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Effect of Activated Flux on Properties of SS 304 Using TIG Welding

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ABSTRACT

This research presents the study on Manganese oxide (MnO_2), Zinc oxide (ZnO), Iron oxide (Fe_2O_3) and Magnesium chloride ($MgCl_2$) used as activated fluxes to find out its effects on SS 304 in Tungsten Inert Gas (TIG) welding. The Ultimate tensile strength, percentage elongation, Penetration depth, width and depth to width ratio of SS 304 have been studied. The experiment indicates that the use of MnO_2 and Fe_2O_3 as flux increases the weld penetration depth and decrease the weld width. The use of ZnO and $MgCl_2$ as flux also shows a little increase in penetration depth and weld depth to width ratio as compared to conventional TIG process. The ultimate tensile strength and the percentage elongation have been increased in Activated Flux TIG welding.

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1. INTRODUCTION

Welding is a fabrication process that is used to join materials that can be either metals or thermoplastics. The TIG welding is considered to be a pivotal arc welding processes. In this process, the heat which is required for welding is generated by keeping an arc in between a non-consumable tungsten electrode and the base metal that is to be welded. The TIG welding process provides high quality metallurgical weld and good mechanical properties. There are few limitations of the TIG welding process like low penetration depth and low productivity. However, these limitations can be recovered up to some extent by using activated flux [1].

Activated flux is the amalgamation of inorganic powder that is suspended in an organic solvent [2]. It applies on the surface of work piece prior to welding. The flux vaporizes from the surface of metal as the weld arc passes over the flux. In TIG welding process not only the welding parameters, also the performance of the activating fluxes plays an imperative role for increasing the weld penetration and productivity of the process [3]. The activated TIG flux-welding eliminates the need of edge preparations in the work-material. So, in comparison to conventional TIG welding, there are less number of welding passes required to complete the joint which further improves the productivity [4]. To enhance the joint penetration of TIG-flux welding, still more research is to be done in this field. The required flux composition depends on the chemical, mechanical and thermal properties of the various base metals to be welded. It is being learnt from the Marya and Edwards [5] work, if argon is used as a shielding gas along with chloride fluxes (LiCl, $CaCl_2$, $CdCl_2$, $PbCl_2$ and $CeCl_3$), then it can increases the weld penetration up to one hundred percent that has not been seen in conventional TIG welding process. Among all selected chlorides mentioned above, cadmium chloride proved to be the most effective for welding process**.** Sun and Pan [6] observed that the use of activating flux on the Ti-6Al-4V alloy surface increases the weld penetration. They also concluded that it is necessary to apply a consistent layer of flux on the surface. Huang et al. [7] observed that a mixture of 80% MnO_2 and 20% ZnO provides full penetration depth for stainless steel 304. It also gives a satisfactory surface appearance and also tends to reduce the hot cracking susceptibility in the welded structure.

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Liming et al. [8] investigated the effect of $CdCl_2$ flux on weld depth and depth to width ratio. They observed in comparison to the conventional TIG welding, $CdCl_2$ flux gave two times more joint penetration and weld depth to width ratio. Venkatesan et al. [4] studied the effect of SiO_2, TiO_2, Cr_2O_3 fluxes for welding of AISI 409 ferritic stainless steel. They observed that SiO_2 flux possesses maximum influence in improving depth of penetration and it can be increases up to 86%. Tseng and Wang [9] investigated the effect of SiO_2-TiO_2 mixed flux on SS 316 with TIG welding. They found that the penetration capability up to 410% can be obtained by using a mixture of 80% SiO_2 and 20% TiO_2. They considered the surface tension gradient mechanism for increased penetration. Kuo et al. [10] compared the performance of CaO, Fe_2O_3, Cr_2O_3, SiO_2 fluxes for mild steel. They observed that SiO_2 powder increases joint penetration and depth to width ratio in comparison to other fluxes. Tseng and Chuang [11] studied the influences of flux powders FeF_2, FeO and FeS on joint penetration, surface appearance and weld aspect ratio in TIG welding. They found these parameters improved considerably with FeO and FeS powders but FeF_2 is preferable only for good surface appearance. After studying the previous research work, it is quite penetrating to know which activated flux should be selected for the welding process so that it may improvise the weld penetration and depth to width ratio. This selection process has to be done to increase the productivity of welding process [12-14]. The present work focuses on the study of effects of surface active fluxes on strength and weld geometry (weld depth, width and depth to width ratio) by using Gas tungsten arc welding (GTAW).

2. METHODOLOGY

The following steps have been followed for the completion of work as shown in the Figure 1.

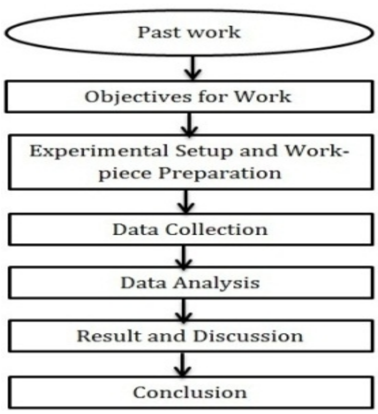

Figure 1. Methodology

3. EXPERIMENTAL DETAILS

3. 1. Work Material The Stainless steel 304 is one of the most commonly used material in manufacturing industries because it has better corrosion resistance and good weldability. The composition and mechanical properties of Stainless Steel 304 are shown in the Tables 1 and 2, respectively [7].

3. 2. Activated Flux The properties of various fluxes used in experiments are shown in Table 3.

3. 3. Experimental Set-up The Tungsten Inert Gas welding machine 'TIG ESAB 400' has been used for the research work at Steel Arcthitect pvt. Limited, Saha (Ambala) as shown in Figure 2. A water-cooled torch with a standard 2% thoriated tungsten electrode rod having diameter of 3.2 mm has been used for the experiment. The parameters selected for TIG welding are shown in Table 4. The tensile test has been performed on Universal Testing Machine having maximum load capacity of 90,000 N. The machine Model-UTM-100, S.N- 3/94, 1782, Make-FIE is shown in Figure 3. The proof stress has been taken as 2% of the actual load. The physical dimensions of tensile test specimen are: Diameter =12.5 mm, Gauge Length = 80 mm.

3. 4. Welded Specimens The dimensions of test specimen were 100 x100 mm and thickness was 6 mm. The surface of each specimen was roughly grinded with 240 grit silicon carbide flexible abrasive paper to remove all the impurities. It was subsequently cleaned with acetone prior to welding. Each powder was mixed with acetone to produce paint like consistency. The 1500 mg of powder has been used along-with 1.5 ml of acetone and then both were mixed in such a way that the mean coating density of active flux was 5 mg/cm^2 for each specimen. The acetone was allowed to evaporate due to which only the flux powder was left on the surface of metal. The welded specimens were obtained after applying different kind of activated fluxes (MnO_2, ZnO, Fe_2O_3 and $MgCl_2$) are shown in Figure 4. The weld beads were appearing at the center of welded specimens.

TABLE 1. Composition of Stainless Steel 304

C (%)	Cr (%)	Ni (%)	Mn (%)	Si (%)	P (%)	S (%)	Fe
0.06	18.67	8.53	1.89	0.42	0.032	0.06	Left

TABLE 2. Mechanical properties of Stainless Steel 304

Tensile stress (MPa)	Yield stress (MPa)	Possion's ratio	Elongation %
605	290	0.25	32

TABLE 3. Properties of flux

FLUX	MnO_2	ZnO	Fe_2O_3	$MgCl_2$
Molar mass (g/mol)	86.93	81.408	159.69	95.21
Appearance	Brown-black	White solid	Red-brown	White
Density (g/cm^3)	5.026	5.606	5.242	1.569
Solubility in water	Insoluble	0.16 mg/ 100ml	Insoluble	72.6 g/ 100 ml

TABLE 4. Process parameters of TIG welding

Welding current	150 A
Welding torch speed	2.3 mm/ sec
Gas flow rate	10 lit/min
Electrode tip angle	45 degree
Shielded gas used	Pure argon
Electrode diameter	3.2 mm
Arc length	2 mm
Welding mode	Direct current electrode negative
Weld type	Autogenously

Figure 2. TIG welding set-up

Figure 3. Universal Testing Machine

4. RESULTS AND DISCUSSIONS

The comparative analysis of ultimate tensile strength and percentage elongation, with and without using different types of activated flux are shown in Figures 5 and 6, respectively. The MnO_2 flux has given the highest tensile strength of 640.32 MPa along with percentage elongation (ductility) of 39.20. This is very high in comparison to the values of strength (605.42 MPa) and ductility (37.90) without using flux. The use of Fe_2O_3 flux results in significant increase in strength from 605.42 MPa to 632.72 MPa and increase in ductility from 37.90 to 38.92. A little variation has been observed in ultimate tensile strength and percentage elongation by using ZnO and $MgCl_2$ flux.

Figure 4. Welded specimens

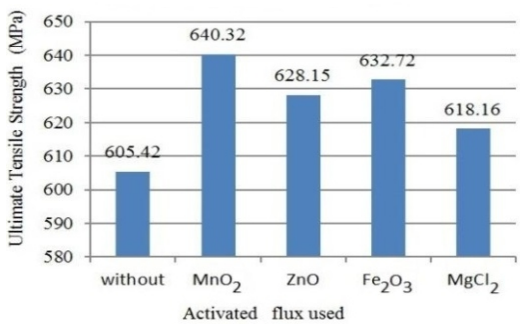

Figure 5. Variation between tensile strength and flux used

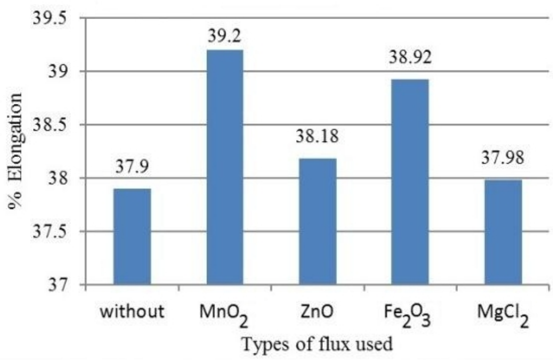

Figure 6. Variation between flux and % elongation

The ultimate tensile strength of 628.15 MPa and 618.15 MPa has been obtained from ZnO and $MgCl_2$, respectively. The percentage elongation of 38.18 and 37.98 has been obtained from ZnO and $MgCl_2$, respectively. The present study shows that the MnO_2 flux has given the highest value of ultimate tensile strength and percentage elongation. The use of $MgCl_2$ has given the lower strength and very little change in percentage elongation for stainless steel 304. The tool maker microscope has been used for checking the weld morphology. The weld morphology is characterized by the penetration depth (D), bead width (W) and depth to width ratio (D/W).

Figures 7 and 8 shows the weld morphology of SS 304 that has been produced without using flux and latter shows $MgCl_2$, respectively. The welds produced by TIG welding without using activated flux has a wide and shallow morphology, while the TIG welds produced using different fluxes has a narrow and deep morphology. It has been observed that the increase in penetration depth and decrease in bead width are significant when surface active fluxes have been used.

The MnO_2 produces the greatest improvement in penetration up to 4.2 mm and width up to 2.8 mm. The Fe_2O_3 increases the penetration from 1.2 mm to 3.8 mm and decrease the width of weld from 5.2 mm to 3 mm. The ZnO and $MgCl_2$ show the penetration of 3.4 mm and 3.8 mm, respectively. The increase in penetration by using different fluxes is shown in Figure 9. The depth to width ratio is an important parameter of weld geometry, higher the value of this ratio results in greater and better properties of weld joint [13, 19].

The maximum value of D/W ratio is 1.50 for MnO_2 activated flux. According to Heiple and Roper, the direction of fluid flow in the molten pool can affect the weld morphology. The temperature coefficient of surface tension is an important factor for finding the direction of fluid flow in the molten pool [12]. During welding, it always has been a difficult task to measure the temperature of the molten pool since this region has been surrounded by hot plasma.

However, it is well known that the temperature gradient always exists on the surface of the TIG molten pool. That has been accompanied by higher temperatures in the pool center under the arc and lower temperatures at the pool edge. A conventional TIG welding without using flux, the temperature coefficient of surface tension on the molten pool exhibits a negative value [12]. If the surface tension in the pool center is lower than the temperature at the pool edge, then the surface tension gradient generates centrifugal Marangoni convection in the molten pool [15].

In this condition, the fluid of the molten pool surface easily transfers from the pool center to the edge, yielding a wide and shallow TIG weld. The temperature coefficient of surface tension on the molten pool changes from a negative to a positive value when TIG welding is incorporated with MnO_2, ZnO, Fe_2O_3 and $MgCl_2$ fluxes. Therefore, surface tension at the pool center has been found higher than surface tension at the pool edge.

It indicates that the surface tension gradient introduces centripetal Marangoni convection in the molten pool. In that condition, the fluid of the molten pool flows towards the pool edge, center and then flows downwards [15, 16]. That causes a narrow and deep TIG weld which forms a peanut shell-like shape [15].

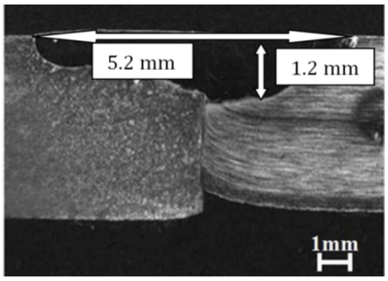

Figure 7. Weld morphology without flux

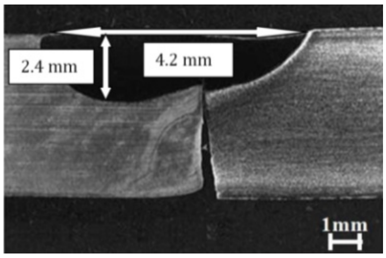

Figure 8. Weld morphology with MgCl2 flux

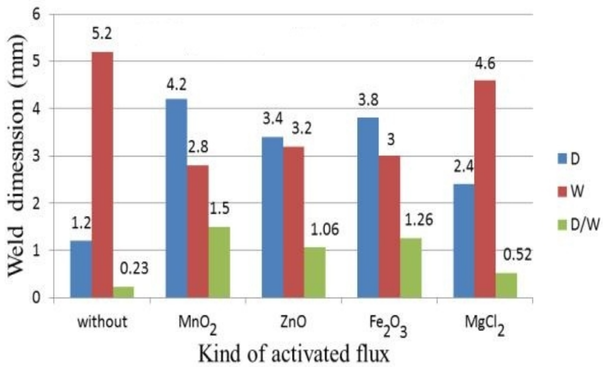

Figure 9. Comparison of weld morphology with and without fluxes

5. CONCLUSIONS

In the present work, the effects of MnO_2, ZnO, Fe_2O_3 and $MgCl_2$ fluxes on weld morphology (weld bead penetration, bead width and weld depth to width ratio) has been studied. Their effects on the ultimate tensile strength and percentage elongation have also been observed during TIG welding of SS 304. The primary results and conclusions are summarized as follows:

1. From the experimental results, we have found that under the same welding condition, the MnO_2 and Fe_2O_3 fluxes can produce the greatest improvement in penetration capability, up to 2-3 times. It also decreases the bead width in comparison to the conventional TIG welding of stainless steel 304. These fluxes also contributed the largest depth to width ratio and hence considerable larger weld cross sectional are produced.
2. The result shows that the MnO_2 and Fe_2O_3 fluxes give the highest tensile strength and percentage elongation for the material Stainless steel 304. Whereas ZnO and $MgCl_2$ fluxes produce a little effect on strength and ductility.
3. In this research, the centripetal Marangoni convection and constricted arc plasma has been adopted as a possible mechanism for increasing the different activated fluxes assisted TIG weld penetration and narrow bead width of welded joints.
4. The result of experiment shows an improvement in the mechanical properties. Whereas weld morphology also improves by using different types of activated flux in comparison to the conventional TIG welding. Hence, it increases the productivity in welding fabrication process in industrial sector.

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چکید

این پژوهش مطالعه ای در مورد اکسید منگنز ، اکسید روی، اکسید آهن و کلرید منیزیم که به عنوان شارهای فعال استفاده می شوند را ارائه می دهد تا اثرات آنها را بر اس اس ٣٠٤ در جوشکاری گاز بی اثر تنگستن (TIG) بیابد. مقاومت نهایی کششی، درصد ازدیاد طول، عمق نفوذ، نسبت عرض و عمق به عرض اس اس ٣٠٤ مورد مطالعه قرار گرفته است. آزمایش نشان می دهد که استفاده از اکسید منگنز و اکسید آهن به عنوان شار، عمق نفوذ جوش را افزایش و عرض جوش را کاهش می دهد. همچنین، استفاده از اکسید روی و کلرید منیزیم به عنوان شار افزایش کمی در عمق نفوذ و نسبت عرض به عمق جوش در مقایسه با فرایند رایج TIG نشان می دهد. استحکام کششی نهایی و درصد ازدیاد طول در جوشکاری شار فعال TIG افزایش یافته است.

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