African Journal of Advanced Pure and Applied Sciences (AJAPAS)

Online ISSN: 2957-644X

Volume 2, Issue 4, October-December 2023, Page No: 224-230

Website: *https://aaasjournals.com/index.php/ajapas/index*

معامل التأثير العربي 2023: (1.55)   SJIFactor 2023: 5.689   ISI 2022-2023: 0.557

Influence of Activated Flux Tig Welding on Penetration Improvement of Low Carbon Steel

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Received: September 09, 2023	Accepted: November 04, 2023	Published: November 11, 2023

Abstract:

Tungsten inert gas welding (Tig) is an arc welding process that is an excellent selection choice for high weld quality with low cost compared with other welding processes like laser or electron beam, but this process has limitations on weld penetration always not exceeding 3 mm in Autogenous welding, to overcome this, a developed technique called activated flux tig welding (A-Tig) is used to enhance penetration by brushing a flux on welding joint before welding. In this experimental trial activated flux Cr_2O_3, Fe_2O_3, MoO_3, Al_2O_3, and CaF_2 Were used to investigate their influence on penetration during welding of low-carbon steel specimens. Results show that Cr_2O_3 has higher penetration and aspect ratio than conventional tig and other activated fluxes whereas CaF_2 has given the lowest depth of penetration.

Keywords: Activated Fluxes(A-Tig), Depth of Penetration, Aspect Ratio, Weld Bead Geometry.

Cite this article as: M. M. Chiampi and L. L. Zilberti, "Induction of electric field in human bodies moving near MRI: An efficient BEM computational procedure," *African Journal of Advanced Pure and Applied Sciences (AJAPAS)*, vol. 2, no. 4, pp. 224–230, October-December 2023.

تأثيراللحام بالغاز الخامل والأكاسيد النشطة على تحسين التغلغل عند لحام الصلب منخفض الكربون

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الملخص

يعتبرلحام الآرجون بإستخدام الإلكترود الغير مستهلك (TIG) أحد أهم عمليات اللحام بالقوس الكهربي ويعتبر أحد الخيارات المفضلة للحصول على جودة لحام عالية وبتكلفة منخفضة مقارنة مع طرق اللحام الأخرى مثل اللحام بالليزر واللحام بالحزمة الإلكترونية. من ناحية أخرى فإن محدودية التغلغل تشكل أحد أهم العيوب لهذه العملية، حيث أن أقصى تغلغل يمكن الحصول عليه لا يزيد عن 3مم أثناء اللحام بدون سللك حشو، وللتغلب على ضعف التغلغل تم تطويرهذه الطريقة وذلك بإضافة إستخدام الأكاسيد النشطة (A-Tig) حيث يتم تعزيز التغلغل لعمق اللحام في هذه الطريقة من خلال طلاء طبقة رقيقة من محلول أحد هذه الأكاسيد على وصلة اللحام قبل البدء في عملية اللحام. في هذه الدراسة تم إستخدام مجموعة من الأكاسيد النشطة (Cr_2O_3, Fe_2O_3, MoO_3, Al_2O_3, CaF_2) وذلك لدراسة مدى تأثير هذه الأكاسيد على زيادة التغلغل أثناء اللحام لعينات من الصلب منخفض الكربون. أظهرت النتائج أن ثاني أكسيد الكرميوم (Cr_2O_3) أعطى أفضل تأثير للتغلغل مقارنة باللحام التقليدي. في حين، أعطى فلوريد الكالسيوم (CaF_2) أقل نسبة تغلغل.

الكلمات المفتاحية: اللحام بالأكاسيد النشطة (A-Tig)، عمق التغلغل، نسبة العمق الى العرض لدرزة اللحام، الأبعاد الهندسية لدرزة اللحام.

Introduction

GTAW (Gas Tungsten Arc Welding) was observed to be one of the most appropriate welding processes used for stainless steel, high-carbon steel, nickel-based superalloys, etc. [1]. On the other hand, the main drawbacks of the TIG welding process lie in its shallow penetration and low productivity, thus limiting the material thickness that can be welded in one pass [2]. The A-TIG welding technique was first proposed in the late 1950s by the EO Paton Institute of Electric Welding in the former Soviet Union [3]. This method was improved to increase the penetration capability, making it possible to intensify the conventional TIG process for joining thicknesses up to 10 mm with full penetration in a single pass without the need for edge preparation or multiphase procedures. In fact, the depth of penetration can be increased by up to 300% compared with conventional TIG [4]. The principle of A-TIG welding is mainly dependent on applying a thin layer of activating flux to the surface of the welding joint prior to welding. However, the exact mechanism by how the flux increases penetration is still debatable. Whereas, two mechanisms considered to be the most agreed upon and proposed by researchers for deeper penetration are arc constriction and the reverse Marangoni effect in the weld metal pool [5]. The theory of arc constriction states that the vaporized flux causes arc contraction by capturing electrons from the outer cooler area of the arc increasing the current density at the anode and the arc force action on the weld pool [6]. However, the reversed Marangoni convection mechanism is based on the effect of molten metal flow on depth of penetration, During the A-TIG process, active flux changed the surface tension gradient, and molten metal flow from outward to inward resulted in deep weld penetration, and this effect is called the Marangoni effect [7]. The vast majority of published papers on the A-TIG technique are about stainless steel. Whereas relatively few scientific publications related to low-alloy and unalloyed steel (8) This can be attributed to the fact that the most convenient method of welding the aforesaid group of steel is the MAG (Metal Active Gas) technique, due to its higher efficiency and productivity than the TIG method (8). On the other hand, previous studies discussing carbon and low carbon steel with the A-TIG welding technique have shown that the most influential parameters on weld penetration are welding current, flux composition, solvent ratio of the flux, arc length, and welding speed [9]. Thus, all these factors have been taken into consideration in this study. In the meantime, it should also be noted that the effect of a certain flux may vary even with the same conditions from study to study depending on the state of the plate surface during the stages of the production process, such as the inclusion of an oxidized layer after a hot rolling or heat treatment process (8). This can make it difficult to draw a general conclusion based on the comparative analysis of results obtained under various conditions. In this study, the effect of activated fluxes (Cr_2O_3, Fe_2O_3, MoO_3, Al_2O_3, and CaF_2) on weld surface morphology was investigated on low carbon steel plates.

Material and methods

In present study the base metal chosen is Commercial low carbon steel, this material is widely used in most fabrication processes, the chemical composition is shown in Table (1).

Table1: Chemical Composition of st37:

C	Mn	Si	Cr	Ni	S	P	Cu	Mo	W	Al	Fe
0.142	0.642	0.142	0.084	0.102	0.019	0.014	0.263	0.020	0.003	0.002	Bal

Autogenous Bead-on-plate welding trails were made on a welding coupon 100mm*50mm of 5mm thickness. The specimen plates were cleaned by a steel brush to remove any rust or debris and then cleaned with acetone before start welding. The activated fluxes (Cr_2O_3, Fe_2O_3, MoO_3, Al_2O_3, and CaF_2) have been selected in this study. These activated fluxes were mixed with methanol and stirred with glass rod, then painted with a brush of 10mm width on the centerline welding specimen surface as shown in figure (1), the surface density of the deposited flux was 1.5mg/cm^2. Mechanized Tig welding with (Esab 450 pro-tig) welding power supply as shown in Figure (2) was used in all welding trails. 2.4-mm non consumable tungsten electrode EWTH-2 was used and the shielding gas used was Argon (99.998% purity) with a flow rate of 10 l/min. Preliminary autogenous welding trails were carried out to choose the proper welding parameters as summarized in Table 2. The measurements of weld penetration and weld width were measured by using optical microscope (Nikon).

Figure 1 a- flux brushed on plate b-flux mixed with methanol

Table (2) Welding parameters

Ampere	(100-170) A
Arc length	3mm
Electrode angle	60°
Gas flow rate	10 l/min
Inclination electrode angle	90°
Electrode type	w-2%tho2
Electrode diameter	2.4 mm
Electrode angle	45º

Figure 2 Mechanized ESAB PRO450 power source

Results and discussion

3.1 Effect of fluxes on weld surface appearance

Figure (3) shows the weld bead surface of different fluxes at the same parameters with current 140 A, speed 105 mm/min and gas flow 10 L/min. It can be seen that the weld shape in picture (a) without flux has a smooth surface with no surface spatter or any irregularities. Cr_2O_3 flux (c) was the best one among other fluxes, with no spatter and no residual slag. The other fluxes Fe_2O, CaF_2, MoO_3 and Al_2O_3, as shown in figures (b, d, e, f) respectively revealed a few traces of spatters. In general, from the experimental results, no surface defects were observed in the weld region, such as visible pores, cracks, or underfills. This can be a result of a suitable combination of welding parameters used.

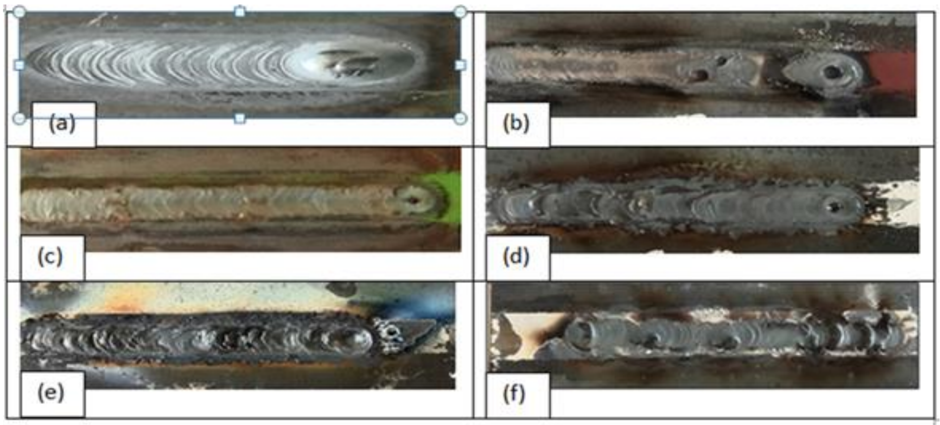

Figure 3 Effect of activating fluxes on the surface appearance: (a) without flux, (b) Fe_2O_3 flux, (c) Cr_2O_3 flux, (d) CaF_2 flux, (e) MoO_3 flux, and (f) Al_2O_3 flux

3.2 Effect of fluxes on weld bead geometry

The shape of weld pool geometry is presented as the ratio of weld depth to width (D/W); Therefore, a typical shape of a weld bead can be expressed as an optimal value of (D/W). As shown in Figures (4, 5, 6), the weld dimensions measured in each sample can provide further insight into the mechanism of increasing depth. The maximum depth of penetration achieved with conventional TIG within the range of parameters was 2.3mm. However, the comparison of different activating fluxes and their effect on penetration and weld bead width revealed that Cr_2O_3 flux has a maximum depth of penetration of 5.05mm, exceeding 200% more than without flux, then comes 4.5mm, 4.2 mm, and 3.91mm, with fluxes of MoO_3, Fe_2O_3, and Al_2O_3, respectively. Since all-used fluxes showed a remarkable increase in penetration. The weld bead formed by using CaF_2 flux revealed a shallower penetration of 2.68 mm compared with that of conventional TIG welding of 2.3 mm. On the other hand, the positive effect of fluxes on arc penetration can be mainly attributed to the pattern of the molten weld bead. In general, as in any fluid system, the liquid flows from areas of high surface tension to areas of low surface tension, and the surface tension is dependent on the degree of temperature. Since the center of the weld is hotter than the edges, the edges have a lower surface tension than the center. Thus, the molten bead flowed from the center to the edges. This is the characteristic seam shape of TIG welding, which is why the seam is wide and the seam is flat. This` is commonly called the Marangoni effect. In contrast, In A-TIG welding, the direction of the weld pool flow is changed by surface-active elements such as oxygen and sulfur. These elements reduce the temperature dependence of surface tension, causing inward fluid flow (from edges to centers) [10]. Therefore, a deeper and narrower bead shape is obtained. Similarly, this phenomenon can be confirmed by the improved D/W ratio values for A-TIG welding compared to TIG welding. According to figure (4), Experimental results showed that improved D/W ratio values of 0.87, 0.67, 0.59, and 0.57 were achieved for Cr_2O_3, MoO_3, Al_2O_3, and Fe_2O_3 fluxes, respectively. A high D/W ratio indicates that the bead is deep and narrow, indicating that a reversed Marangoni effect mechanism occurred.

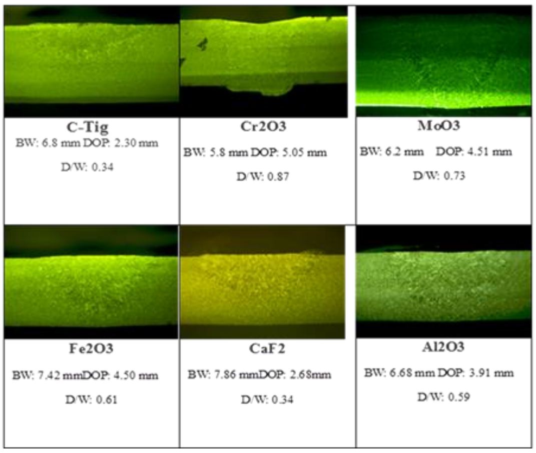

Figure 4 Weld bead cross-section macrograph C- Tig and A-Tig.

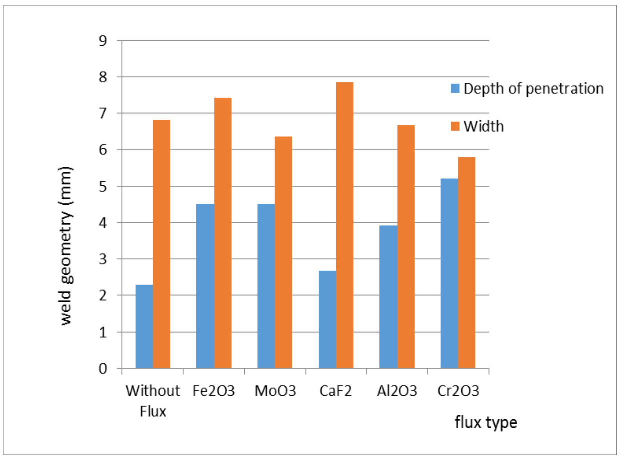

Figure 5 Relative changes in penetration depth and of width of welds with and without flux.

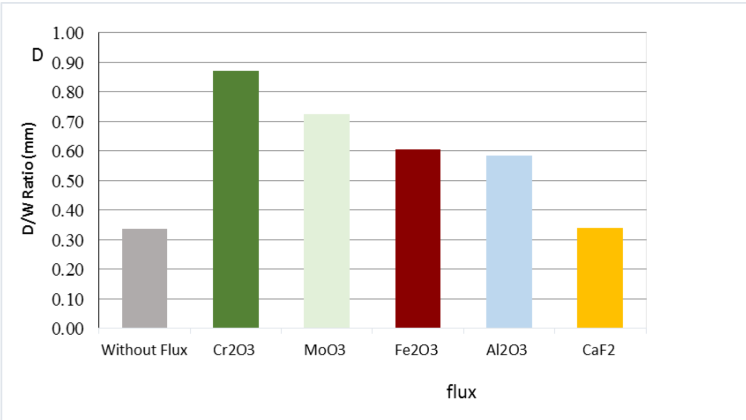

Figure 6 Relative changes in D/W ratio of welds with and without flux

3.3 Effect of current on D/W ratio with Cr_2O_3

In fact, welding current has a predominant parameter effect that can increase the depth of penetration up to an optimum limit [5]. And as the Cr_2O_3 flux has revealed the best value of depth penetration. More experiments were needed for this flux to study its effect on the D/W ratio at different ranges of current (from 100 to 170 amps). Whereas, the other parameters remained constant at 100 mm/min welding speed and 10 L/min gas flow rate. However, the effectiveness of flux can be evaluated by its ability to increase not only the depth of penetration but also the depth-to-width ratio. Therefore, a reversed Marangoni mechanism can be achieved. From Figure (7) it can be seen that, when the current was between 120 and 130 amps, the aspect ratio greatly increased, about 40% from 0.56 to 0.77, then slightly increased to the optimum limit at 140 amps with 0.80. After the upper limit (140 amps), the D/W decreased dramatically reaching 0.63 at 150 amps, then fluctuated between 0.69 at 160 amps and 0.6 at 170 amps. As a result, Cr_2O_3 flux has reached the optimum limit value of 0.87 D/W at 140 amps. This implies that arc constriction and reversed Marangoni where the main causes for increasing penetration and decreasing the width of the weld bead resulting in a better D/W ratio.

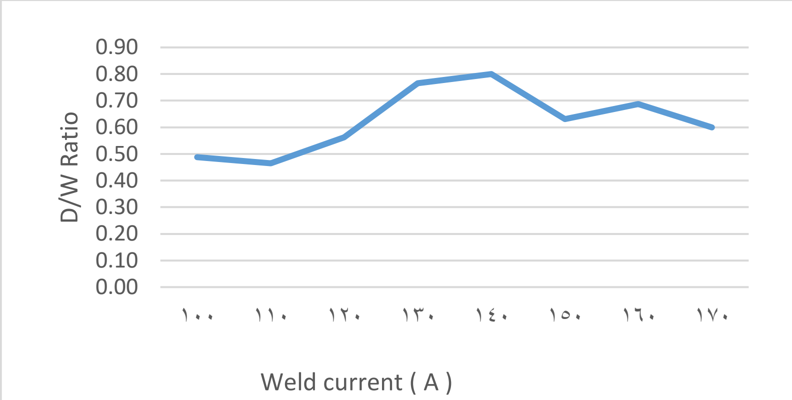

Figure 7 Effect of current on D/W ratio with Cr_2O_3

3.4 Effect of current on depth and width of bead with Cr_2O_3

Figure (8) presents the variation of the weld-bead depth and width by using a Cr_2O_3 flux at different values of current (100 to 170 amps). As can be seen, with an increase in current, both penetration depth and bead width increase since more heat energy enters the workpiece at higher current levels. However, at the optimum limit point where the full penetration to thickness was obtained, the width should be taken as the optimal value. Therefore, the effectiveness of certain fluxes can be defined at this point. On the other hand, increasing welding current beyond the optimum limit (140 amps) has an insignificant effect on the depth of penetration, but it has remarkably increased the width by 40%, from 6.5 mm at 140 amps to 9.1 mm at 170 amps. Hence, decreasing the depth-to-width ratio (W/D). This suggests the possibility, that after the point of full penetration, the weld bead width will dramatically increase to absorb the higher quantity of heat input entering the workpiece.

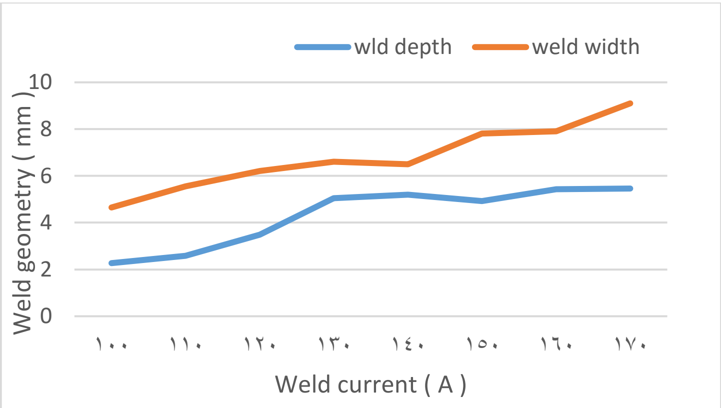

Figure 8 Effect of current on depth and width bead with Cr_2O_3.

3.5 Effect of speed on depth and width bead with Cr_2O_3

The most important parameters that directly determine the shape and weld bead geometry are the welding current, the arc voltage, and the welding speed [11]. Therefore, this study involves studying the effect of speed as an important influencing parameter. Different ranges of speed were applied (90, 100, 110, 120, and 130 mm/min) with a constant current value of 140 amps. from Figure (9) at speed of 90 mm/min, both the depth and width were at their highest points, with 5.4 and 7.6, respectively. At 100 mm/min, there was a significant decrease in weld width, which was the lowest point in the range of given parameters at 5.6mm. From 100 to 110, the width went up, reaching 6.88 mm, then from 110 to 120, slightly decreased, reaching 6.29, then 6.65 at 130 mm/min. On the other hand, the changes in depth witnessed slight changes with 9.92, 4.98, and 4.82 at 100, 110, and 120 mm/min, respectively, where at a speed of 130, the depth considerably decreased to 3.42 mm, The reason can be referred to the fact that as the speed accelerated, the heat input lowered, resulting in shallow penetration.

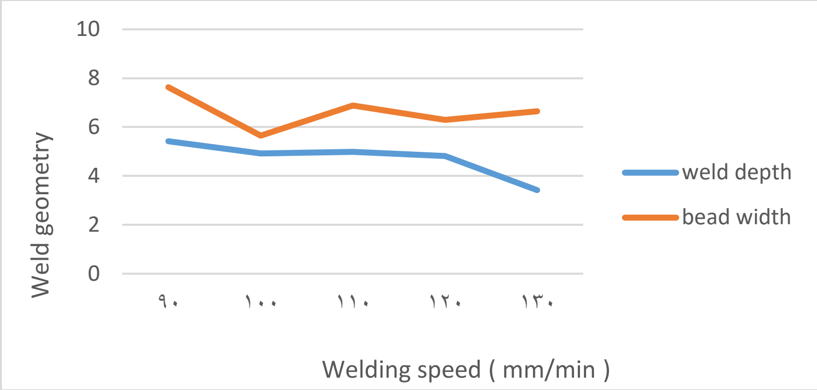

Figure 9 Effect of speed on depth and width bead with Cr_2O_3

3.6 Effect of speed on D/W ratio with Cr_2O_3

It has been observed from Figure 10, That when speed was increased from 90 to 100mm/min the D/W ratio was remarkably increased at the highest point with (0.87) then as speed increased to 110 the D/W ratio decreased to 0.72 and 0.76 at speed of 120mm/min. then at a speed from 120 to 130 mm/min The D/W ratio was sharply decreased reaching the lowest value with 0.51. From the graph blow it can be concluded the acceptable range of speed was between 100 to 120 mm/min and more speed than 120 has deteriorated the D/w ratio due to the lowering in heat input.

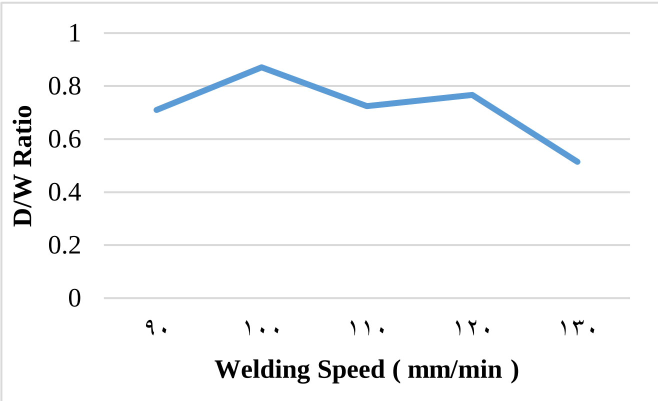

Figure 10 Effect of speed on depth and D/W ratio with Cr_2O_3

Conclusion

The main results obtained can be summarized as follows:

- An Acceptable surface appearance of welding samples has been obtained by using different types of activated fluxes.
- The maximum penetration was obtained by using Cr2O3 activated flux with 5.05 mm exceeding 200% than conventional Tig welding. This can be attributed to Reverse Marangoni Convection and arc constriction mechanisms. Also, fluxes like MoO3, Fe2O3, and, Al_2O_3 showed a considerable increase in weld penetration.
- Optimum welding parameters obtained for maximum penetration and D/W ratio were 140 amps current ,100 mm/min welding speed, and 10 L/min gas flow, by using Cr_2O_3 flux.
- The current and speed were the predominant effect on depth penetration.

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