Welding, 3**,** 1989, pp. 19-23.

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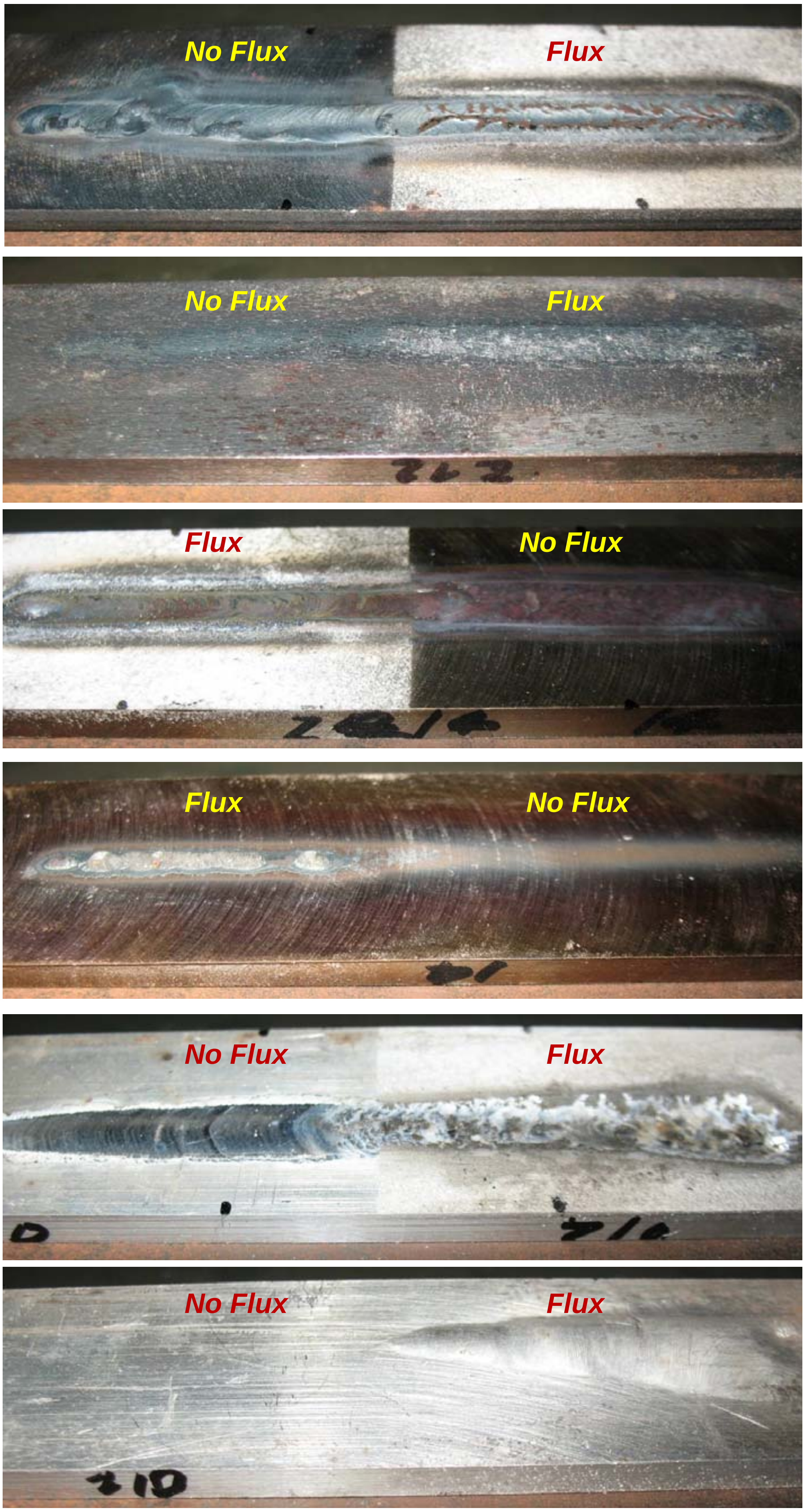

(a1) Mild steel - face

(a2) Mild steel - root

(b1) Ferritic stainless steel - face

(b2) Ferritic stainless steel - face

(c1) Aluminium - face

(c2) Aluminium - root

Figure 8. Face (1) and root (2) pictures for bead-on-plate weldments for (a) mild steel; (b) ferritic stainless steel and (c) aluminium. (for scale, consider plate thickness as 5 mm).