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# Effect of $TiO_2$ Addition in Saw Flux on Mechanical Properties of AISI 1020 Welds

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*Abstract* - **This work presents a study of the effect of $TiO_2$ additions in fluxes on the mechanical properties and microstructure of the weld metal formed during Submerged-Arc Welding (SAW) of AISI 1020 steel plates. The relationship between microstructure, tensile strength, Hardness and toughness of the weld deposit was studied by means of full metallographic, tensile test, Hardness and Charpy-V notch of the welds. Three fluxes with about 10, 12 and 14% Ti were used with a low-carbon electrode with three level of welding current (300, 350, 40) and other welding conditions were kept constant. The best combination of microstructure and impact properties was obtained in the range of 14% titanium with 400A. The increase in the percentage of acicular ferrite and a decrease in its length were observed with an increase in titanium content. The increase in titanium content in fluxes also improved the toughness and ductility of the welds.**

*Keywords* -Submerged-Arc Welding, Fluxes, Hardness, and Toughness.

## 1. INTRODUCTION

It has been recognized that excellent mechanical strength and toughness can be achieved in steel submerged-arc weld metals by the formation of acicular ferrite microstructure arising from titanium alloying additions. This is due to the fact that the titanium inclusions promote the acicular ferrite in the submerged-arc welds [1, 8]. This effect is very use full for the recent demands for clean energy and increasing needs for transportation of higher volumes of natural gas through high-pressure steel pipelines, have led to manufacture of modern high-strength pipe line steels [15]. It was found that composition of the inclusions, which promote the ferrite nucleation, and concluded that it is strongly influenced by the aluminum content of the weld metal [13]. The alloying elements such as Ni, Mo, Cr, and Ti play an important role in micro structural control [6]. It was investigated that Carbon contents of weld metal decrease with addition of slag in fresh flux and Improve the toughness of the weld metal by reducing the sulphur and phosphorous content from the weld metal [14]. In doing so, the best possible combination of strength and toughness levels for pipeline steels is required. Such pipelines currently experience internal transmission pressures in low ambient temperature down to −40 °C [3]. The aim of the present work was to study the effect of $TiO_2$ additions in fluxes at different level of welding current(300, 350, 400) on the weld metal microstructure and mechanical properties during the Submerged-Arc Welding (SAW) of AISI-steel plates and optimize the result by design of expert with help of Taguchi technique.

## 2. LITERATURE REVIEW

The effect of $TiO_2$ additions in fluxes on the mechanical properties and microstructure of the weld metal formed during Submerged-Arc Welding of 1020 MS plates. In this research four types of alloyed fluxes were prepared by the addition of 9, 12, 15 and 18% of $TiO_2$ in flux and improved the impact strength of the welds, with a slight loss of tensile strength.

Acicular ferrite is promoted in the weldment with increase in titanium content in fluxes [1]. The microstructure and properties of ferritic steel welds containing boron and titanium was investigated in the research and it was found that the volume fraction of ferrite increased with an increase in titanium content when accompanied by low concentrations of boron. An excess of titanium was reported to promote bainite structure in the weldment, because beyond the optimum percentage of the titanium promotes the hard structure not ferrite structure due to which impact strength reduces [8].

The variation of microstructure and mechanical properties in various sub-zones was investigated and it was found that the lowest impact energy and the highest hardness level (160J and 218 HV) were recorded in the fusion zone [15]. The microstructure depends on the alloying elements and the thermo-mechanical processing. Alloy elements such as manganese (Mn), nickel (Ni), molybdenum (Mo), and chromium (Cr), niobium (Nb), vanadium (V) and titanium (Ti) are commonly added to pipeline steels to achieve the desired microstructure and mechanical properties [6]. Waste slag is generated by conventional submerged arc welding and mix with the fresh original flux. It was found that Carbon contents of weld metal decrease with addition of slag in fresh flux and Improve the toughness of the weld metal by reducing the sulphur and phosphorous content from the weld metal [14]. The amount of manganese inclusions can be control with the addition of titanium to the weld but more than the optimum percentage of the titanium promote the banitic structure due to that impact strength of the weld metal reduces.The best mechanical properties in the weld series were obtained in two compositions, i.e. 1.92%Mn–0.02%Ti and 1.40%Mn–0.08%Ti [5].

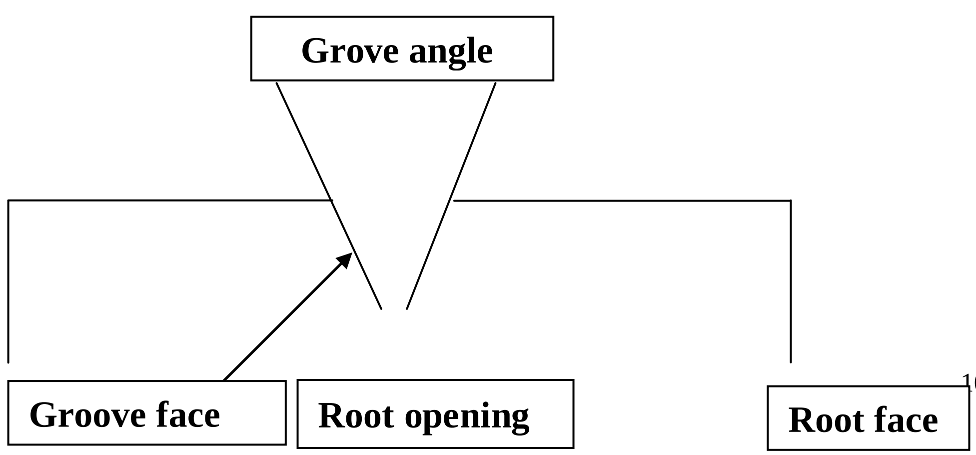
## 3. EXPERIMENTATION

Design of experiment is very important in the efficient analysis of the process [11, 14, 17]. Minitab software was used to determine the no. of experiments to be conducted with the predetermined variables and their levels. L9 orthogonal array was selected with different values of variables at different levels and accordingly nine experiments were designed. After finalization of the process parameters and levels, table no. 1 shows the complete set of nine trials has been prepared as per orthogonal array selected from the Minitab software. Three fluxes containing 10, 12 and 14% $TiO_2$ were prepared by mechanical mixing of a commercial flux with titanium oxide. A copper plate was used as a backing plate to avoid leveling error, control the molten metal by the SAW and welding was done by keeping all other welding condition constant.

Table no. 1 Orthogonal array

| Sr. No. | Current | %age composition |
|---|---|---|
| 1 | 300 | 10 |
| 2 | 300 | 12 |
| 3 | 300 | 14 |
| 4 | 350 | 10 |
| 5 | 350 | 12 |
| 6 | 350 | 14 |
| 7 | 400 | 10 |
| 8 | 400 | 12 |
| 9. | 400 | 14 |

AISI1020 low carbon steel plates had been used having dimensions 300x300x13mm with mild steel copper coated electrode. SAW process was used with three different level of welding current (300,350,400), 28 V and a welding speed of 15 m/h, keeping the same welding conditions for all welds. Fig. no.1 shows the parameter for the welding joint
V- Butt joint angle was made,
Groove angle - 45 degree
Root opening - 2mm
Root face - 2mm.



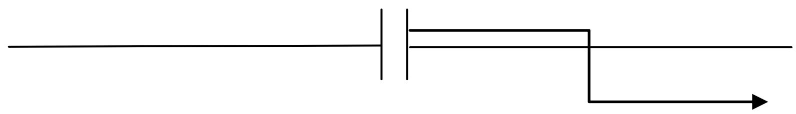


Fig. no. 1 shows the Design of V- Butt joint

Table no.2 shows the chemical composition of base metal, welding electrode, different weld sample and the flux. After welding the welded specimens are cross sectioned for different tests according to the specified sample size. An average of the three readings was taken to determine the hardness, toughness and tensile strength by performing the micro hardness test, Charpy V notch test and tensile test of the materials respectively. The values of hardness, toughness and tensile strength after performing the different tests are shown in the table no. 3.

Table no. 2 chemical compositions

| Elements | C | Si | Mn | Ti | S | Fe |
|---|---|---|---|---|---|---|
| Base plate | 0.21 | 0.0151 | 0.479 | 0.0001 | 0.016 | Rest |
| Electrode | 0.068 | 0.17 | 0.4 | - | - | Rest |
| Weld 10% | 0.232 | 0.016 | 0.4991 | 0.0048 | 0.019 | -- |
| Weld 12% | 0.241 | 0.017 | 0.5056 | 0.0052 | 0.021 | -- |
| Weld 14% | 0.244 | 0.017 | 0.5121 | 0.0067 | 0.018 | -- |
| Flux | $SiO_2 + TiO_2$ 15% | | $Al_2O_3$ + MnO 30% | | CaO + MgO 20% | CaF 35% |

Table no. 3 Recording the response

| Sample No. | Hardness (VHN) | Impact (energy J) | Tensile strength (Mpa) |
|---|---|---|---|
| 1 | 178 | 120 | 395 |
| 2 | 162 | 126 | 386 |
| 3 | 147 | 132 | 378 |
| 4 | 170 | 123 | 391 |
| 5 | 156 | 129 | 383 |
| 6 | 154 | 130 | 382 |
| 7 | 162 | 126 | 387 |
| 8 | 147 | 132 | 379 |
| 9 | 132 | 138 | 371 |

The taguchi technique was used for the analysis of result obtained after testing and to find out the main effect of the process parameters and the percentage contribution of each parameter on the output. The analysis of variance (ANOVA) is performed to evaluate the statistical significance of parameters and their levels. The factors having p-value less than 0.05 are considered as significant. Larger is better option was selected to analysis the result of impact test. To get minimum micro-hardness and tensile strength smaller is better option was selected from Taguchi Design.

**3 RESULTS AND DISCUSSION**

The chemical composition of the weld beads from table no. 3 corresponding to the fluxes 10, 12 and 14% of $TiO_2$. It can be noticed that the amount of Ti increased in weldment with the increase in Ti content in the fluxes. The Si and Mn contents also showed a trend to increase with the increase in the content of these elements in the flux. The C content for the welds increased with the increase in Ti for the fluxes.

### 3.1 MECHANICAL PROPERTIES

Fig. no.2 shows the Vickers hardness, impact (CVN) and tensile properties for the weld metals at room temperature. It can be noticed that the Vickers hardness, as well as the tensile strengths, decreased with an increase in the titanium content. The pearlite percentage in welds seems to be responsible for the higher strength and hardness since the presence of pearlite increases with the decrease in the titanium content in the welds. On the other hand, ductility as well as the impact energy, increased with the titanium content in the welds.

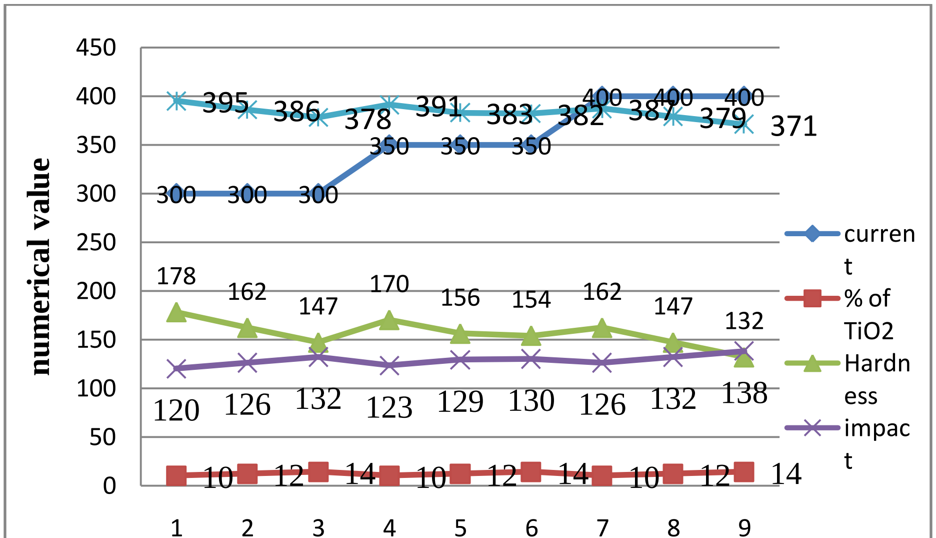



**Fig. no. 2 shows the mechanical properties with different level of current and % composition of TiO2**

Fig. no. 3, 4 and 5 shows the interaction and which one is the more significant factor between the current and the percentage composition of the $TiO_2$ and it can be easily figure out that percentage composition $TiO_2$ and current both are significant factor.

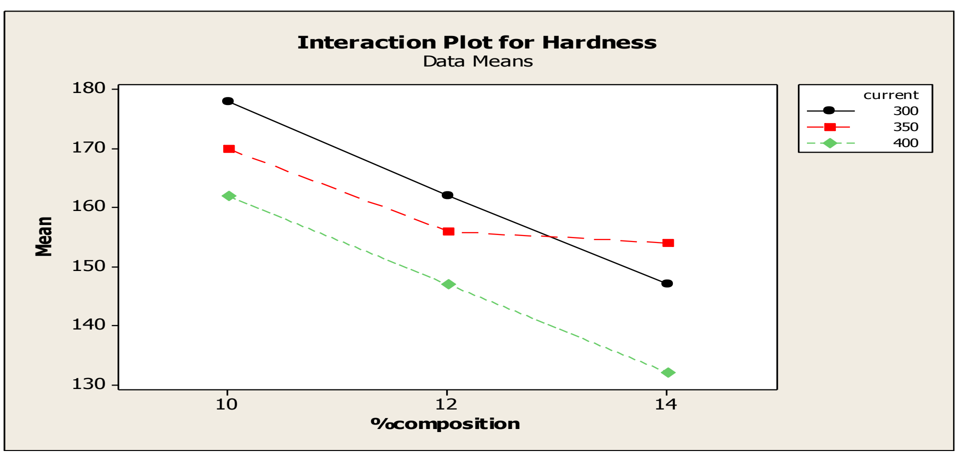



Fig. no. 3 shows the interaction for hardness.

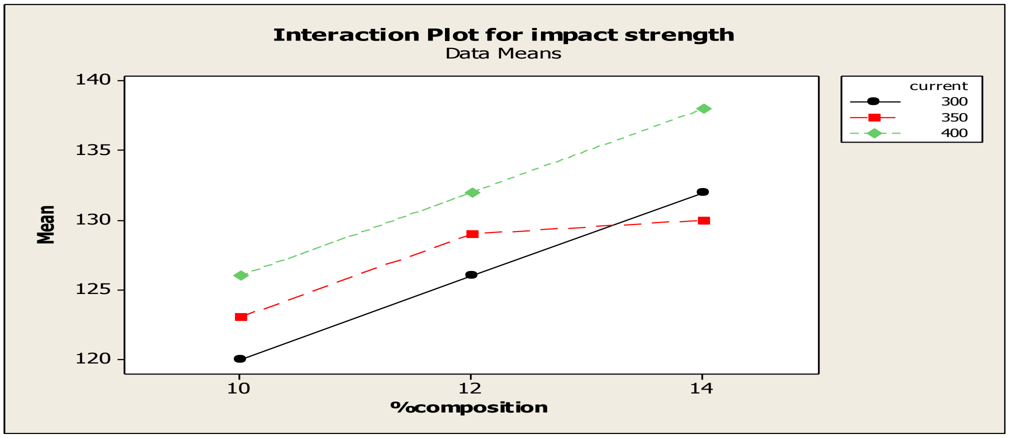



Fig. no. 4 shows the interaction for impact

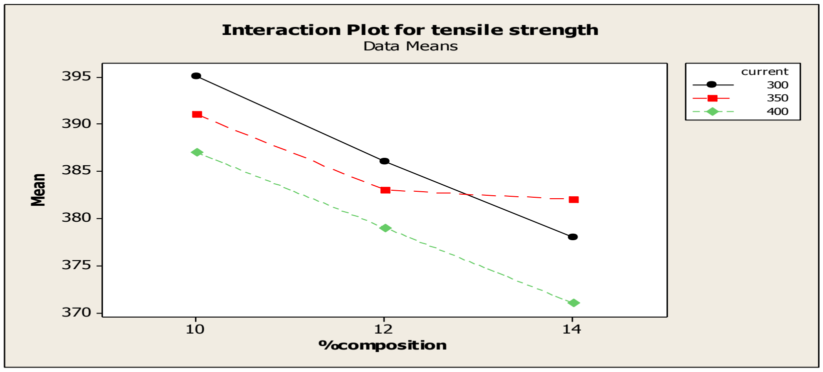
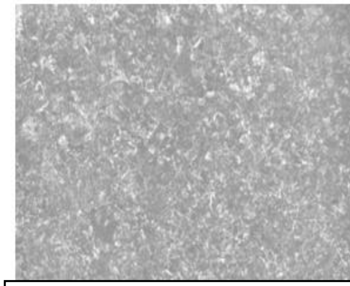



Fig. no. 5 shows the interaction plot for tensile strength

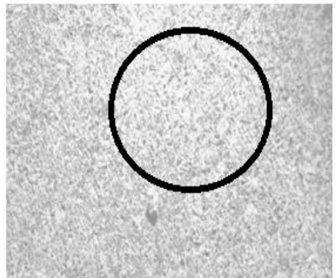
The term interaction, expressed by inserting “x” mark between the two interacting factors, is used to explain a condition in which the influence of one factor upon the result, is dependent on the condition of the other. Two factors A and B are said to interact written as (A x B) when the effect of changes in the level of A, determines the influence of B and vice versa. If there is absolutely no interaction, these lines would be parallel.

### 3.3 MICROSTRUCTURE

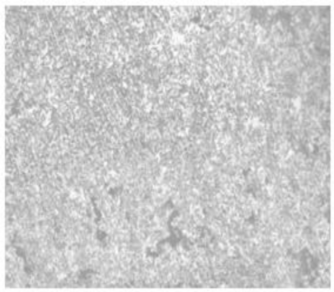
All the welded samples show a microstructure composed of acicular ferrite. It is confirming that Ti containing white inclusions in the sub-arc weld metals plays a very important role for the heterogeneous nucleation of acicular ferrite [1]. Two types of inclusion, bright and dark, were observed in the polished weld surfaces with SEM. The Ti-containing inclusions were bright, as shown in Fig. 6. Microstructure analysis of these inclusions indicated the presence of titanium, as shown in the corresponding X-ray spectrum in Fig. 6. In contrast, the dark inclusions showed almost no concentration of Ti. It has been reported that when the aluminum content of weldmetal is lower than that of titanium, the inclusions are predominantly TiO, and when it is higher the inclusions are mainly $Al_2O_3$ with the titanium often reacting with nitrogen to form TiN [9]. According to microstructure analysis of the bright inclusions, oxygen was detected for this type of inclusion. Thus, they may correspond to titanium oxide. The Ti-containing inclusions were continuously increases with increases the titanium content in weld metal.



Microstructure with 10% $TiO_2$



Microstructure with 14% of $TiO_2$



Microstructure with 12% of $TiO_2$

Fig. no. 6 Black circle indicates that with increase in the $TiO_2$ content, white inclusion in weld metal microstructure increases.

## 5. CONCLUSIONS

Among all the welded specimens maximum (138 J) impact strength is observed in specimen welded with parameters 400 A current at 14 percentage composition of titanium and minimum (120 J) with 300 A current and 10 percentage composition of titanium. The percentage composition of titanium has the most significant effect on impact strengths. It increases the amount of acicular ferrite in the weld with increase in the percentage composition of titanium.

It has been observed that with increase in the percentage composition of titanium increases the white inclusion or ferrite in the weld metal. Ti containing white inclusions in the weld metals plays a very important role for the heterogeneous nucleation of acicular ferrite. The increase in titanium content in fluxes improved the toughness and ductility of the welds, with a slight loss of tensile strength.

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