Study on Effect of Dilution on Grain Size and Mechanical Properties

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ABSTRACT

This study has been conducted to reveal the effect of dilution on grain size and mechanical properties of the welds in SAW in low carbon steel weldments. In this study, the fluxes were designed using binary and ternary phase diagrams and RSM has been used for designing the number of experiments. The fluxes were made by agglomeration technique. This study reveals that the tensile strength of the welds increases with increasing weld dilution and the impact strength reduces with increasing dilution.

Keywords : Submerged arc welding; SAW; dilution; grain size; impact strength.

1.0 INTRODUCTION

The Submerged arc welding process is very old and it was developed in 1920s in USA. In recent years, fully automatic and semi-automatic SAW equipment have resulted in an increase in welding speed and their use has made possible to obtain high quality joints. In SAW, the electrode is fed mechanically through an electrical contacting nozzle or collet. A welding current passes through the collet to the electrode and the arc is maintained between the base metal and electrode. The electrode is melted by taking the heat from the arc and by this heat the parent metal and the flux is also melted. In this welding process the arc is protected by the molten slag and unused flux. This welding process is used at very high current as it is used for joining the thick plated. The current density is 5-6 times higher than that of shielded metal arc welding (SMAW). Due to high current, the melting rate of the electrode and speed of the welding is much higher than that of SMAW process. The electrodes used for SAW are either bare or are copper coated to prevent them from corrosion. The coating also increases the electrical conductivity of the electrode wire. For welding of various types of steels various combinations of electrodes and fluxes are in use.

SAW is widely used because of its inherent quality of good finish, high deposition rate, double protection from the atmospheric contamination and easy control on process variables [1]. In SAW, the arc remains hidden in the flux so it is not visible to the operator. So, it is difficult to guide the arc. In this process as the arc is double shielded from the atmospheric contamination, there is no need of applying any shielding gas. As the flux is used in large quantity in this welding so a hopper is used for this purpose and this hopper travels with the torch. SAW is also calles as versatile type welding process because it can take a variety of current and various thickness of metals can be welded. The usual current used in SAW may be up to 2000 A [2]. The properties of the weld are decided by the chemical composition of the welds. The chemical composition is decided by the welding process parameters, flux composition, dilution reactins and slag metal reactions [3]. Both AC and DC current can be used. The welds made by the SAW process have high strength and ductility with low hydrogen and nitrogen content. This welding process is used for low alloy steels, mild steels, low carbon steels as well as nickel based alloys, stainless steels and other non-ferrous metals.

1.1 SAW Fluxes and Function of Fluxes

Fluxes are the chemical substances that are used as a cleaning agent in welding. The SAW fluxes contain lime, silica, manganese oxide, calcium fluoride and other compounds. In SAW as the weld pool is being submerged in the molten bath of the flux so, it is protected from the atmospheric contamination. In the liquid state, the flux becomes conductive and acts as a conductor between the electrode and work piece. Fluxes can be categorized depending upon the method of manufacture, the extent to which they can affect the alloy content of the weld deposit and the effect on weld deposit properties.

For formulation of fluxes, it is essential to understand their behavior during welding. The functions of fluxes may be classified as primary and auxiliary. The primary functions of the fluxes are [4, 5].

a) To protect the weld pool from the atmospheric contamination by covering the metal with molten slag at the top of the bead.

b) To get a weld pool of desired or modified chemical composition.

1.2 Weld Dilution

It is defined as the ratio of the cross sectional area of the weld metal below the original surface of the base metal to the total area of the weld metal. It is also defined as the ratio of

$$\frac{A_P}{A_P + A_R} \text{ where}$$

where, A_P is area of penetration and A_R is area of reinforcement. The dilution of the weld also affects the gain or loss of the elements like Mn, Si and others. It also affects bead geometry and shape relationship of the weldments. Control of dilution may be important in joining dissimilar materials. In cladding if the corrosion resistance of he filler is large and the corrosion resistance of base metal is low, low dilution is desired [6]. The dilution affects the composition of the welds and as the dilution is reduced the composition of the weld becomes almost similar to the composition of filler. The dilution of the welds also helps in removing the undesirable phase formation in the welds. Chandel [7] derived the equations for the dilution of welds in terms of welding process parameters in SAW. The results were close to the experimental values. Hari Om and Sumil Pandey [8] developed the equation for weld dilution in terms of wire feed rate, open circuit voltage, welding speed and polarity. The developed model wads tested for its significance.

2.0 EXPERIMENTAL PROCEDURE

The fluxes were made by agglomeration technique. All the ingredients of flux s were mixed in a container and potassium silicate was added as binder. After addition of binder, the green pellets were made. These pellets were crushed into smaller size balls and thus the granular flux was made. The es were dried for almost 24 hours and then were baked in a furnace maintained at 400°C for 5 to 6 hours. The agglomerated fluxes were contained in air tight jars. For this study 20 bead on plate, welds were made from the designed and made twenty fluxes. The welding parameters were decided on the basis of a pilot experiment and these were made as constant. The SAW welding parameters were decided by making trial runs. The welding parameters such as voltage, current, travel speed, nozzle to plate distance and wire feed rate were decided by laying beads on plates with varying amount of voltage, current and travel speed. The major criteria for optimum weld parameters were good bead appearance, slag detachability and bead geometry.

1. Twenty fluxes were designed by using RSM and central composite design. This type of design is supposed to be very compact and effective. The **Table 1** contains the design matrix in the coded form. The additives were considered as factors and are shown in **Table 2. Table 3** and **Table 4** contains the wire composition and used welding process parameters. These welding parameters were selected according to the pilot study conducted before the experimentation.
2. The ratio of base fluxes CaO, SiO_2 and Al_2O_3 was decided by considering the melting point of the steel as 1450°C and based on ternary phase diagrams. This ratio was calculated as 7:10:2 as per binary and ternary phase diagrams. The additives CaF_2, FeMn and NiO were added in the range of (2 – 8)% as the general practice is to keep all the additives below 30%.
3. The fluxes were prepared by agglomeration technique.
4. Beads on plate welds were made on 18 mm thick MS plates as this is widely used steel in fabrication work.
5. The area of penetration and reinforcement were measured by calliper pro soft ware.
6. The measured responses are given in **Table 5.** The prepared samples for the study of dilution are given in **Fig. 1(a)** and **1(b)**. **Fig. 1(c)** shows the bead geometry.

Table 1 : Design matrix used

No. of Experiment	CAF_2 wt % A	FeMn wt % B	NiO wt % C
1	+1	-1	-1
2	0	+1	0
3	+1	-1	+1
4	-1	-1	-1
5	0	0	0
6	0	0	0
7	+1	+1	+1
8	0	0	0
9	0	-1	0
10	+1	0	0
11	0	0	+1
12	-1	-1	+1
13	0	0	0
14	0	0	0
15	+1	+1	-1
16	-1	0	0
17	0	0	0
18	0	0	-1
19	-1	+1	+1
20	-1	+1	-1

Table 2 : Levels of input factors

Factors	Additives	Lower Level %	Middle Level %	High Level %
A	CaF_2	2	5	8
B	FeMn	2	5	8
C	NiO	2	5	8

Table 3 : Composition of wire and base plate.

Composition	Carbon %	Silicon %	Manganese %	Sulphur %	Phosphorus %	Nickel %
Base Plate	0.03	0.07	0.34	0.017	0.022	-
Wire	0.11	0.09	0.45	0.021	0.021	-

Table 4 : Welding parameters used

S.No.	Voltage	Current	Travel speed
1	30 V	475 A	20 cm/min.

Fig. 1(a) : Bead on plate

Fig. 1(b) : The polished samples

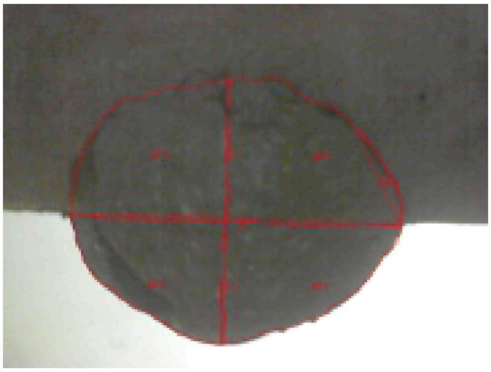

Fig.1(c) : Showing bead geometry

Table 5 : The measured parameters

Flux No.	CAF_2 (%)	FeMn (%)	NIO (%)	Dilution $\frac{A_P}{A_P + A_R}$	AP (mm^2)	Ar (mm^2)	I.S. Joules	UTS MPa	BI
1	8	2	2	0.387	149.51	236.24	58	270	0.839
2	5	8	5	0.179	91.68	419.79	55	318	0.847
3	8	2	8	0.454	186.48	224.58	64	320.2	0.973
4	2	2	2	0.366	171.42	296.54	20	189.8	0.710
5	5	5	5	0.467	168.04	191.6	12	300	0.840
6	5	5	5	0.281	131.46	335.72	14	320	0.840
7	8	8	8	0.257	121.48	351.6	56	190.7	1.00
8	5	5	5	0.555	229.77	184.17	23	284.7	0.840
9	5	2	5	0.399	185.91	280.16	60	280.1	0.832
10	8	5	5	0.388	138.87	218.66	46	292.6	0.910
11	5	5	8	0.251	111.31	331.68	12	240	0.910
12	2	2	8	0.351	192.85	357.52	14	175.7	0.832
13	5	5	5	0.473	161.01	179.28	14	330.9	0.840
14	5	5	5	0.411	191.7	274.27	40	326.5	0.840
15	8	8	2	0.338	117.11	229.13	56	351	0.847
16	2	5	5	0.398	211.05	319.96	36	152.3	0.773
17	5	5	5	0.482	208.88	224.71	14	319.5	0.840
18	5	5	2	0.405	166.82	245.16	12	351	0.773
19	2	8	8	0.454	188.83	227.53	58	128.8	0.847
20	2	8	2	0.566	312.27	239.34	60	319.5	0.714

3.0 CORRELATIONS OF WELD DILUTION WITH GRAIN SIZE AND MECHANICAL PROPERTIES

The **Fig. 2** shows that the grain size is reduced with increasing dilution of the weld. From this it can be interpreted that grain size is reduced with increasing dilution of the weld. This may be attributed to the melting of base metal and wire. This study reveals that the tensile strength of the weld increases with increase of weld dilution. It is shown in the **Fig. 3**. High dilution welds exhibit higher tensile strength in compared to low dilution welds. It is in agreement with the results obtained by [9]. This variation of tensile strength may be attributed to the change in microstructure of the weld or the change in grain size. The impact strength does not change much with increase in weld dilution. This has been given in the **Fig. 4.** This may be attributed to the change in grain size with increase of dilution of the welds. Figure 5 shows that the weld dilution is reduced with increasing basicity index of the flux.

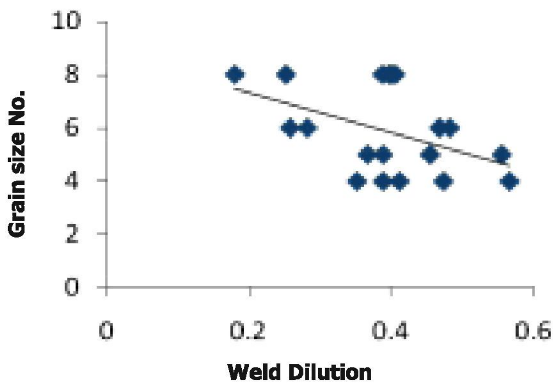

Fig. 2 : Correlation of weld dilution with grain size.

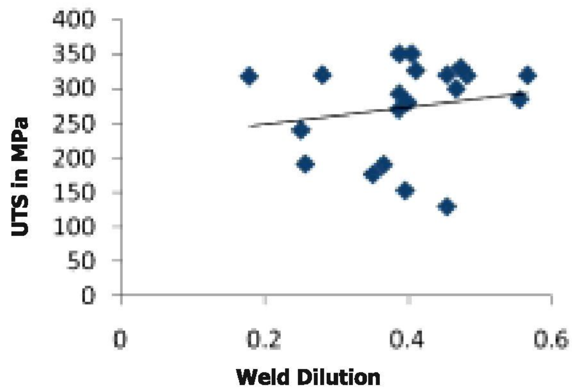

Fig. 3 : Effect of weld dilution with UTS.

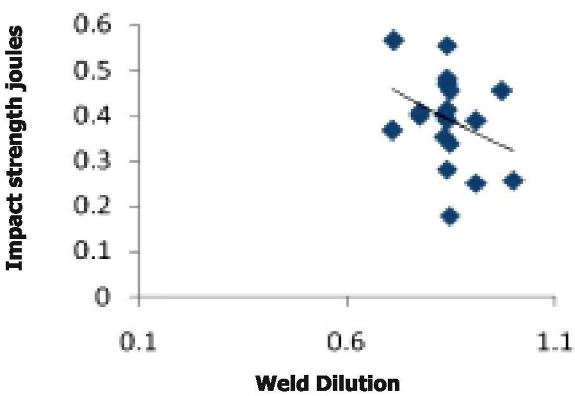

Fig. 4 : Effect of weld dilution on impact strength

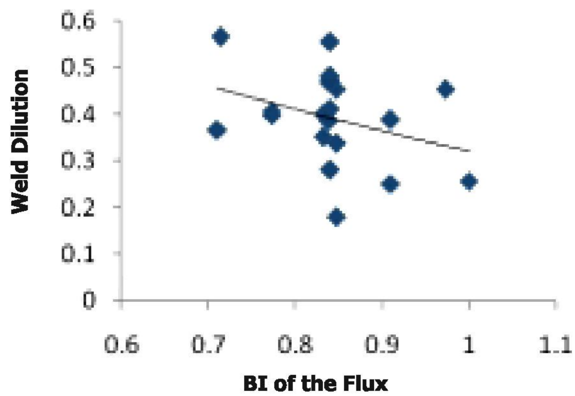

Fig. 5 : Effect of BI on weld dilution.

CONCLUSIONS

1. The grain size number is reduced with increasing dilution.
2. The ultimate tensile strength increases while the impact strength is reduced with increasing dilution.
3. The basicity index has a definite effect on weld dilution. It can be revealed from this study that weld dilution is reduced with increasing BI of the flux.

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