Investigation on Various Aspects of using Activated Tio2 Flux in GTAW on Stainless Steel (AISI 304l)

Chetan raj[1], Anil Punia[2]

[1] Post graduate student, Department of Mechanical Engineering, Rao Pahlad Singh College of Engineering and Technology, Balana, Mohindergarh-123023
[2] Assistant professor, Department of Mechanical Engineering, Rao Pahlad Singh College of Engineering and Technology, Balana, Mohindergarh-123023

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***Abstract**- The main objective of industries reveals the better quality production at minimum cost and increase productivity. TIG welding is the most important and common operation use for joining of two similar or dissimilar material with heating or applying the pressure or using the filler material for increasing productivity with less time and cost constrain. In the present research project, an attempt is made to understand the effect of TIG welding parameters such as welding speed, current and percentage of flux on responsive output parameters such as weld penetration and hardness of weld zone by using optimization philosophy. Generally, TIG welding welds thin sections for good surface finish. A major drawback in the process is having shallow penetration as compared to other arc welding process. This problem can be overcome by using active flux with conventional TIG welding. In the present study it is decided to investigate the optimization of A-TIG welding process on 304L stainless steel for an optimal parameter and the effect of various process parameters (welding current (I), welding speed(V), active flux. In the present study, efforts were made to improve the weld penetration and micro-hardness by applying the active flux and to optimize the process parameter. TiO_2 used as active flux in the present investigation. Taguchi method is used for design of experiment and Taguchi based grey relation optimization model is used in this work. Optimized parameters were again used to find the optimum characteristics for activated TiO_2 flux TIG welding sample. Microstructure analysis is done for weld bead of the samples.*

Keywords- Tungsten inert gas welding, Activated TiO_2 flux, heat affected zone, fusion zone, depth of penetration.

1. INTRODUCTION

Use of activated flux in welding can increase weld properties of TIG welding. It causes proper shielding of weld area which stops formation of oxide as well decrease the cooling rate. **Kamal H. Dhandha et al.** used Fe2O3, ZnO, MnO2 and CrO3 fluxes to weld 2–3 mm thick plates of carbon steel, stainless steel by Gas Tungsten arc welding process in the Argon shielding under autogeneous mode. A TIG welding using a thin layer of an active flux caused a great increase in weld penetration and hardness and width value was also changed. Penetration was increased and the bead width was decreasing. These effect were recorded better with the use of activating - fluxes Fe2O3, ZnO, MnO2 and CrO_3[1]. **K. Devendranath Ramkumar et al.** investigated the weld ability of stainless steel AISI 430 by GTAW technique by using activated fluxes into it. Tensile failures were observed at the parent metal of AISI 430 without flux addition and while employing SiO2 flux; whereas at the fusion zone for Fe2O3 flux assisted weldments. The use of SiO2 and Fe2O3 flux improved the depth of penetration and also joints was achieved in single pass whereas double pass welding was required for obtaining the joints without flux addition[2]. **Rui-Hua Zhang et al.** have proposed a mechanism to increase penetration of stainless steel by using activating flux. With flux, the oxygen which changes the temperature dependence of surface tension grads from a negative value to a positive value caused significant changes on the weld penetration. Fluid flow was inward along the surface of the weld pool toward the cantered then down. This fluid flow pattern efficiently transferred heat to the weld root and produced a relatively deep and narrow weld[3]. **Jelli Lakshmi Narasimha Varma et al.** investigated the study that addresses the comparison of metallurgical and mechanical properties of autogeneous and activated compound flux assisted gas tungsten arc welding (GTAW) of super-austenitic stainless steel AISI 904L.The use of compound flux for better depth of penetration was compared to autogeneous welding. Tensile study showed that the fracture occurred at the fusion zone for both the weldments. Ductility was found to be greater for the flux-assisted weldments[4]. **P. Vasantharaja et al.** showed that in Low Activation Ferritic–Martensitic steels (LAFM) can be chosen as the candidate material for structural components in fusion reactors. The structural components are generally fabricated by welding processes. Activated GTAW (A-TIG) welding is an efficient process for welding of thicker metal components[5]. **Er. Bhawandeep singh et al.** has given a comprehensive overview of the process of TIG welding is main welding in those industries where it is important to control the weld bead shape and its metallurgical characteristics. Comparing to the other arc welding process, the low penetration of the TIG welding makes it unable to weld thick metals in a single pass and due to this productivity is low in this case[6]. This is why they have done several trials to improve the productivity of the TIG welding. The present study shows the welding on SS304 L by GTAW using TiO_2 as activated flux.

2. MATERIAL USED

Stainless steel 304 L is used because of its wide application in Heat Exchangers, Pipelines, Pressure Vessels, Flanges and Fittings. Chemical composition and Mechanical properties are written in Table 1 and Table 2

Table 1 Chemical composition of 304L stainless steel

Composition	C	Cr	Ni	Mo	Cu	Si	Mn	P	S
% of Weight	.023	17.95	8.32	.257	.38	.68	1.73	.027	.024

Table 2 Mechanical property of stainless steel AISI 304L

Mechanical Properties	Hardness (Vickers)	Ultimate Tensile Strength	Modulus of Elasticity	Impact Strength (Charpy)
Value in SI Units	159 HV	5.64×10^8 N/m^2	2×10^{11} N/m^2	216 J

Specimen is cut with power saw with water cooling and proper finish is given in shaper. The finished sample size was 100mm×50mm×6mm. Flux material used was TiO_2 which was applied on the surface of specimen by mixing it with acetone as shown in Figure 1.

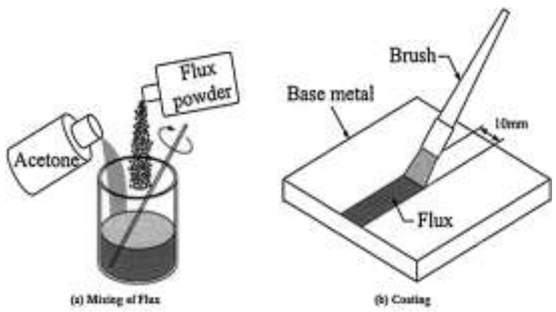

Figure 1 Preparation and application of flux paste.

3. METHODOLOGY

3.1. Process parameters and their range

A lot of trial experiments were made before finalizing the parameters. The selected parameters with different level is given in table 3

Table 3 Different levels of parameters range

Parameter	Units	Notation	Level 1	Level 2	Level 3	Level 4
Current	A	C	100	120	140	160
Welding Speed	m/min	S	0.15	0.18	0.21	0.24
Flux (tio$_2$)	gram	G	2	3	4	5

3.2 Design of experiment

Design of Experiment is done as per Taguchi L16 array in for three different parameter level. Total 32 samples were prepared for various parameter ranges as given in table 3.5. Out of which 16 samples were prepared for A-TIG welding (with TiO_2 flux) and remaining 16 samples were prepared by conventional TIG (without Flux). Bead on plate welding is done in this work. Design of experiment for without flux welding is also done by Taguchi's L16 array for variation in speed and current.

Table 4 Design of experiment as per Taguchi's method L16 orthogonal array for welding with flux

Sample. No.	TiO_2 Flux used (g)	Current (Amp)	Welding Speed (m/min)
1	2	100	0.15
2	2	120	0.18
3	2	140	0.21
4	2	160	0.24
5	3	100	0.18
6	3	120	0.15
7	3	140	0.24
8	3	160	0.21
9	4	100	0.21
10	4	120	0.24
11	4	140	0.15
12	4	160	0.18
13	5	100	0.24
14	5	120	0.21
15	5	140	0.18
16	5	160	0.15

Bead on plate welding was done on stainless steel 304L as per Taguchi's L16 array. After welding the specimens were cut into test samples of dimension 40mm×15mm×6mm with the help of power saw. During the work piece cutting regular water flow which are protect work piece to heat generation otherwise which can affect microstructure and grain growth of weldments. After cutting the test samples were polished by rotating polishing machine. Emery papers of various grades were used under regular flow of water. All sample sequence polished on velvet cloth with alumina slurry and mixture of water and kerosene was applied as lubricant. After that all 32 sample were etched in nital solution (5.5% nitric acid and 94.5% distilled water) to observe different zone of welding.

Figure 2 Work piece after etching

Etched were then dipped in distilled water and cleaned with ethanol and allowed to dry. Depth of penetration and weld bead width were measured with optical microscope and their values are given in table 5.

Table 5 Depth of penetration and weld bead width for A-TIG weld and TIG weld

S. No.	A-TIG weld (TiO_2 flux)		TIG weld (without flux)	
	P(mm)	W(mm)	P(mm)	W(mm)
1	1.33	3.82	0.62	4.52
2	1.43	2.45	0.98	2.36
3	1.82	3.40	1.32	2.08
4	1.93	2.64	1.75	2.61
5	2.12	2.82	0.52	4.46
6	2.44	4.32	0.92	3.28
7	2.72	4.4	1.03	4.73
8	3.30	3.98	1.24	3.37
9	2.84	4.09	0.68	2.56
10	2.98	2.25	0.69	2.95
11	3.30	2.95	1.25	2.01
12	3.62	2.4	1.95	3.45
13	2.02	2.15	0.60	2.35
14	2.11	3.98	0.85	2.45
15	2.25	2.83	1.75	3.98
16	3.89	2.09	2.02	4.58

For morphological analysis, microstructures were captured at different zooming condition. Micros hardness test results are given in table 6.

4. RESULT AND DISCUSSION

Results show that hardness of the activated TiO_2 flux TIG weldment is less than TIG welding with no flux. Figure 3 is graph for hardness comparison for maximum heat input sample whereas Figure 4 is explaining hardness comparison for minimum heat input sample. Hardness number of the weld bead for A-TIG is obtained near 220 $HV_{0.5}$, whereas at HAZ it is closer to 200 $HV_{0.5}$. Slightly decrease in hardness gives confirmation of less brittleness of the joint which will be analyzed in morphological behavior[6]. The result on bead on plate experiment shows that the hardness values vary in TIG welding with and without flux. This is because flux is making cooling rate of weld slow making coarse pearlite structure[7].

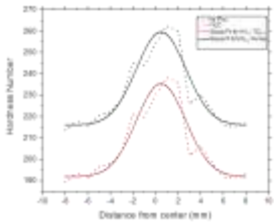

Figure 3 Hardness number comparison of TIG welds with and without flux at maximum heat input.

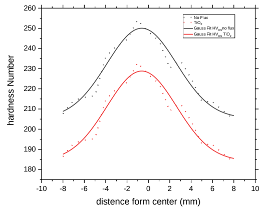

Figure 4 Hardness number comparison of TIG welds with and without flux at maximum heat input.

Result shows that hardness of welded material is slightly less when welded with Tio_2 flux. Similarly with minimum heat input sample hardness obtained is slightly less as shown in figure-4. Hardness number is found to be reduced when we increase the amount of flux on the weld surface[6]. Also Hardness of the weldment has effect of welding speed as well as current. Sample welded with activated TiO_2 flux have less effect of these parameter in compared with sample with no flux. Reason is as mention as per literature, activates flux is causing slow cooling rate of weld area, which gives some time to grain for development[8]. The average hardness at different flux amount is given in table-6.The changes in microstructure as observed from the microscopes, also reveals the fact that the mechanical property such as hardness of weld zone will change at different input current.

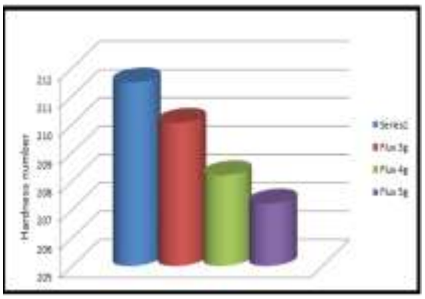

Figure 5 Chart showing variation in hardness with increase in amount of flux used

This is because of the fact that fusion welding process result in melting and solidification at high temperature with in a small zone and the mechanical property of the weld bead will largely depend on the nature of the microstructure developed as post welding effect[9].

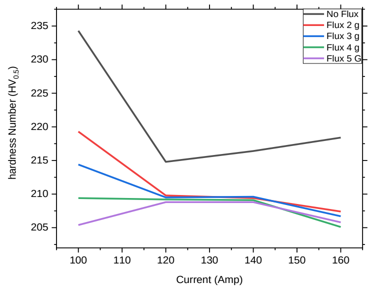

Figure 6 Graph showing variation of hardness number with current

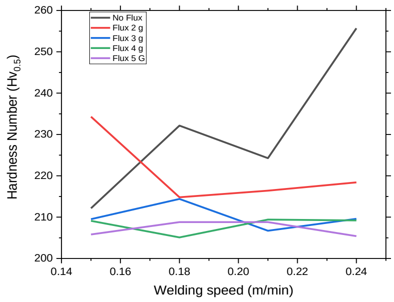

Figure 7 Graph showing variation in hardness with welding speed

Table- 6 Average hardness number value for different flux amount weld

Weight of TiO_2 used (g)	Hardness Number value for different welding condition ($HV_{0.5}$)				Average hardness Number value ($HV_{0.5}$)
2	219.3	209.8	209.4	207.4	211.475
3	214.4	209.5	209.6	206.7	210.050
4	209.4	209.2	209.1	205.1	208.200
5	205.4	208.8	208.8	205.8	207.200

With increase in current hardness of the weld ment is decreasing as shown in figure 6. This is because of high heat input is causing more time to cool and hence time for grain boundaries to grow is more[9]. Figure 7 shows the variation of hardness with variation in welding speed. Depth of penetration is found to be increased with the use of activated TiO2 flux. To compare results, in this work minimum heat input sample and maximum heat input sample were consider. Figure 8 shows that penetration is most in case of welding with TiO_2 flux as compared to weld without flux. Even flux weld with minimum heat input is having higher penetration than weld without flux at maximum heat input In the case of welding with flux; weld is showing slightly optimal hardness value[10]. This value becomes better with increase in amount of flux used. But after some time, depth of penetration starts decreasing. At 4g flux, depth of penetration was 3.185 mm whereas at 5g flux it is 2.5675 mm. So flux weight needs to be optimized. Weld bead width is found to be decreased with the use of activated TiO2 flux which is good result as depth of penetration is increasing.

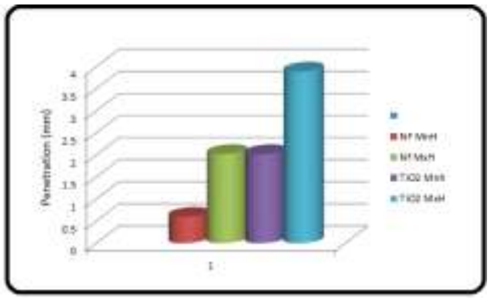

Figure 8 Chart showing variation in penetration with or without flux

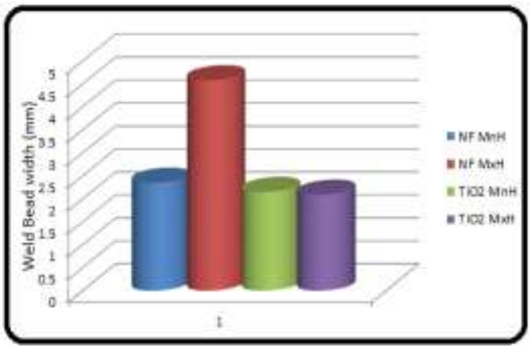

Figure 9 Chart showing variation in weld bead width with minimum and maximum heat input

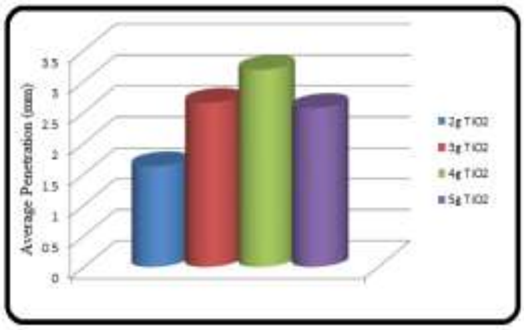

Figure 10 Chart showing variation in average penetration with increase in weight of flux used

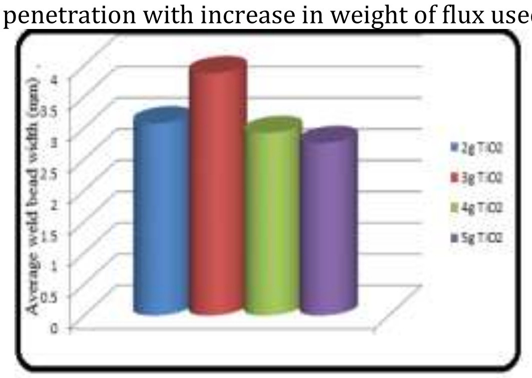

Figure 11 Variation in average weld bead width with incraese in amount of flux used

Table- 7 Average penetration value for different flux amount weld

TiO_2 used	Penetration value for different welding condition (mm)				Average penetration (mm)
2g	1.33	1.43	1.82	1.93	1.6275
3g	2.12	2.44	2.72	3.33	2.6525
4g	2.84	2.98	3.3	3.62	3.185
5g	2.02	2.11	2.25	3.89	2.5675

It makes welding to be penetrating with less affecting base metal. To compare results, in this work minimum heat input sample and maximum heat input sample were consider. Figure 8 shows that depth of penetration is most in case of welding with TiO_2 flux as compared to weld without flux[5]. Average weld bead width is less affected with the variation in weight of flux used. The average weld bead width value is given in table 8 and comparison with different flux composition in shown in figure 11.

Table- 8 Average weld bead width value for different flux amount weld

TiO_2 used	Weld bead width value for different welding condition (mm)				Average weld bead width (mm)
2g	3.82	2.45	3.4	2.64	3.0775
3g	2.82	4.32	4.4	3.98	3.88
4g	4.09	2.25	2.95	2.4	2.9225
5g	2.15	3.98	2.83	2.09	2.7625

The results of bead on plate welding trials apparently showed that the addition of flux increased the depth of penetration (DOP). In trail experiment DOP achieved for autogeneous welding without flux addition was noticed Activating fluxes change the direction of weld pool convection, therefore content of melt will be more in the center than that near the edge of weld fusion zone. The direction of fluid flow in the molten pool can affect the weld geometry[4]. The temperature coefficient of surface tension is a factor, driving the direction of fluid flow in the molten pool. The addition of oxide flux changes the temperature dependence surface tension and it will be higher at center and lower at pool causing fluid flow will be inward towards the center producing narrow and deep penetration. The structure of welded area is found that it is completely different from base metal[8]. It seems that grains structure has also changed with flux employment. The sizes of grains are coarser in case of without use of flux in TIG welding but with flux uses it is found that welding grains becomes finer from previous TIG weldment.

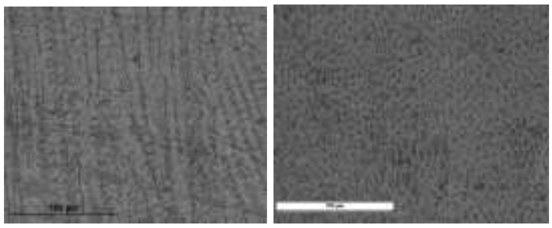

Figure 12 Weld bead microstructure without flux (left) and with Tio_2 flux (right) (50x magnification)

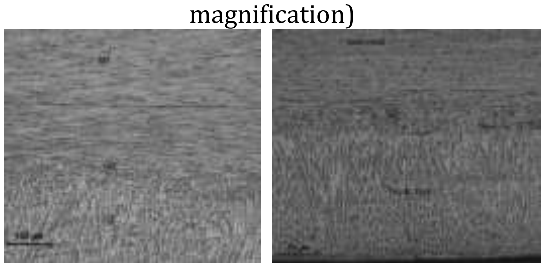

Figure 13 Microstructure showing fusion zone, HAZ and base metal of weld without flux (left) and with Tio_2 flux (right) (50x magnification)

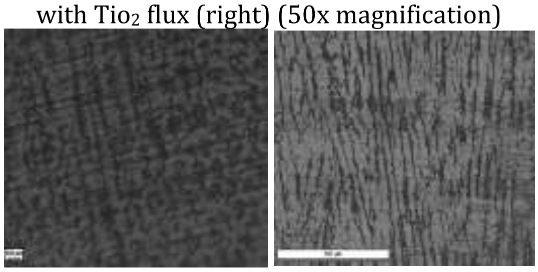

Figure 14 Weld bead microstructure without flux (left) and with Tio_2 flux (right) (100 x magnification)

From the microstructure it has been also revealed that grain size of Tio_2 flux coated weldment is finer than Sio_2 flux coated weldment. As current is very crucial welding parameter and has huge effect on microstructure of AISI 304Lstainless steel, a study has been carried out to investigate the changes in microstructure occurring as a post welding effect[9]. The study of micrographs of welded zone shows changes in microstructure as a post welding effect in different zone of welding area[10]. A considerable variation in the metallurgical structure of the weld zone from the base material is found to be present.

5. CONCLUSION

In present work for fulfill the objective an experimental model has developed to study the changes in microstructure, depth of penetration and micro hardness of SS (AISI304L) by TIG welding. A design of experiments has performed to identify the effect of input parameters like Current (C),welding speed (S), and flux percentage (P) on response depth of penetration, Vickers's micro hardness and microstructure of the weld bead. In order to validate the output, results have correlated with published results. Taguchi based grey optimization is performed.

Further, the predicted optimal solution was validated using the welding process parameter values obtained during experimentation at optimal condition. Based on the results, the following conclusions could be drawn:

- From the microstructural it concludes that more fine grains structure has been found in SS (AISI304L) by using TiO_2 as compared to without using flux.
- From Vickers's Micro hardness observation It has been observed from experiment that the hardness is increased in SS (AISI304L) when the percentage of TiO_2 slightly less.
- Experimentally it has been observed that the depth of penetration increase in SS (AISI304L) as the percentage of TiO_2 increases than the other parameters and it has been showed that the maximum value of depth of penetration got at the welding speed 0.15 m/min., current 160 Amp and 3.4g flux.
- The proposed methodology was found efficient to predict the optimal set of welding process parameter.
- By using the proposed methodology, the obtained optimal parameters are 3.4g flux weight, 160 Amp. Current, 0.15 m/min. welding speed. The optimize value of depth of penetration is found 3.58 and micro-hardness is found 202.85 $HV_{0.5}$.

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