CONDITIONS FOR FORMATION OF DEFECT-FREE WELDS IN NARROW-GAP MAGNETICALLY CONTROLLED ARC WELDING OF LOW TITANIUM ALLOYS

V.Yu. BELOUS
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

Conditions providing defect-free welds on low titanium alloys by using narrow-gap magnetically controlled arc TIG welding were experimentally studied. The mechanisms causing deflection of the welding arc at different parameters of the welding process were established.

Keywords: *titanium alloys, TIG welding, tungsten electrode, magnetic control of the arc, deflection of the arc, weld metal*

Narrow-gap welding (NGW) by the TIG method is an efficient and cost-effective process for joining more than 16 mm thick titanium. It has certain technological advantages over the V- or U-groove welding processes, such as reduction of the weld and HAZ width, and decrease in amount of the deposited metal, which is especially important for welding titanium. In addition, NGW has labour engineering advantages as well, i.e. reduction of labour consumption in edge preparation and substantial increase in labour productivity [1]. As the major part of the heat energy of the free-burning arc is consumed for repeated penetration of the previous-pass weld metal, to successfully implement the process it is necessary to provide reliable melting of the side walls of the groove. This requires redistribution of the heat input into the welded joint, which can be achieved by mechanically moving the tungsten electrode and welding arc [2], or affecting the arc by an external controlling magnetic field [3].

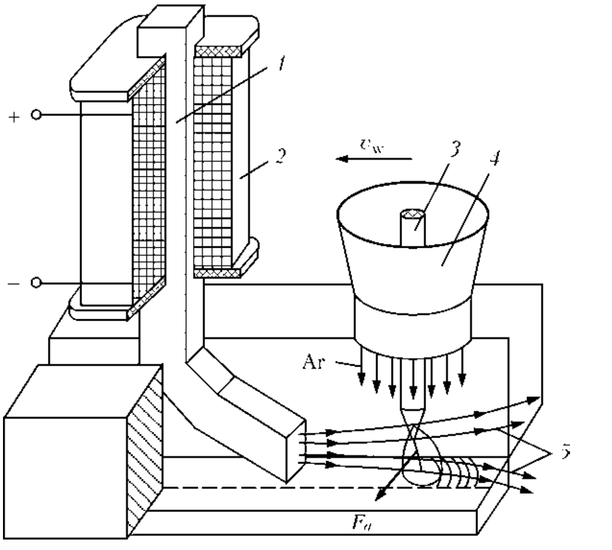

Figure 1. Flow diagram of NGW with controlling magnetic field: *1* — electromagnet core; *2* — electromagnet coil; *3* — tungsten electrode; *4* — protective nozzle; *5* — force lines of controlling magnetic field

Flow diagram of NGW of titanium by using the controlling magnetic field is shown in Figure 1. Welding was performed at a direct current of straight polarity with the tungsten electrode lowered into the groove, the protective nozzle being located over the weld edges. The magnetic field within the arc zone is formed by an electromagnet with a core. In welding it acts as a magnetic conductor, and is placed in the narrow groove. The electric current flowing through the electromagnet coil induces the magnetic field within the arc zone, the force lines of the field being oriented mostly along the welding direction (see Figure 1). This magnetic field is transverse with respect to the arc. Interaction of the magnetic field and arc current results in formation of Lorentz force F_a, which deflects the arc in a direction of action of this force. Alternate deflection of the welding arc to the side walls of the groove is caused by changes of polarity of the current flowing through the electromagnet coil.

Experimental investigation of the character of formation of the weld in NGW made it possible to establish the effect of such parameters of the controlling magnetic field as frequency of reversing and value of magnetic induction on the weld shape [4]. However, the quality of the welded joint produced by narrow-gap magnetically controlled arc TIG welding depends not only on the parameters of the controlling magnetic field, but also on welding current I_w, welding speed v_w, arc voltage U_a, and shape of the tungsten electrode tip. Therefore, to ensure conditions required for quality formation of the welded joint it is necessary to experimentally study the mechanisms causing deflection of the welding arc at changes of the welding conditions and magnetic field parameters.

The purpose of this study was to investigate conditions required for formation of defect-free welds on titanium at different welding and magnetic field parameters, as well as at different shapes of the tungsten electrode tip.

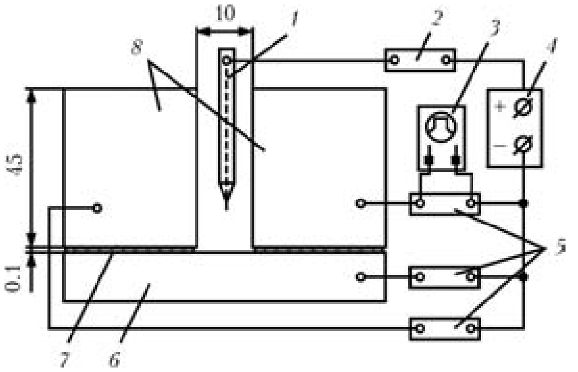

Figure 2. Scheme of the unit to measure the current flowing through the side walls of the groove in NGW with the controlling magnetic field: *1* — tungsten electrode; *2* — shunt to measure the welding current; *3* — oscillograph; *4* — power supply; *5* — shunts to measure the welding current flowing through the side and bottom walls; *6* — bottom wall of the groove; *8* — side walls

The method of measuring the electric current flowing through the side walls of the groove by the divided anode procedure was used to evaluate the character of the effect of welding conditions on deflection of the welding arc, and select the optimal welding parameters [5]. The scheme of the unit utilised to measure the current flowing through the side walls of the groove in NGW with the controlling magnetic field is shown in Figure 2. The degree of deflection of the welding arc was estimated from the value of the current flowing through the side wall of the groove by using parameter X:

$$X = \frac{I_s}{I_w},$$

where I_s is the current flowing through the side wall of the groove.

Tungsten electrodes used in the study had a cone-shaped tip, or a flat tip 2.5 mm wide. In welding they were located with their wide side across the weld axis.

Examinations of macrostructure of the welds made by NGW were performed to establish the required deflection of the welding arc. These examinations revealed a high probability of lacks of penetration at points of intersection of a vertical wall of the groove with a surface of the previous-pass weld (Figure 3). Lacks of penetration may form on one side (Figure 4, *a*) or on both sides of the groove (Figure 4, *b*), and may be either continuous or intermittent.

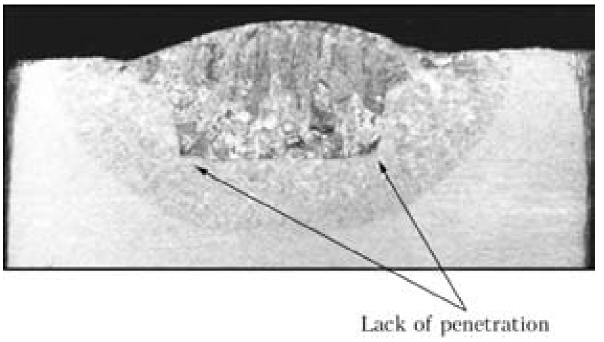

Figure 3. Macrosection of the deposited metal with lack of penetration at the groove corners (material — titanium alloy PT3V, filler wire VT1-00)

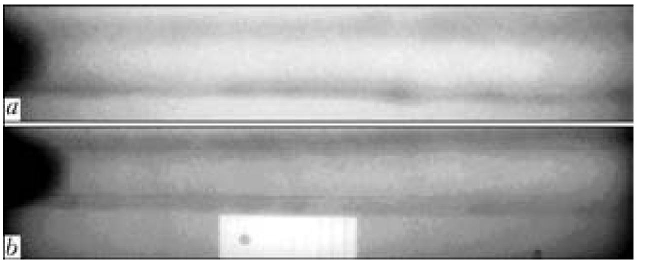

Figure 4. X-ray picture of welds with lacks of penetration at the groove corners (*a*, *b* see in the text)

Analysis of temperature conditions of the welding process showed that the difficulty of achieving the guaranteed penetration at the point of intersection of the groove wall with the surface of the previous-pass weld was caused by an intensive heat removal from the given region of the base metal during the welding process. It was determined that to achieve the guaranteed melting of the side wall of the groove at a point of its intersection with the surface of the previous-pass weld it is necessary to deflect the welding arc to such an angle, where the conditional centre of the anode spot, O, will coincide with the point of intersection of the side and bottom walls of the groove (Figure 5). In NGW, in a case where S_b is equal to S_s, the values of the current flowing through the side and bottom walls of the groove are equal, i.e. the

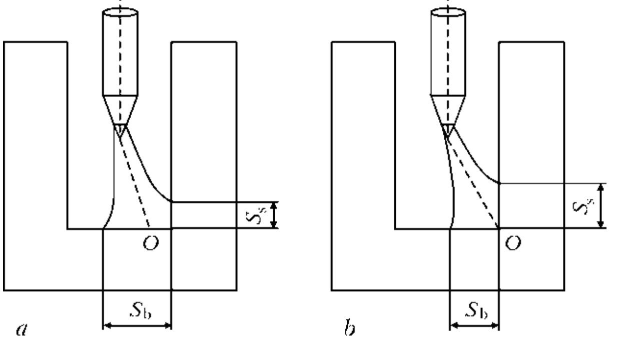

Figure 5. Schematic of location of the anode spot at insufficient (*a*) and optimal (*b*) deflection of the arc in the groove: S_b, S_s — distances from the centre to edge of the anode spot at the bottom and side walls, respectively

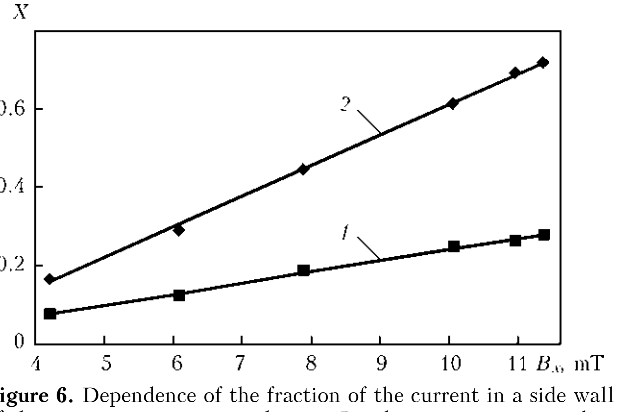

Figure 6. Dependence of the fraction of the current in a side wall of the groove on magnetic induction B_x when using tungsten electrodes with cone-shaped (*1*) and flat (*2*) tips (I_w = 400 A)

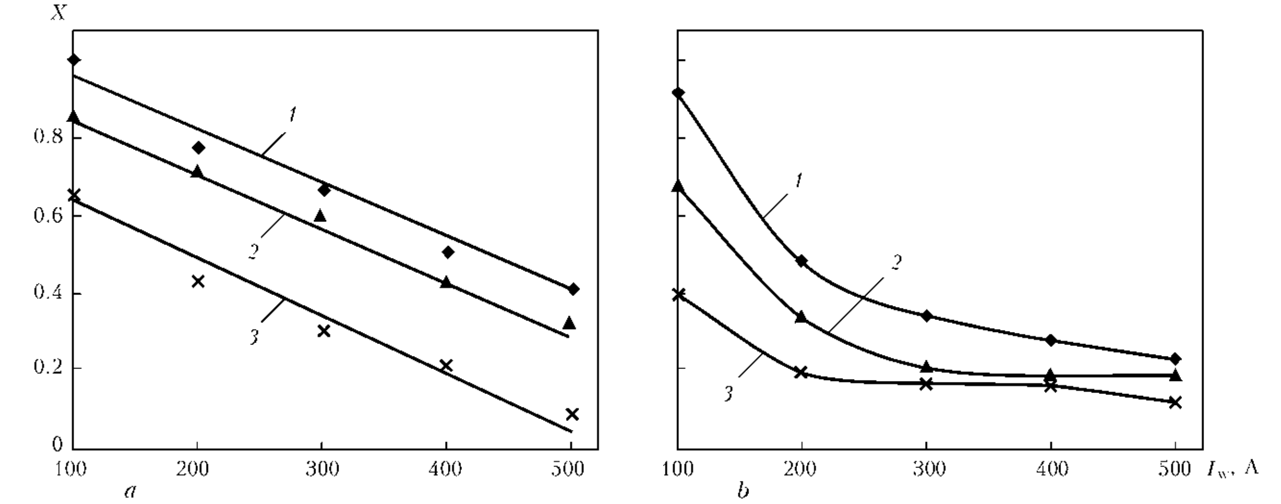

Figure 7. Dependence of the fraction of the current flowing through the side wall on the welding current when using electrodes with flat (*a*) and cone-shaped (*b*) tips: *1* — B_x = 11.4; *2* — 10.1; *3* — 6.1 mT

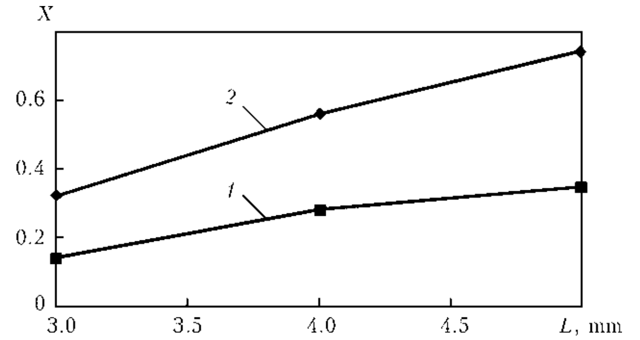

Figure 8. Dependence of the fraction of the current in a side wall of the groove on arc gap length *L* when using electrodes with cone-shaped (*1*) and flat (*2*) tips at B_x = 11.5 mT and I_w = 400 A

fraction of the current flowing though the side walls is 50 % of the total welding current.

As established by measurements of the current flowing through the side walls of the groove, its values are directly proportional to the values of a transverse component of magnetic induction in welding direction, B_x (Figure 6).

When using the electrode with a cone-shaped tip, the fraction of the current in the side walls is no more than 30 % of the welding current, which, based on the experimental data, is insufficient to melt the vertical walls of the groove and provide the quality formation of the weld.

To prevent lacks of penetration, the *X* ratio should be not less than 0.5, this corresponding to a location of the centre of the anode spot at a corner of the groove. This condition is met when using the electrodes with a flat tip. Other conditions being equal, the fracture of the current in the side walls decreases, i.e. displacement of the anode spot decreases, with increase in the welding current (Figure 7).

Increase in length of the arc gap leads to growth of the value of the current flowing through the side walls, i.e. deflection of the welding arc increases (Figure 8).

Therefore, as shown by the investigations conducted, it is necessary to form the magnetic field within the arc zone with an induction of not less than 8 mT at a welding current of 400 A and arc gap length of 4 mm to provide defect-free welds in NGW of low titanium alloys by using the controlling magnetic field. The results of examinations of macrostructure of the welds made on low titanium alloys at the above welding parameters proved the absence of lacks of penetration and lacks of fusion in the weld metal.

CONCLUSIONS

1. The mechanisms causing deflections of the welding arc in narrow-gap magnetically controlled arc TIG welding at changes of the welding and magnetic field parameters were experimentally studied. Conditions that provide the defect-free welds were optimised.

2. It was determined that narrow-gap magnetically controlled arc TIG welding requires the use of tungsten electrodes with a flat tip 2.5 mm wide.

3. It was established that deflection of the welding arc from the central plane of the groove is directly proportional to the value of a transverse component of induction of the magnetic field, B_x, and length of the arc gap, and is inversely proportional to the value of the welding current.

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