Effect of Flux on A-TIG Welding of Mild Steels †

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Abstract

A-TIG welding is a method in which TIG welding is conducted by covering a thin layer of activating flux on the weld bead beforehand. . The emphasis of this paper lies in introducing the development of flux composition, analyzing the influence factors and the mechanism for increased penetration with A-TIG welding of mild steels. Experimental results confirmed that with the developed activating flux of this work, the arc was obviously constricted and the penetration was increased more than two times more than that of current TIG welding for mild steels.

KEY WORDS: *(A-TIG)(Weld penetration)(Activating flux)(Arc constriction)(Surface tension)*

1. Introduction

TIG welding is widely used in modern industry. It produces high-quality welds, and is applied in almost all kinds of metal constructions, especially stainless steels and nonferrous metals, but a disadvantage lies in poor penetration and low productivity. Recently, a new type of welding method (A-TIG welding) attracted attention all over the world. "A-TIG" which is also known as activating flux TIG is a method that can improve the weld penetration by using a thin layer of activating flux on the surface of weld bead before welding with conventional TIG. In A-TIG welding, compared with conventional TIG, the advantages lies in that the penetration and productivity can increase by 1~3 times, and for plates of 3~12mm thick the groove preparation will not be needed. Because of this, Ukraine, UK, Japan, USA and other countries have emphasized its use [1-6]. So far the Paton Electric Welding Institute of the National Academy of Science of Ukraine have applied this technology in some important industrial structure productions such as welding of tube components in a nuclear reactor, etc [2]. The emphasis of this paper lies in introducing the development of the flux composition, analyzing the influencing factors and the mechanism for increased penetration of mild steels A-TIG welding.

2. Experimental

2.1 Materials and samples

The plates used in the experiments were carbon steels, the main elements of activating fluxes were SiO_2, TiO_2, CaO, MgO, halogenide, Cr_2O_3, etc. The size of samples was 200 x 80 x 8mm.

2.2 Experimental methods

A thyristor-controlled, DC-AC welding power supply, made by Tangshan Matsushita Industrial Equipment Co. Ltd., was used in the experiments with welding current 130A and welding speed 70mm/min. The balance used to weigh the components for the activating flux was accurate to 0.01mg. The activating flux mixed proportionally was stirred to a paste with acetone then brushed on to the surface of weld bead before welding. Under the same welding conditions, doped zones and no-doped zones were welded in a single pass. The arc behavior and arc voltage were observed during welding

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and the shape of weld joint, the penetration depth and width of weld pool were measured after welding. The effect of influencing factors such as composition and granularity of the flux, arc length, thickness of coating were studied throughout the experiments.

3. The Result of Experiments

3.1 The effect of mono-component on penetration

The effect of mono-components of TiO_2, SiO_2, Cr_2O_3, CaF_2, NaCl and Ti-Fe etc. was measured and the result is shown in Fig.1. We can see that different mono-component has a different effect on the penetration of A-TIG.

3.2 The effect of CaF_2 content in the mixed compound on penetration

Three kinds of fluxes (A1, A2, A3) in this group of experiments were used to examine the effect of CaF_2 content in the mixed compound on the penetration, in which the content of CaF_2 were 5%, 10% and15% respectively. The results are shown in Table 1.

The effect of CaF_2 content on the penetration is indicated schematically in Fig.2. From Fig.2, we can find that the penetration decreases with increasing of CaF_2 content.

Table 1 Effect of CaF_2 content on penetration

Content	Change of Voltage (V)	Penetration (mm)	Width (mm)	Phenomena of the arc and weld shape
A1	15.0~16.0	2.5~5.0	9.0~7.5	Obvious constriction of arc, elegant shape, the width of weld become obviously narrower.
A2	15.0~16.0	3.0~4.5	8.5~8.5	Arc is constricted, ordinary shape, the width of weld scarcely changes.
A3	14.5~15.5	3.0~3.5	8.5~8.5	No obvious constriction of arc, bad shape, the width of weld scarcely changes.

3.3 The effect of NaCl content on penetration

Six series NaCl containing fluxes (B1~B6) were prepared in this group of experiments. The results are shown in Table 2 and Fig.3. From Fig.3 and Table2, we found that the weld penetration increased with increasing of NaCl content in the mixed flux.

Table 2 Effect of NaCl content on penetration

Content	The change of Voltage (V)	Penetration (mm)	Width (mm)	Phenomena of the arc and weld shape
B1	13.1~13.9	2.0~4.2	7.0~6.0	Obvious constriction of arc, elegant weld shape, steady voltage
B2	13.7~14.3	2.0~5.0	7.0~6.0	Obvious constriction of arc, elegant weld shape, vigorous reaction in doped zones.
B3	13.2~14.0	2.0~5.5	7.0~6.5	Obvious constriction of arc, elegant weld shape, penetrate through partly in doped zones.
B4	13.0~13.9	2.2~6..0	6.5~6.0	Obvious constriction of arc, elegant weld shape. penetrate through partly in doped zones.
B5	13.7~14.7	2.0~6.0	7.0~6.5	Obvious constriction of arc, elegant weld shape, the arc voltage increases a little, and penetrate through partly in doped zone.
B6	13.2~14.3	1.7~6.0	7.0-6.5	Obvious constriction of arc, elegant weld shape, and penetrate through partly in doped zone.

3.4 The effect of flux thickness and arc length on penetration

With increase of arc length, the effect of flux on the arc phenomena and weld penetration is shown in Table 4 and Fig.4. It is found that when the arc length is 3mm,

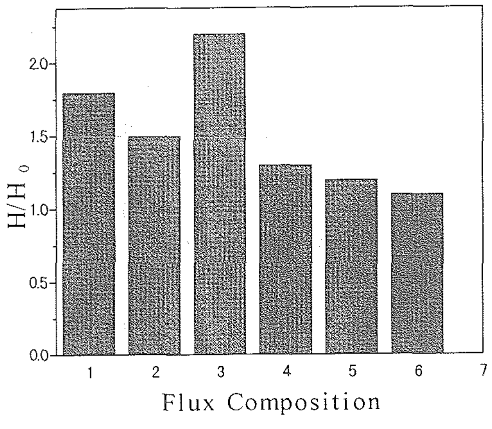


Fig.1 Effect of mono-component on penetration of A-TIG weld

(1)TiO_2, (2)SiO_2, (3)Cr_2O_3, (4)CaF_2, (5)NaCl, (6)Ti-Fe

Note: H/H0 indicates the ratio of weld penetration depth with flux to that without flux.

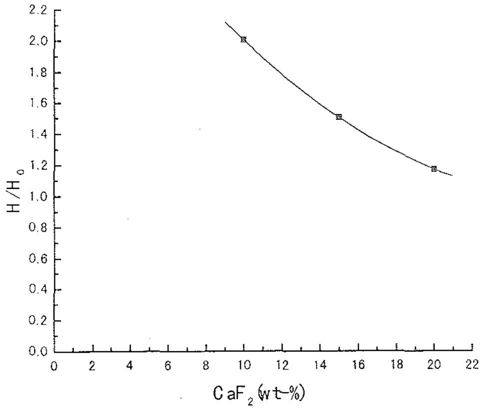


Fig.2 Effect of CaF_2 content on penetration of A-TIG weld

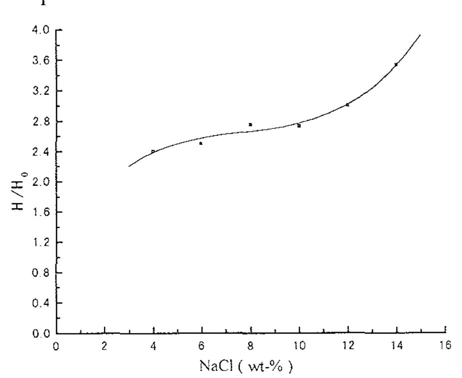


Fig.3 Effect of NaCl content on penetration

the penetration ratio reaches a peak value, in this case the

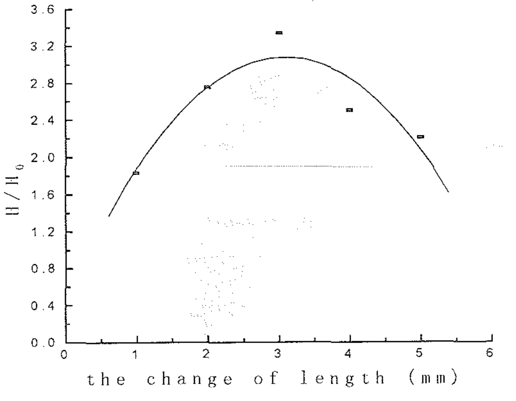


Fig.4 The effect of arc length on H/H_0

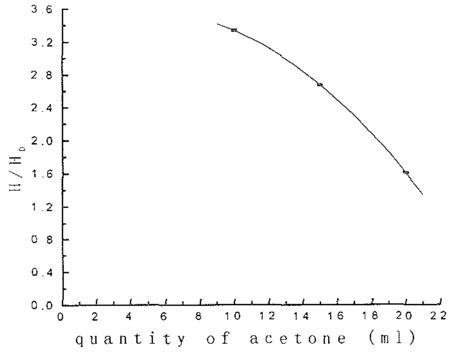


Fig.5 The influence of flux thickness on the penetration

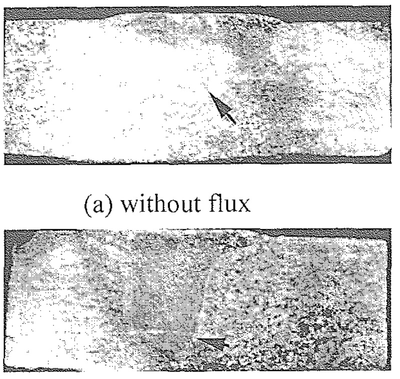
welding arc was obviously constricted, and the weld shape was very fine.

The effect of flux coating thickness on arc behavior and weld shape was experimentally examined by increasing the amount of acetone solution for the same flux powder and the results are shown in Table 4 and Fig.5. From Fig.5, it can be seen that the penetration ratio increases with increase of the flux thickness e.g. the decrease of acetone.

4. Discussion

After a lot of experiments with various mixed fluxes, a proper activating flux suitable for A-TIG welding of mild steels has been obtained, and with the developed flux the weld penetration depth can increase by two times compared to the conventional TIG welding (see Fig.6)

By analyzing the previous work [1-8] and our results, the main reason that the flux can increase the penetration lies in the following two aspects. The European scholars prefer the first aspect, namely, the arc constriction. While the U.S. scholars believe that the change of surface



(a) without flux

(b) with flux

Fig.6 Typical photographs of A-TIG weld penetration

constriction in experiments. Arc constriction during A-TIG welding will cause a concentration of current density and a decrease of conducting area at the anode. Thus the arc heat input density and the electromagnetic force in the weld pool increase as well. This will cause an increase of penetration.

We think there are three reasons for arc constriction:
(1) The temperature of arc is higher than the decomposition temperature of molecules at the center in the lower part of the arc, where shielding gas and atoms of fluxes are ionized to electrons and positive ions. The materials evaporated still exist as molecules and decomposed atoms in the outer (cooler) region of the arc.

Table 3 Effect of arc length on the penetration

Arc length (mm)	The change of Voltage (V)	Penetration (mm)	Width (mm)	Phenomena of arc and weld shape
1	11.2-11.7	3.0-5.5	5.5-4.5	Obvious constriction of arc, steady voltage, good weld shape, clear surface.
2	12.7-13.4	2.0-5.5	6.5-5.5	Arc constrict, unsteady voltage, good shape.
3	13.0-14.0	1.5-5.0	6.5-6.0	Obvious constriction of arc, steady voltage, good weld shape, clear and level surface.
4	13.8-14.8	2.0-5.0	7.5-6.0	Obvious constriction of arc, unsteady voltage, good weld shape.
5	14.3-14.8	2.5-5.5	8.5-7.0	Obvious constriction of arc, steady voltage, with gas cavity.

Table 4 Effect of flux coating thickness on the penetration

Acetone (ml)	The change of Voltage (V)	Penetration (mm)	Width (mm)	Phenomena of the arc and weld shape
20	13.3~13.9	1.5-2.8	6.5-6.5	Obvious constriction of arc, comparatively good shape, the width scarcely changes.
15	13.1-13.8	1.5-4.5	7.0-5.5	Obvious constriction of arc, unsteady voltage, comparatively good shape.
10	13.0-13.8	1.5-5.0	6.5-5.5	Obvious constriction of arc, comparatively good shape, but the surface is rough.

tension gradient is the main reason for increased penetration. So far there is no commonly agreed mechanism for the effect of the flux on penetration in the A-TIG welding process.

4.1 The constriction of arc

Many authors have observed the phenomenon of arc

Decomposed atoms absorb electrons to form charged particles to cause the decrease of main conducting materials, then the conducting ability decreases and arc constricts [(1)].
(2) Because the components of fluxes we used are all molecules of multi-atom, under the atmosphere of the arc the components dissociate thermally. Thermal

dissociation is an endothermic reaction, so, on the basis of principle of least voltage, arc root constricts.

(3) Because the electric conductivity of the flux is much lower than that of metal vapors, and the flux melting and boiling point are higher than weld metal, so the metal evaporation can only generate in higher temperature zone near the center of arc to form an anode spot, that is, the existence of flux causes a decrease in the area of the anode spot, therefore the arc root constricts.

4.2 The effect of surface tension gradient

Generally, surface tension gradients decrease with increasing of temperature in pure metal and many alloys, namely, $d\sigma/dT<0$, and fluid flows from the region with low surface tension to that with high surface tension. The temperature is higher near the center of the weld pool, so that the surface tension near the center is lower than that in the outer region. Thereby, fluid flows as indicated schematically in Fig.7 (a), producing a relatively wider and shallower weld. However, surface-active elements such as oxygen and sulfur can change the direction of the fluid flow in weld pool. With coating activating elements at the surface, that is, $d\sigma/dT>0$, fluid flows as indicated schematically in Fig.7 (b), thereby producing a relatively deeper and narrower weld [4].

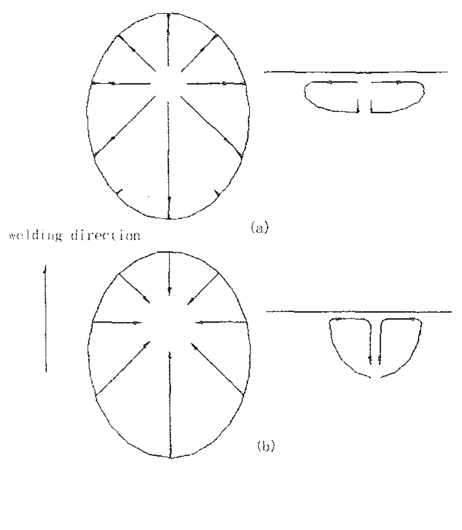
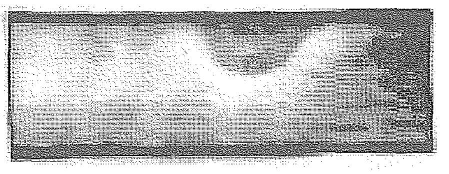


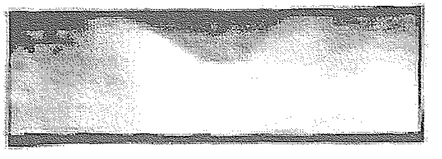
Fig.7 Schematic indication of fluid flow and weld penetration

4.3 Further discussion

For the factors of constriction of arc and the surface tension gradient of weld pool, which one is the main factor to affect the penetration? We also made defocused electron beam welding experiments. Because there is no arc in electron beam welding, we need not consider the constriction of arc. So, for electron beam welding there would be only the effect of surface tension. The result is shown in Fig.8. It is found that in the case of electron beam welding the weld penetration changes little with the A-TIG flux compared to that without flux. This result could suggest that the change of surface tension is not the main reason for increased weld penetration in A-TIG welding of mild steels, but the mechanism in which a constricted arc can cause the weld penetration to increase by two times still needs quantitative study. So far, there are some numerical simulations of the effect of positive surface gradient driven fluid flow in weld pools, but for most the effect of sulfur content in weld metal was considered [7,8]. This is not the case in a common A-TIG welding flux. The simulation result of Matsunawa [9] showed that if the anode spot size is large the fluid flow in weld pool is outward and the penetration is shallow even under the condition of positive surface tension gradient. Therefore, further investigation into the mechanism of A-TIG welding is still needed.



(a) without A-TIG flux



(b) with A-TIG flux

Fig.8 The photographs of weld penetration with defocused electron beam welding

5. Conclusions

Through the experiments and discussions above, we can obtain the conclusions as follows.

(1) A proper activating flux suitable for A-TIG welding of mild steels has been developed, and with the

developed flux the penetration depth can increase by more than two times compared with conventional TIG welding.

(2) In the A-TIG welding of mild steels, both arc constriction and positive surface tension have effects on the increased penetration, while the main reason for the increased penetration may be the constriction of arc, but the mechanism needs further study.

(3) In A-TIG welding, the increase of penetration is affected by the composition of activating flux, and it also relates to the thickness of flux coating and arc length as well as arc current etc.

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