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ACTIVE FLUX TUNGSTEN INERT GAS WELDING OF AUSTENITIC STAINLESS STEEL AISI 304

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The paper presents the effects of flux assisted tungsten inert gas (A-TIG) welding of 4 (10) mm thick austenitic stainless steel EN X5CrNi1810 (AISI 304) in the butt joint. The sample dimensions were 300 ´ 50 mm, and commercially available active flux QuickTIG was used for testing. In the planned study the influence of welding position and weld groove shape was analysed based on the penetration depth. A comparison of microstructure formation, grain size and ferrit number between TIG welding and A-TIG welding was done. The A-TIG welds were subjected to bending test. A comparative study of TIG and A-TIG welding shows that A-TIG welding increases the weld penetration depth.

Key words: A-TIG welding, austenitic stainless steel, QuickTIG active flux, microstructure, bending test

INTRODUCTION

Active flux TIG (A-TIG) welding is also called flux assisted TIG welding. Active fluxes (AF) have the tendency to increase the penetration depth of TIG welding. A significant increase in the productivity is possible, due to reduction in the number of weld passes and no need for edge preparation. The active fluxes were first introduced by EO Paton Institute in late 1950s. In the first published papers the A-TIG welding was done on titanium alloys and later also on steels [1, 2]. A-TIG welding enables full penetration in 12 mm thick material with a single pass [3].

A number of mechanisms were proposed to explain the arc constrictions of an activating flux, which usually consists of some of these oxides (Cr_2O_3, MnO_2, ZnO, V_2O_5, KCr_2O_7, NiO, CaO, Cu_2O, TiO, TiO_2, Ti_2O_3, SiO_2, Al_2O_3, Fe_2O_3, sulphur, aluminium, selenium,) and halides (CaF_2, AlF_3, MgF_2, CdCl, $MgCl_2$, Na_2WO_4) [4–7]. The Heiple-Roper (1982) theory explains the difference in penetration depth as the consequence of active agent in the liquid metal. If the concentration of oxygen or sulphur exceeds 50 ppm, it changes the surface tension gradient (dγ/dT) from negative to positive and thus reversing the Marangoni convection and making the weld pool deeper (Figure 1). At negative surface tension gradient the central warmer liquid metal is pulled towards the colder regions of the weld pool which has higher surface tension, and this makes shallower welds (Figure 1a). In case of positive surface tension gradient of liquid metal the metal flow is in direction from the colder outer region to the weld center, where the heat is transferred to the pool bottom, which increases the penetration depth (Figure 1b) [4, 5].

Simonik proposed a theory of effectiveness of a flux constituent in constructing arc and linked it to a higher temperature of molecule formation, high energy of electrons and ionisation [8]. He proposed that charged particles at the outer region of the arc has smaller mobility like the one in the center, which leads to increased current density in the arc plasma (arc center). Lukas and Howse used Simonik's theory to explain the observed arc constriction for increased penetration. They explained that arc constriction will be promoted by com-

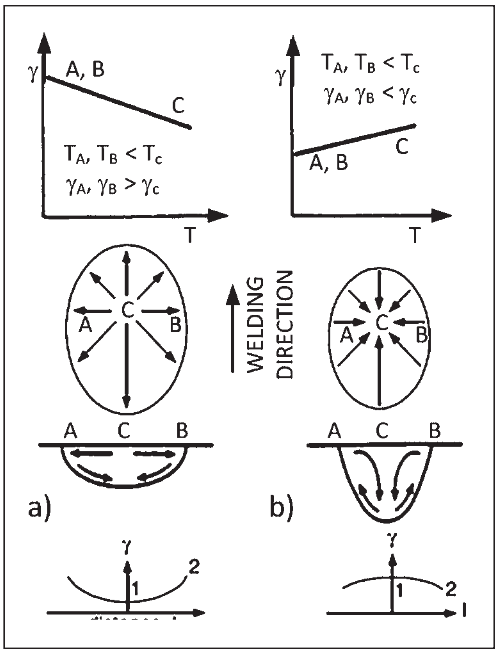

Figure 1 Heiple-Roper model for Marangoni convection in weld pool (a) low sulfur steel and (b) high sulfur steel [5]

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ponents of active flux, whose molecules or atoms have a large electron attachment cross section when dissociated i.e. have a stronger affinity for electrons. Active compounds like metal oxides have smaller electron attachment diameter, but have a higher dissociation temperature. They provide higher number of vaporised molecules and atoms in the outer region of the arc and with that increased arc constriction. [3, 9]

Active flux significantly increases the weld depth penetration when using TIG or plasma arc welding, or at laser welding and at electron beam welding [6, 9–11]. Active flux welding changes penetration depth at welding stainless steels, titanium alloys, aluminium alloys, magnesium alloys and other steels [12-19].

Mizutani and Katayama demonstrated increased penetration by laser pre-treatment of surface in oxygen, with which oxygen is introduced into this surface. At later TIG welding of this surface a through weld in 8 mm thick plate with clean surface was obtained [19].

EXPERIMENTAL WORK

A standard 1.4301 (EN X5CrNi1810, AISI 304) stainless steel with chemical composition 18,25 % Cr, 9,25 % Ni, ≤ 0,07 % C, ≤ 1,0 % Si, ≤ 2,0 % Mn, ≤ 0,03 % P, 0,003 % S, 0,092 % N and the rest Fe was used. Its yield strength is 215 MPa and tensile strength 505 MPa [20].The test coupons were 4 (10) mm thick with dimensions 300 ´ 50 mm, and were welded in a butt joint. At TIG and A-TIG welding argon shielding gas at 10 l/min was used. The electrode tip workpiece distance was constantly at 1 mm. We used the commercially available active flux suspension “QuickTIG”, which does not contain the health hazardous oxides of chromium and nickel [22]. One thin layer of active flux was laid to the surface of workpiece prior welding. From the welds, samples for macro/microstructure analysis and bending test were sectioned. The samples for macro/microstructure analysis were etched in a solution of “royal water” i.e. the hydrochloric nitrogen acid (HNO_3 + 3 HCl) in glycerine and examined using a light optic microscope equipped with the digital camera.

In the welds the amount of delta ferrite i.e. ferrit number (FN) was measured using Feritoscope MP 30.

RESULTS AND DISSCUSION

Figure 2 shows microstructure of TIG and A-TIG welds, welded with 135 A at 2,5 mm/s and at heat input of 745 kJ/m on a 4 mm thick plate.

The weld penetration depth at TIG weld is only ~ 1 mm, while a full penetration is obtained at A-TIG welding (Figure 2a, d). This difference in the weld shape changes the orientation of grains due to different direction of heat conduction. In both cases the transcrystalic grains are formed in the direction of temperature gradients. In case of TIG welding this is in the direction from weld toe to its root, in the case of A-TIG welding the

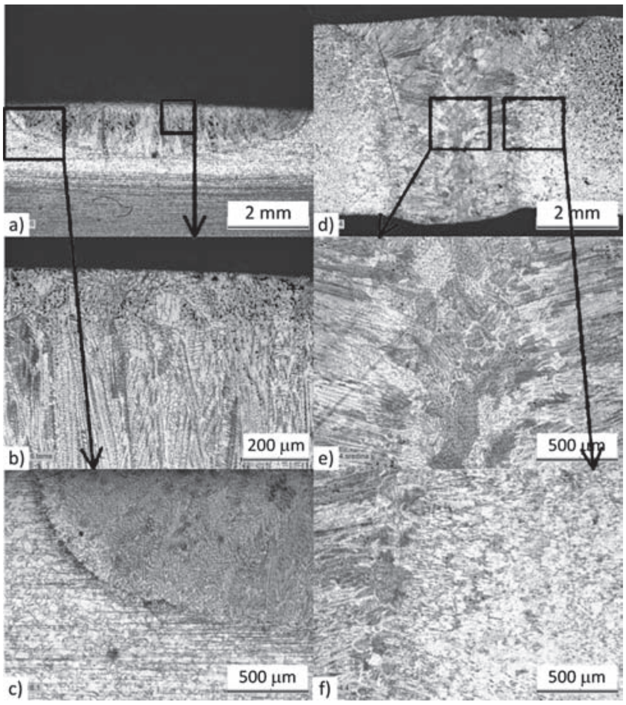

Figure 2 Microstructure of a–c) TIG and d–f) A-TIG welds (135 A, 2,5 mm/s, Q = 745 kJ/m)

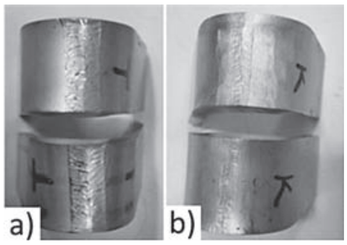

Figure 3 Bending test results of weld a) apices and b) toe (A-TIG, 135 A, 2,5 mm/s, 745 kJ/m)

grains are formed perpendicular to the plate thickness (Figure 2b, d). The grains at TIG welding are small and have a dendritic structure (Figure 2b, c). At A-TIG welding a larger globular grains are formed in the middle of the weld centre (Figure 2e), and are surrounded by transcrystalic grains, which are larger than the grains of the base metal (Figure 2f).

A bending test of A-TIG welds was done in order to establish the influence of different grain size and orientation on mechanical properties of welds. The results shows that a full 180° bends were done without crack appearance at bending over the weld toe or apices (Figure 3). This suggests that the grain size and orientation inside the weld have no negative effect on mechanical properties tested using bending test.

Welding in different positions was done to establish the influence of welding position on the penetration depth. Standard EN ISO 6947 defines the welding positions as PA flat position, PC horizontal position, and plate vertical -up position (PF) and -down position (PG). Figure 4 shows A-TIG welds obtained at welding speed 2,5 mm/s in different positions and at welding currents from 130 A to 140 A. A full penetration weld

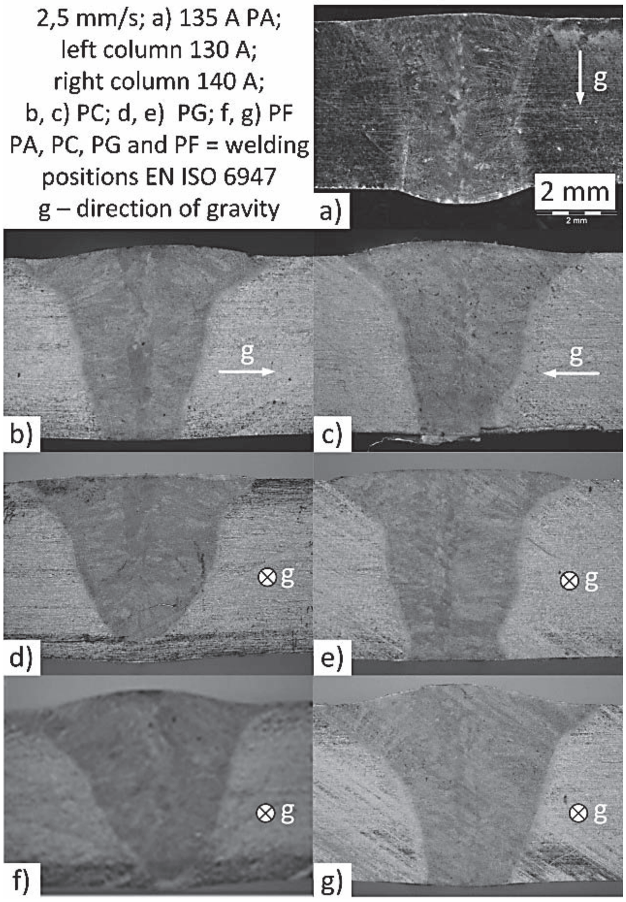

Figure 4 A-TIG welds obtained at welding speed 2,5 mm/s in different positions and at welding currents from 130 A to 140 A

was obtained at 135 A in PA position (Figure 4a) and also in PC position when welding with 130 A and 140 A (Figure 4b, c). In PC position the fusion at weld toe is much smaller than in PA position, and weld apices are shifted in direction of gravity. When welding on plates in vertical position uphill (PF) or downhill (PG) at 130 A the weld penetration was not full (Figure 4d, f) and was smaller in PF position. When welding with 140 A, a full penetration was obtained in both welding positions (Figure 4e, g). The gravity increases the penetration depth or shifts the molten weld. If the gravity does not act in the direction from weld apices to the toe the welding current should be slightly bigger to obtain the full penetration.

The influence of weld edge preparation on the weld penetration was studied on the prepared V, U and flat grooves in 10 mm thick plate, with 5 mm rift height. They were welded in flat position. The tests were repeated with different welding currents up to 180 A and by variation of welding speed. At flat groove the full penetration was obtained at 145 A and at 2 mm/s (Figure 5c). The welding current was 15 A higher and the welding speed was 0.5 mm/s slower as when welding 4 mm thick plate, due to a bigger plate thickness and heat sink. At U groove a full penetration was obtained at 170 A and 1,7 mm/s, while only ~ 3 mm penetration depth was obtained at V groove at 180 A and 1 mm/s (Figure

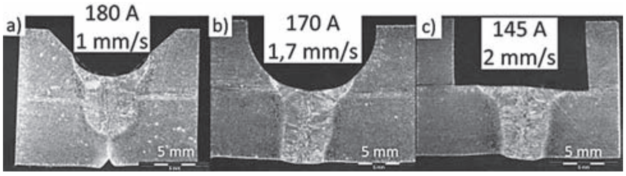

Figure 5 Macrosections of A-TIG welds on 10 mm plate with a) V groove, b) U groove and c) flat groove

Table 1 **Ferritic number of welds vs. heat input**

	586 kJ/m	745 kJ/m
A-TIG	6,3	7,17
TIG	5	6,8

5a, b). The smaller penetration in V groove results in melting the sides of the groove. This fills the groove and results in thicker rift height without full penetration. A U grooved edge preparation should be a preference for A-TIG welding.

The results show that ferrit number (FN) in welds is increasing with increasing heat input (Table 1). The FN is between 6 and 20 % higher and melting rate ~ 33 % higher at A-TIG welding compared to TIG. FN is less than 10, which is the limit for good corrosion resistance.

CONCLUSIONS

The following conclusions can be summarized:

- At A-TIG welding a bigger globular grains are formed in the weld centre and are surrounded by transcrystalic grains. These welds have good bending properties.
- The gravity in direction from weld apices to the toe increases the penetration depth. When welding in other positions heat input should be increased to get full penetration.
- A U grooved edge should be used for A-TIG welding of thicker plates.
- The FN at A-TIG welding is up to 20 % higher compared to TIG welding with the same welding parameters.

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Note: The responsible translator for English language is mag. Katja Hrovat, prof.