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INFLUENCE OF ACTIVATING FLUXES ON METALLURGICAL CHARACTERIZATIONS IN WELDING PROCESS FOR STEELS - A REVIEW

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Activating fluxes can be used in welding processes like gas metal arc welding (GMAW) or tungsten inert gas welding (TIG) to improve the welding outcomes, as they can affect mechanical properties and microstructure as well as weld bead geometry, depth of penetration, shielding gas behavior, etc. The application of activating fluxes was researched on a wide range of welding materials like iron, magnesium, aluminum, or titanium alloys. This paper offers a summarized review of the effects of activating fluxes on the metallurgical properties of ferrous materials, presenting the influence of activating fluxes on the increase of ferrite content, phase transformation, and grain size.

Key words: steels, GMAW, TIG, content of phase, mechanical properties

INTRODUCTION

Activating flux can be used in a variety of metals, such as stainless steel, low-carbon steel, nickel-based alloys, and magnesium-based alloys [1-6]. It is obtained by mixing inorganic substances in a medium, usually a paste. Before welding, a layer of active flux is applied to the welding area, and when the flux evaporates during welding, it will affect the arc column, thereby influencing penetration, productivity, and the weld profile as well as the mechanical properties of the welded joint.

Activating fluxes can be utilized in various welding processes, including TIG [2], GMAW [1], and laser welding [7]. Metallic Oxides, Fluorides, and Chlorides are commonly used as activating fluxes, such as SiO_2, TiO_2, Cr_2O_3, MnO_2, Fe_2O_3, ZnO, Na_2CO_3, $NaHCO_3$, $CaCl_2$, MoO_3, $MgCO_3$, Al_2O_3 and borax (metallic Oxides are the most used one); research papers offer a detailed analysis of the physical characteristics of typical fluxes [7, 8]. Also, commonly, the content of these papers offers the description of the preparation and application of activating fluxes in the welding application of activating fluxes in the welding process [9, 10], and/or flux and its weight/density information [11, 12].

Studies of activating fluxes in welding, like the work of P. Vasantharaja et al. [13] focus on the improvement of mechanical properties and microstructure, changes of weld bead geometry (i.e. weld penetration increase) or reduction of the energy input. The influence of the activating fluxes application on weld penetration is well studied in papers [14-16]. Papers [17, 18] offer studies of application of activating fluxes on various steels. The focus of papers [19-22] is again on weld penetration depth and the effect of the different activating fluxes use; and N. Rakesh et al. [23] in their paper offer an extensive review of the effects of fluxes on penetration during TIG welding process.

Influence of mechanical properties (i.e. hardness, tensile strength, toughness or ductility) is important in the study of application of activating fluxes, research has shown that fluxes can increase tensile strength [24, 25] and have an impact on hardness [26, 27] and toughness of the welds [28-30].

Application of activating fluxes influence the microstructure of the welds as well, therefore, in this paper the summary review of the effect of activating fluxes on grain size, ferrite content and microstructural phases is offered.

EFFECT ON MICROSTRUCTURAL CHARACTERISTICS

Ferrite content

The application of activating fluxes can indeed impact the ferrite content in ferrous metals. This is typically attributed to the more uniform heating of the weld metal across the weldment thickness when the weld current is increased in conjunction with activating fluxes.

Tseng [8] employed a newly developed activating flux composed of SiO_2 (30 %), TiO_2 (25 %), Cr_2O_3 (25 %), MoO_3 (10 %), NiF_2 (5 %), and MoS_2 (5 %) in the TIG welding process for 316L stainless steel and re-

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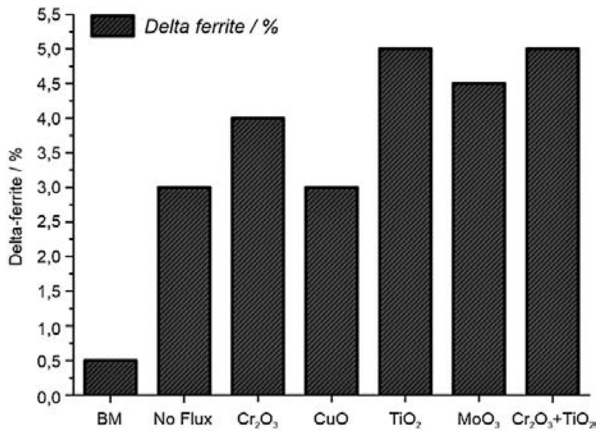

Figure 1 Variation of delta ferrite content with different fluxes [12]

vealed that the ferrite content in activating TIG welding was higher compared to conventional TIG welding. This was contributed to the higher arc energy density associated with A-TIG welding, characterized by lower heat input and consequently rapid cooling rates.

Loureiro et al. [9] revealed that the flux increases the ferrite content in the welds. Welds performed using TiO_2 activating flux generally show higher ferrite content than welds made without flux.

Huang [10] studied the effects of activating flux in the microstructure of TIG and Plasma Arc Welding using stainless steel (AISI 304) and results showed that activating flux can increase ferrite content in both welding processes compared to welding without the flux.

Liu et al. [11] showed that addition of self-developed activating fluxes, including SiO_2, Cr_2O_3, Al_2O_3, CuO, NiO, TiO_2, MnO_2 could increase the ferrite content of the welding bead for 304 stainless steel, but not influence the microstructure significantly.

Kulkarni et al. [12] applied both single (Cr_2O_3, CuO, TiO_2, MoO_3) and multi ($TiO_2 + Cr_2O_3$) fluxes for 316 SS welding. The austenitic-ferritic microstructure was found in the weld zone and it also revealed that the increase of delta ferrite was also observed in A-TIG weld zone, as shown in Figure 1.

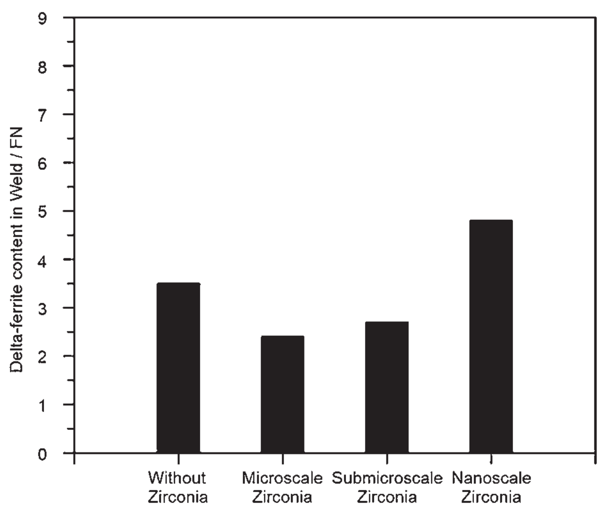

Figure 2 Average delta-ferrite content in AISI 316LN stainless steel TIG welds produced with and without ZrO_2 [14]

Ren [13] applied four activating fluxes in the welding of 316L the studies demonstrated that the addition of these active fluxes leads to more delta ferrite precipitation in the heat-affected zone, which can improve the mechanical properties of the welded joint.

According to K. H. Tseng [14], the particle size of the activating flux can also have an influence on the ferrite content in TIG process for AISI 316LN stainless steel. In their study, powdered ZrO_2 with different particle sizes was used as the flux. As shown in Figure 2, delta-ferrite content for microscale or submicroscale are reduced compared to without activating fluxes, while using nanoscale ZrO_2 flux can help to increase the delta-ferrite content significantly.

Grain size and phases:

Stainless steel

316 series is a typical stainless steel in a related study. Vasantharaja et al. [15] revealed that activating flux can influence the grain size and phase composition significantly. The grain size in HAZ of the A-TIG weld joint was about 1,5 times compared to the grain size in TIG welding.

In the welding study of 304 stainless steel, using TiO_2 can increase the spacing between the skeleton ferrite and can enlarge the size of lathy ferrite structure comparing to the other two activating fluxes (CaF_2 and Al_2O_3) [16].

The research conducted by Ren [13] revealed that an activating flux applied in TIG for AISI321 welding could lead to refined grains in the welds, and an increased area of grain boundaries, which could effectively hinder the movement of dislocations, thereby contributing to grain boundary strengthening. Furthermore, some intermediate phases such as Cr_2Ni_3 and Fe_3Ni_2 were formed in the welds with activating flux.

Zhang Haoxue [17] stated that the microstructures of 304 and 321 stainless steel TIG and A-TIG joints are all austenite + δ ferrite; the addition of activating fluxes refines the grains in the fusion zone of A-TIG welded joints, so tensile properties of the A-TIG joints are better than those of the TIG joints, and the corrosion resistance of the joints is also slightly improved.

P91/P92

9Cr-1Mo (P91) steel is mainly applied in high-temperature applications, and the addition of activating flux usually leads to coarse grains in the heat-affected zone, which has a negative impact on the mechanical properties of the material.

In the research of Dhandha et al. [18], MnO_2 was employed in the weld joint for P91 steel plates. The findings indicated the presence of tempered martensite and carbide precipitates in both the TIG and A-TIG welding processes' heat-affected zones (HAZ). It stated that the higher peak temperature with activating fluxes could lead to the formation of a coarse-tempered martensitic structure with precipitates and delta-ferrite islands in weld zone. However, this phenomenon was not obvious in traditional TIG weld joints.

Arunkumar et al. [19] developed an activated flux of Fe_2O_3, SiO_2, and TiO_2 and applied it in the TIG welding process for P91. The results revealed that the grain size in the HAZ of the A-TIG weld joint was approximately 80 µm due to the higher temperature conditions, whereas in TIG weld joint it was around 60 - 65 µm. In another paper by the same authors [20], they highlighted two main differences between the A-TIG and TIG weld in terms of microstructures. (1) there were delta ferrite islands in the A-TIG, but not this kind of phase for TIG; (2) a coarser tempered martensitic structure was obtained in A-TIG welds, but it was finer in TIG weld joints.

Vidyarthy et al. [21] used CeO_2 and MoO_3 as activating fluxes in A-TIG weld P91 steel. The results showed that the martensitic structure was observed in the fusion zone of TIG and A-TIG joints, and spherical shape fine MX-type precipitates were observed to be distributed homogeneously within the grain boundaries in the Fine Grain Heat-Affected Zone (FGHAZ) and intercritical heat-affected zone.

Arivazhagan et al. [22] studied microstructure and mechanical properties of P91 steel weld joints using mixture of SiO_2 and TiO_2 as activating flux and found that in the as-weld microstructure, the martensite lath was found to be higher in A-TIG (0,7 µm) than GTA weld (0,35 µm).

P92 can be obtained by reducing Mo content and increasing the W and B content in P91. Microstructures of P92 steel weld joints using TIG and ATIG (using a mixture of TiO_2, SiO_2, Cr_2O_3, NiO and CuO as flux) were compared by Maduraimuthu [23]. It is revealed that the microstructure in TIG consists of patches of delta-ferrite within a lath martensite structure. In ATIG, ferrite is formed along the fusion boundary; In TIG, there are fine $M_{23}C_6$ precipitates that cause dissolution, and tempered martensite is observed in Fine Grain Heat-Affected Zone (FGHAZ). While in ATIG, delta ferrite, and carbide precipitates form in tempered martensite and the distribution is uneven. The overall grain size in the Coarse Grain Heat-Affected Zone (CGHAZ) and FGHAZ of the A-TIG welded joint is relatively large.

Dissimilar materials

A multicomponent flux comprising 35% TiO_2, 40% SiO_2, 15% NiO, and 10% CuO was applied as an activating flux in ATIG for the P91-316L joint. The results revealed that delta ferrite of vermicular shape, lathe martensite, and twins were observed in the HAZ of the 316L side. It also revealed that the grain sizes of P91 steel in FGHAZ was 40 ± 33 µm and it was finer than that of the CGHAZ, which was 70 ± 25 µm, but coarser than that of the as-received P91 steel (21 ± 15 µm) [24].

Co_3O_4 and TiO_2 applied as activating fluxes in TIG welding for SS 316LN to LAFM (Low Alloy Ferritic-Martensitic) material [25]. The results showed that a fine lathy martensitic structure was observed in TIG. A combination of martensitic and delta ferrite microstructure was observed using TiO_2 as flux. While in ATIG with Co_3O_4 as flux, the microstructure exhibited a martensitic and austenitic structure. This is attributed to the presence of delta ferrite and austenite stabilizers, which prevent the formation of carbides, resulting in the absence of delta ferrite.

A multi-component flux comprising (25 % MoO_3, 25 % TiO_2, 25 % V_2O_5, 15 % SiO_2, 10 % Co_3O_4) was used in 316L-Alloy 800 dissimilar metal joint ATIG welding [26]. The results revealed that an unmixed zone with a ferritic-austenitic structure was found in the AISI 316L fusion zone interface, and a significant grain coarsening was observed in Alloy 800 HAZ.

In P92 steel and 304H dissimilar ATIG welding (TiO_2 as activating flux) [27], untempered lath martensite phases and polygonal austenite were observed in weld fusion zone. The CGHAZ (P92) showed complete dissolution of precipitates and FGHAZ(P92) showed partial dissolution of precipitates.

Other alloys

Activating fluxes on ATIG of incoloy 800H (UNS N08810), which comes under the group of austenitic nickel-iron chromium steel [28], were studied by Sridhar et al. The results revealed that finer equiaxed grain structure were found when using TiO_2 compared to TIG, which was preferred for better mechanical properties.

The study of ATIG using SiO_2 and TiO_2 fluxes for Inconel 718 revealed that laves phases and niobium-rich eutectics were formed in the fusion zone. It is also found that there are less laves phase due to the faster cooling rates [29].

The effects of activating fluxes, $Al_2(SO_4)_3$ and Borax, on grain size for AISI 1080 during MIG welding were studied. The results showed that activating fluxes could refine the grain in FZ, while they can increase the grain size in CHAZ and FHAZ [3].

EFFECTS ON THE ELEMENT CONTENT

Whether the activating fluxes will affect the weld elements is also a very important research direction. From the current literature, it can be concluded that the addition of activating fluxes has some influence, but the influence is not obvious.

Ren [13] performed energy spectrum analysis on 1Cr18Ni9Ti welded joints using different activating fluxes. It revealed that the content of Si, Ti and Cr elements in each flux's component is relatively high, while the fluctuation range of other flux elements is small due to their small content. Compared with the joint without activating flux, the content of Fe element all decreased in different degrees, fluctuating between 70,38 - 71,69 %. Overall, the element content of the joints coated with the active agent changed, but not significantly, compared to the joints without the active agent.

Zeng [30] compared the chemical composition of weld metal with and without activating fluxes and found that the composition of alloying elements in TIG welds and A-TIG welds was in the same range, and there was no significant change, indicating that the addition of activating fluxes would not great influence on weld metal composition.

CONCLUSION

The effects of activating fluxes on ferrous metal welding processes have been studied in this paper. The main conclusions and summaries are as follows:

1 The addition of activating fluxes generally leads to an increase in delta-ferrite content. This is because the welding process with activating fluxes can elevate the temperature, promoting the formation of delta-ferrite;

2 Welding with activating flux has varying effects on grain size, depending on the welding area and the properties of the activating flux. Typically, the grains in the heat-affected zone tend to increase in size, while the fusion zone experiences a refining effect;

3 Activating fluxes have an influence on the metal phase of the weld. When comparing welds with and without flux, different phases can be obtained under the same welding parameters. This variation in phases directly affects other material properties, such as microhardness and tensile strength;

4 The addition of activating fluxes does have some influence on element content of the weld joints, although the impact may not be significant.

It should be noted that the use of activating fluxes is predominantly focused on TIG welding processes. However, this review suggests that other welding processes, such as GMAW additive manufacturing, could also benefit from activating fluxes to achieve higher properties or improved microstructures.

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