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The effect of activating fluxes in TIG welding by using Anova for SS 321

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ABSTRACT
Gas tungsten arc welding is fundamental in those industries where it is important to control the weld bead shape and its metallurgical characteristics. However, compared to the other arc welding process, the shallow penetration of the TIG welding restricts its ability to weld thick structures in a single pass (~ 2 mm for stainless steels), thus its productivity is relativity low. This is why there have been several trials to improve the productivity of the TIG welding. The use of activating flux in TIG welding process is one of such attempts. In this study, first, the effect of each TIG welding parameters on the weld's joint strength was shown and then, the optimal parameters were determined using the Taguchi method with L9 (9) orthogonal array. SiO2 and TiO2 oxide powders were used to investigate the effect of activating flux on the TIG weld mechanical properties of 321austenitic stainless steel. The experimental results showed that activating flux aided TIG welding has increased the weld penetration, tending to reduce the width of the weld bead. The SiO2 flux produced the most noticeable effect. Furthermore, the welded joint presented better tensile strength and hardness.

I. Introduction

TIG welding is a process that uses a shielding gas (argon or helium) in which a non-consumable tungsten electrode is used for establishing an electric arc. It is commonly used for welding hard-to-weld metals such as stainless steels, magnesium, aluminium, and titanium. High quality metallurgical weld and good mechanical properties are the benefits of the TIG process. In contrast, low penetration depth and low productivity are its limitations. Therefore, it has limited economic justification when compared to consumable electrode arc welding processes in sections thicker than 10 mm (0.375 in.). On the other hand, the tendency towards higher quality products and more productivity in recent years has led to the development of various provisions in TIG welding process. One of the most striking provisions is the use of activating fluxes in TIG welding process, which was coined in the early 1960s, and now is known as Active TIG (A-TIG) method. In this method, a thin layer of activating flux is applied on the surface of base metal. During welding, certain conditions in the arc and the weld zone lead to an increased penetration depth, and increased productivity in joining thick parts. In addition, TIG welding parameters are not only the main factors in determining the depth of weld penetration and productivity of the process, but also they affect the performance of the activating fluxes. But there is not yet any analytical relationship between these parameters and welding geometry. However, knowledge of the relationship between welding parameters and weld quality is essential for controlling the process. Quality of welds can be analyzed through weld geometry (depth and width). However, weld geometry affects its shape and plays an important role in determining the mechanical properties of weld. In general, for determining the optimal parameters, time consuming and costly tests should be used due to the complexity and non-linearity of welding process. Taguchi method, which is an effective method for estimating optimal parameters of welding process, has been used in this study. Taguchi method is a powerful tool for designing high quality systems. It provides a simple, efficient, and systematic approach to optimize designs for performance, quality, and cost. Experiments planned by statistical methods are the key tools of Taguchi method for designing the parameters. In statistical methods, the process is optimized through determining the optimal operating conditions, investigating the effect of each factor on the outcome, and estimating the outcome under optimal conditions .This method was used in this study to determine the optimal welding parameters for a weld with the maximum penetration depth and minimum width. Creating a weld with high penetration depth and low width will increases productivity and decreases the welding part distortion. The effect of the activating fluxes on weld geometry and mechanical properties of joint has been studied comparatively. Information extracted from the experiments conducted in this study can be useful for the application in various industries.

II. Experimental Procedure

321 austenitic stainless steel with a chemical composition presented in Table 1 was used to

conduct the tests. For this purpose, sheets with the dimensions of 100×70×6 mm were prepared and tests were conducted in two steps. In the first step, optimal parameters of welding process were determined using Taguchi method with L9(9) orthogonal array. The L9(9) means that to investigate 3 factors on a qualitative index with 3 levels for each factor, all required tests will be three L9(9) orthogonal array . Using Taguchi method, such study is applicable with only 9 tests. In this study, three main parameters of TIG process including welding current, gas flow rate, and the flux proportion were evaluated at three levels. The values of each A, B, C, parameters. Selecting values of the parameters levels were made in the light of theoretical and experimental standpoints at the three levels of low, medium, and high. Taguchi experimental layouts are shown in Table 3. In order to ensure results and minimize the effects of uncertainty, all tests were repeated three times, and the averaged results were evaluated. In all tests, bead shape welding has been done with the filler metal on the sheet in a single pass. It is noteworthy that the tungsten electrode diameter which contains 2% thorium (3.2 mm), and high purity argon Debye (L/min) were in all welds. In order to determine the parameters which significantly affect the depth to width ratio, investigation of the welding parameters was done using ANOVA analysis. The S/N ratio was selected based on the bigger-the better criterion in order to achieve the optimal parameters. The three L9 orthogonal array wise two constant welding flux are constant and the third L9 orthogonal array is taken as welding flux proportion are taken as shown in table:

To evaluate the effect of parameters variations on qualitative index, participation percentage was also used. Taguchi S/N ratio defines the ratio of signal factors (fixed factors) to turbulence factors (uncontrollable factors). Analysis of the S/N ratio is used to determine the best test performance or the best composition of various factors in order to reach the optimal result.

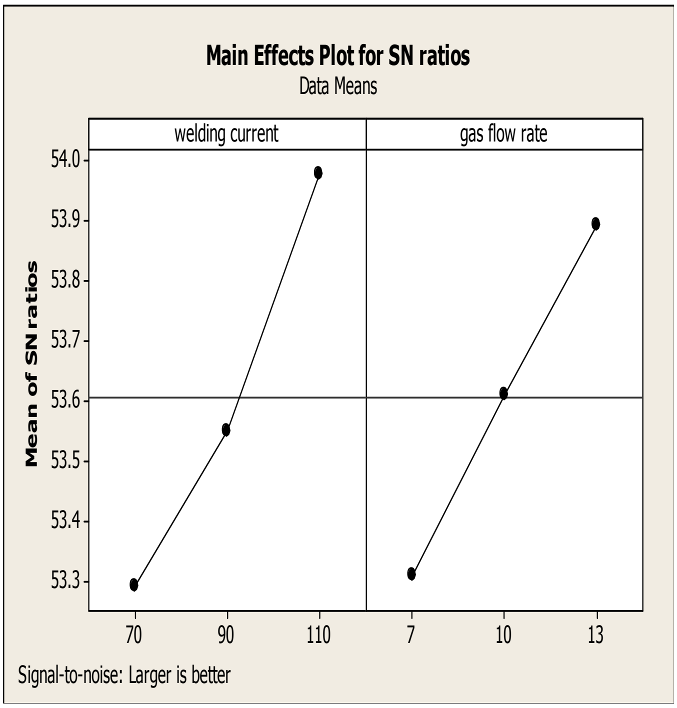
The ANOVA analysis is another powerful tool of Taguchi process which is done after S/N ratio analysis. Error variance and relative importance of the factors are determined in this analysis. In the second step, the effect of activating fluxes on TIG weld was studied according to the optimal parameters of the first step experiments. SiO2 and TiO2 powders with particle size of 100 gm have been used as the activating fluxes. A suspension of oxide powders and acetone was prepared and set aside to transform to pulp; after that, some of it was applied on the surface of the joint by a brush. Then all samples were put under the equal welding conditions. After welding, cross sections of the welded specimens were prepared and cleaned by K2 paste weld bead and HAZ (heat affected zone) of the samples were measured by optical microscopes. Tensile test specimens were prepared in small size according to ASTM standard. To ensure the accuracy of tensile test results, three tensile specimens of each weld have been tested, the average result of which was the tensile properties criterion. Fracture surface of the tensile specimens was analyzed by UTS.

Table 1 chemical composition

Type	*C (%)*	*Mn(%)*	*P (%)*	*S (%)*	*Si (%)*	*Cr (%)*	*Ni (%)*	*Mo (%)*
321	*0.08*	*2.00*	*0.040*	*0.030*	*1.00*	*17.00/19.00*	*9.00/12.00*	*0.75/0.75*

Graph 1: welding current vs gas flow rate response to tensile strength of TiO_2

As shown in graph 1 the welding current VS gas flow rate response to tensile strength The analysis is made with the help of a software package MINITAB 16. The main effect plots are shown in Fig.1, and Fig.2.These show the variation of individual response with the two parameters i.e. welding current, gas flow rate, and constant TiO2 flux of. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response. The main effects plots are used to determine the optimal design conditions to obtain the optimum surface finish. Second fig show the signal to noise ratio with welding current , gas flow rate and constant TiO2 flux response to tensile strength.



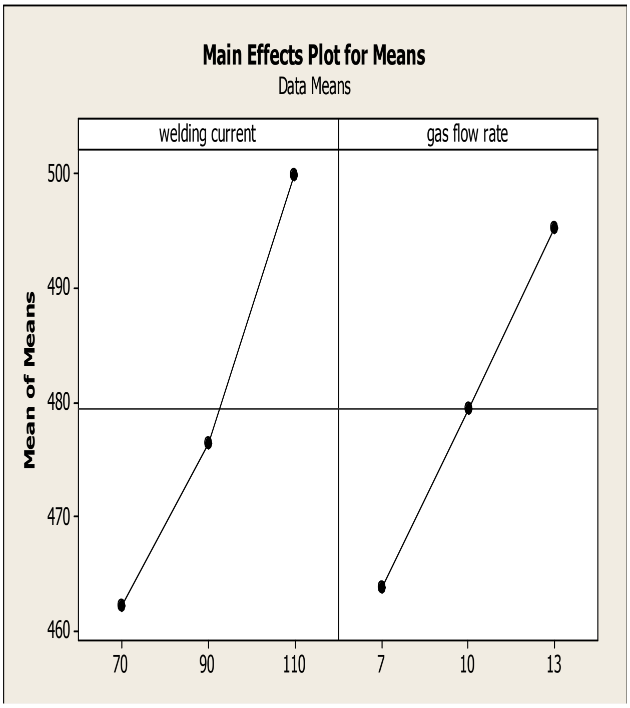


Figure 1 graph for TiO2

According to this SN ratio plot the optimal condition is larger is batter tensile strength and minimum tensile strength is Welding current at level 1 (70 Amp) Gas flow rate at level 1 (7 L/min)

According to this main effect plot fig.1, the optimal conditions for minimum tensile strength are:

- Welding current at level 1 (70Amp),
- Gas flow rate level 1 (7 L/min),

Graph : welding current vs gas flow rate response to tensile strength of SiO2

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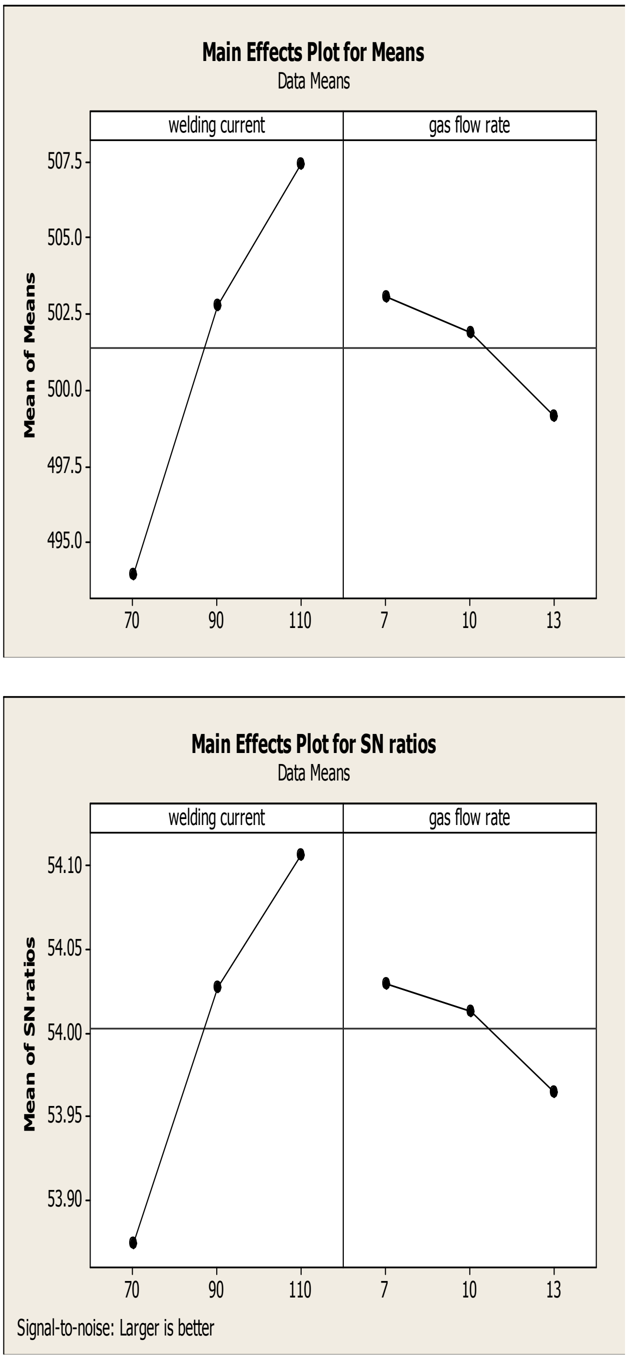


Figure 2 graph for SiO2

According to this main effect plot fig.1, the optimal conditions for minimum tensile strength are:

- Welding current at level 1 (70Amp),
- Gas flow rate level 3 (13 L/min),

According to this SN ratio plot the optimal condition is larger is batter tensile strength and minimum tensile strength is

- Welding current at level 1 (70Amp)
- Gas flow ate at level 3 (13 L/min)

Graph : welding current vs gas flow rate response to tensile strength of SIO2 + TIO2

The analysis is made with the help of a software package MINITAB 16. The main effect plots are shown in Fig.1.These show the variation of individual response with the three parameters i.e. welding current , gas flow rate, and flux proportion separately. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response. The main effects plots are used to determine the optimal design conditions to obtain the optimum tensile strength.

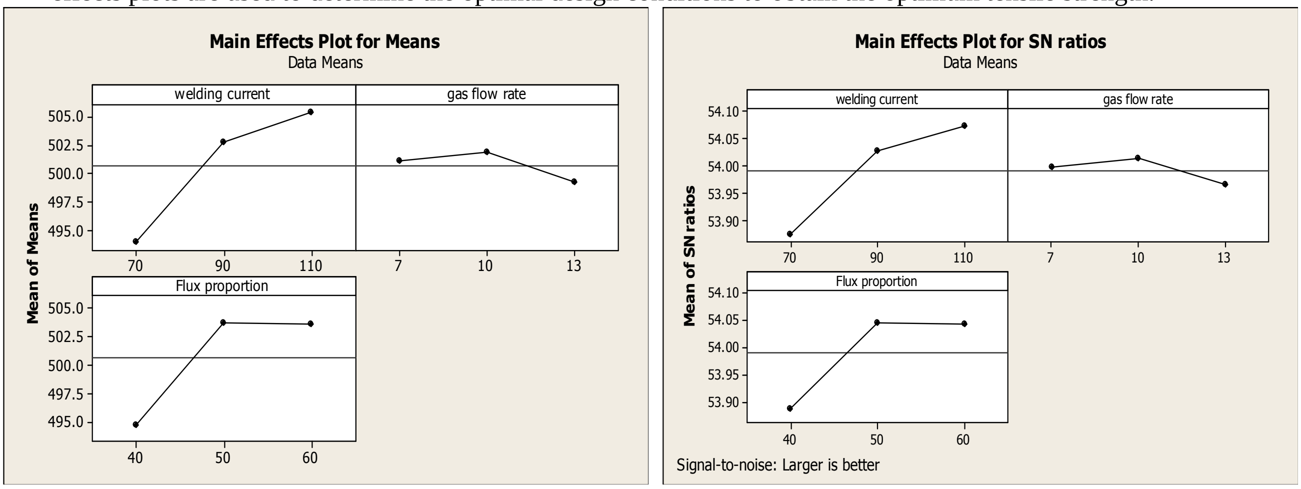


Figure 3 graph for SiO2+ TiO2

According to this main effect plot fig.1 , the optimal conditions for minimum tensile strength are:

- Welding current at level 1 (70 Amp),
- Gas flow rate at level 3 (13 L/min),
- Flux proportion at level 1 (40 %)

According to this SN ratio plot the optimal condition is larger is batter tensile strength and minimum tensile strength is

- Welding current at level 1 (70Amp)
- Gas flow ate at level 3 (13 L/min)
- Flux proportion at level 1 (40 %)

Table 2 Factor and levels for constant flux TiO2 and SiO2.

factors	Process parameter	Level 1	Level 2	Level 3
A	Welding Current (A)	70	90	110
B	Gas flow rate (L/Min)	7	10	13

Table 3 Factor and levels for Flux proportion of TiO2 and SiO2.

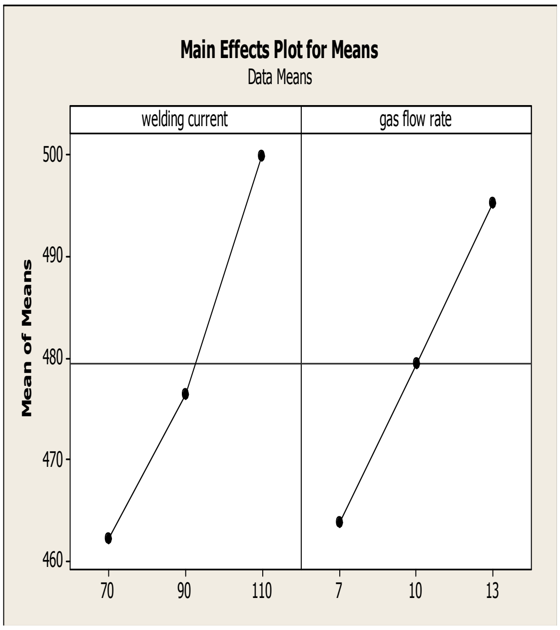
Factors	Process parameter	Level 1	Level 2	Level 3
A	Welding Current (A)	70	90	110
B	Gas flow rate (L/Min)	7	10	13
C	Flux proportion	40	50	60

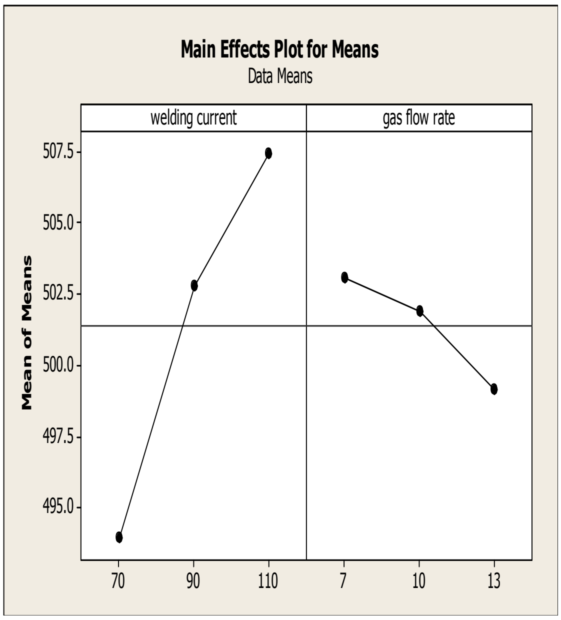
COMPARISON OF FLUX SiO2 AND TiO2

The silicon oxide is the transparent crystal powder is easily available in nature and used as the

welding flux , precursor to glass , food and pharmaceutical application etc. its molar mass is 60.08 g/mol , density 2.648 g.cm-3 , melting point 1600 to 1725˚C and boiling point is 2230˚C.
As compare to silicon oxide the titanium oxide is white solide powder and used as welding flux , paint pigment , printing inks, fibers, rubber, cosmetic products etc its molar mass is 78.866 g/mol , density 4.23 g/cm3 , melting point 1843˚C , and boiling point is 2972˚C.
So it is conclude from the above composition the titanium oxide is higher specification and easily weld as a flux while the silicon oxide is lower so it takes time in welding so it increases strength and penetration of joint as compare to titanium oxide.

Titanium dioxide (INS no. 171; CAS no. 13463-67-7) is produced either in the anatase or rutile crystal form. Most titanium dioxide in the anatase form is produced as a white powder , whereas various rutile grades are often off-white and can even exhibit a slight colour, depending on the physical form, which affects light reflectance. Titanium dioxide may be coated with small amounts of alumina and silica to improve technological properties.
Comparison of mean effect plot between TiO2 flux and SiO2 flux





It is seen from the graph the welding current remain same at low tensile strength but gas flow rate is vary at lower strength in TiO2 flux as level 1 and SiO2 flux at level 3

III. Results and Discussion

Determining TIG welding process optimal parameters Taguchi experimental results of weld penetration depth are shown in Table 4.Each test was performed one time , and its result was considered as the penetration depth criterion. Sum of squares and S/N ratio was calculated for each factor separately in order to determine the effect of different factors on the result. S/N ratio calculated values of Taguchi layout are shown in Fig. 1. The purpose is to increase the penetration depth, and decrease the TIG weld width. So S/N ratio was selected on the basis of bigger-the better criterion. ANOVA analysis and used to determine the relative contribution of each factor. According to its results, optimal parameters were selected to achieve maximum strength of joint and minimum weld width. So the optimal parameters of the process are welding current 110 A, gas flow rate 13 L/min , at constant TiO2 flux. And for SiO2 flux the optimal parameter of the process are welding current 110 A , gas flow rate 7 L/min, for using the proportion flux the optimal process parameter are welding current 110 A , gas flow rate 7 L/min and flux proportion are 60 % SiO2 and 40% TiO2 flux .
Effect of activating fluxes on mechanical properties
Following Taguchi experiments and determining the optimal parameters, activating fluxes were used. Cross section of the welds, using optimal parameters, and at different states of using and not using the activating fluxes. the use of flux leads to the major changes in weld penetration and tensile

strength of joint. According to the percentages of increased penetration in the use of TiO2 and SiO2 and proportion flux respectively, as compared to the case with no flux. Increased penetration can be due to the mechanisms which occur because of the flux decomposition.

Tensile and hardness test results of welds are shown in figure. As can be seen welds containing flux have a relatively higher hardness and yield strength than those of no flux. The obtained result are in agreement with finding of previous research considering that the fracture area of all specimens has been in the heat affected zone (HAZ) examined was applied to this area. According to the observation the HAZ of the welded specimen in the presence of activating flux has a smaller grain size than those without flux welding arc contraction via flux resulting in less heat entering the area around the weld can be considered as the reducing factor of tensile properties of weld are increased due to the decrease in grain size using TiO2 and SiO2 activating fluxes.

IV. Conclusion

Taguchi experimental result showed that among three main parameter of welding i.e. welding current, gas flow rate, flux proportion. Welding current and flux proportion are most effective ones and increase the penetration. Weld penetration depth is increased in due to the increase in the current and it was determined that the use of activating flux not only increase the weld penetration depth but also decrease the weld width which is important term of welding distorting. Activating fluxes improve the joint mechanical property by decreases the grain size of heat affected zone.

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