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Characterization of Agglomerated Fluxes

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Abstract : Submerged arc welding is a fusion welding process in which the welding arc is submerged under the granular welding flux. Our purpose is to design and develop agglomerated fluxes and to study the effect of voltage and trolley speed on the hardness, toughness and metallurgical properties of the welded joint. The 22 factorial design matrix is chosen to optimize the effects and the values of the welding parameters in order to obtain best properties in the welded joint. The hardness and toughness tests help to understand the effect of the voltage and trolley speed variations on the properties of welded joints. The study of microstructures using a metallurgical microscope is helpful in understanding the results of the experiments. This paper gives a detailed explanation of how we went about our experimentation and studies.

Keywords: Submerged arc welding (S.A.W), Agglomerated fluxes, Characterization

I. Introduction

Flux constitutes half of the total welding cost in submerged arc welding. The primary function of fluxes is:

1. It should provide the required arc stability.
2. It should have a known current carrying capacity.
3. It should give the desired welding speed.
4. It should give the required penetration.
5. It should control the bead shape and size.
6. It should have good rust tolerance.
7. It should have good detachability after solidifying.

II. LITERATURE SURVEY

In the course of our research, various research papers, journals, manuals and welding handbooks were studied and surveyed by us. The basic concept was prepared after studying a number of research papers on submerged arc welding ([11],[14]-[16]) and other processes from the American Welding Society ([12]-[14]) website. The area of study was mainly the design and development of agglomerated fluxes, parameters affecting the physical properties of the SAW welded joints and the ways in which the effect of various parameters can be controlled and analyzed. The topics studied were various testing techniques i.e. Charpy and other toughness tests, hardness tests and metallurgical determination of heat flow in welding [17]. The design of matrix and their formation, statistical analysis on the basis of test results, response surface formation, and the 2^2 design matrix was selected for the analysis on submerged arc welding process after studying the various methods from the 'Design and Analysis of Experiments' book by Douglas C Montgomery [7]. Hardness testing and the various steps, indenter types used were studied from the 'Foundations of Material Science and Engineering (4th ed.)' book, written by William Smith, Hashemi and Javad [8]. Based on this study the hardness test on Rockwell scale B was chosen for the mild steel specimens. Detailed study of the Rockwell hardness test and the parameters were carried out [5][6].

III. METHODOLOGY

A. A. Design and Fabrication of Fluxes

The four fluxes were selected with the following composition:

Table 1
Composition Of Different Fluxes

Flux No.	CaO	Al_2O_3	TiO_2	MgO	CaF_2	NiO_2
1	1050g	1050g	300g	200g	200g	200g
2	900g	900g	600g	200g	200g	200g
3	750g	750g	900g	200g	200g	200g
4	600g	600g	1200g	200g	200g	200g

Alloying elements and additives were added and mixed mechanically in a ball mill for 15 min so that the ingredients could form a homogenous mixture. 20% solution of ammonium silicate binder was added to wet the dry mix powder and mixed for 15 min and passed through a 10 mesh screen to form small pellets. These pellets were mixed and dried separately in air for 24 hours and then baked at 500 ˚C for 3 hours in a furnace. The baked mass was then crushed and sieved to the required grain size.

B. Selection of Base Metal and Electrode Wire

Low alloy steel bars were chosen as the base material on which welding was to be performed. The selection was based on the availability of material, machining facilities and heat treatment facilities. The welding electrode was a low alloy steel wire electrode, coated with copper to increase its current carrying capacity. The copper layer also prevents its corrosion. The electrode was chosen as it was similar to the base metal in composition and was able to fill the weld zone groove in three passes of the weld. The weld electrode was chosen to be of 3.15mm in diameter.

C. Selection of Welding Parameters

The various welding parameters which affect the properties of welded parts and the weld quality in a welding process are: type of welding process, heat source, voltage rating, heat treatments, type of flux and shielding gasses used, trolley speed, electrode and workpiece material.

The two factors whose effect on the submerged arc welded specimen was studied were:

- Voltage
- Trolley speed

The above 2 factors are to be varied by two levels. The two levels of trolley speed were: 0.25m/min and 0.30 m/min

The two levels for voltage were: 28 volts and 32 volts.

Table 2
Factors And Their Two Level Values

Factors	Low level (0)	High level (1)
Voltage	28 V	32 V
SPEED	0.25 m/min	0.30 m/min

D. Metal Cutting

The mild steel bars were cut into a standard length of 150mm. This operation was performed using a power hacksaw. The blade material was made up of high speed steel- HSS. After this operation, the standard 150mm plates were machined on a vertical milling machine in order to produce a single V-Butt weld groove. The groove angle was 45 degrees with a root face of 1.5mm and a root gap of 2mm. The root gap was provided to increase the depth of penetration. The cutter used was an end mill of 8 mm diameter, made of High Speed Steel. Each pair of plates were numbered by a punching tool. A total of 16 pairs of plates, in butt joint form, were prepared for welding on the SAW machine.

E. Welding of Plates on SAW Machine

Two plates of each pair were first tacked using GMAW in order to form the weld cavity of V-shaped butt joint with a root gap of 2 mm. The welding flux was filled in the hopper of the SAW machine. The voltage and trolley speed levels were used accordance to the design matrix. The upper voltage was 32 V and the lower level was at 28 V during the welding process. The flux was preheated at 500 ˚C. A constant voltage power source was used in order to perform the welding on the SAW machine.

The readings of voltage, current and trolley speed were noted down and this data was later used in the analysis of the process parameters. The unused welding flux was re-collected and was reused in the next welding run. The plates were left to cool naturally and a safe distance was maintained from them to avoid any damage. Consequently, the slag layer was removed and weld bead was brushed in order to clean remaining slag.

F. Specimen Preparation for Testing

The welded metal plates were cut along the transverse axis to prepare the charpy impact strength test specimens. The metal cutting was performed using surface grinders. A V-notch was cut on the bead surface of each part to be used for the charpy test ([9],[10]). The burrs were removed by filing operation and rough grinding, where required. For the micro structural study, test specimens were cut from the welded plates using an abrasive cutter. Following this, the cross section of the bead on these specimens was finely ground on a rough grinder. Extra surface finishing was achieved by grinding them on a fine grinder. The finished surfaces were then ground by applying a paste of abrasive diamond powder. The finely finished surfaces were then used to examine the microstructure of the weld bead by using a metallurgical microscope.

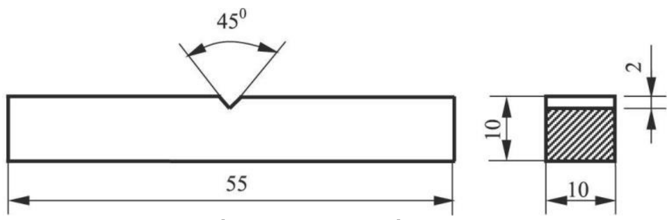

Fig.1 Charpy impact strength test specimen

G. Hardness and Impact Testing

A total of 16 specimens were prepared and tested using the Charpy impact test. The results were noted down and were used in the analysis of the effect of the welding parameters on the toughness of the welded joint. The impact energy according to ASTM is expressed in J/m or ft-lb/in.

The welded plates were tested on the HRB scale in order to determine their hardness and the readings were noted down. The workpiece was placed on the anvil of the tester and a minor load of 10 kgf was applied in order to compensate the effect of surface roughness on the indentation depth. After this, a major load of 100 kgf was applied in order to make an indentation so that it could be used to find out the required hardness number for the material being tested.

Table 3
The Charpy Impact Strength Test On The Welded Joint Specimen

Specimen No.	Energy used in fracture
1 (flux1,32v,0.25 m/min)	128
2(flux1,28v,0.30 m/min)	136
3(flux1,32v,0.30 m/min)	135
4(flux1,28v,0.25 m/min)	133
5(flux2,32v,0.25 m/min)	140
6(flux2,28v,0.30 m/min)	148
7(flux2,32v,0.30 m/min)	146
8(flux2,28v,0.25 m/min)	144
9(flux3,32v,0.25 m/min)	148
10(flux3,28v,0.30 m/min)	158
11(flux3,32v,0.30 m/min)	156
12(flux3,28v,0.25 m/min)	150
13(flux4,32v,0.25 m/min)	168
14(flux4,28v,0.30 m/min)	176
15(flux4,32v,0.30 m/min)	174
16(flux4,28v,0.25 m/min)	170

Table 4
Hardness Test On Welded Joint Specimen

Specimen no.	Hardness (HRB)
1 (flux1,32v,0.25 m/min)	91
2(flux1,28v,0.30 m/min)	96
3(flux1,32v,0.30 m/min)	95
4(flux1,28v,0.25 m/min)	94.5
5(flux2,32v,0.25 m/min)	89
6(flux2,28v,0.30 m/min)	95
7(flux2,32v,0.30 m/min)	95
8(flux2,28v,0.25 m/min)	94
9(flux3,32v,0.25 m/min)	88.5
10(flux3,28v,0.30 m/min)	93
11(flux3,32v,0.30 m/min)	92.5
12(flux3,28v,0.25 m/min)	92
13(flux4,32v,0.25 m/min)	87
14(flux4,28v,0.30 m/min)	92.5
15(flux4,32v,0.30 m/min)	91
16(flux4,28v,0.25 m/min)	90

IV. ANALYSIS

A. Effect of Change of Voltage

The voltage has very dominant effect on the width of the bead in the weldment. Arc voltage also affects dilution. Bead width and dilution in plate welds and square edged butt welds increases as the arc voltage is increased, while the depth of penetration is not affected very much. But the penetration decreases if the joint is open as in our case of a with a small angled single V- butt joint.

The arc voltage controls the arc length as it is directly proportional to the arc length. The arc voltage also affects the flux consumption, metal properties. Increasing the arc voltage increases the arc length so that the weld bead width is increased. The flux consumption also increases but the reinforcement is decreased. Also, the probability of arc blow is increased with the increase in arc voltage. A combination of high arc voltage and low welding speed can produce a mushroom shaped weld bead with solidification cracks at the bead sides [1].

The arc voltage also determines the shape of the fusion zone and weld reinforcement. Higher welding voltage produces wider, flatter and lower depth of penetration compared to low welding voltages. The depth of penetration is maximum at optimum arc voltage [4]. As the voltage increases, the arc length also increases, so does the demand for arc shielding. Higher values of arc voltage produce wider weld beads. Heat input also increases as the arc voltage is increased. The most accurate way to determine arc voltage is to measure the voltage drop between the contact tip and the work piece. This may not be practical for semi-automatic welding. Lower levels of voltage induces welding defects like porosity [3].

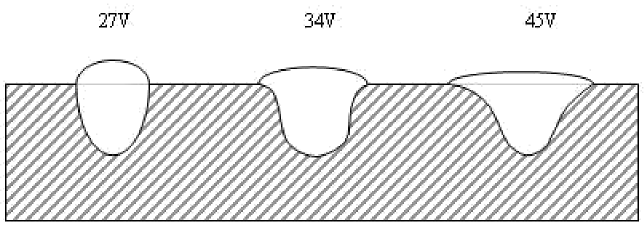

Fig 2: The weld bead shapes at different voltage levels process [2]

B. Effect of Change of Trolley Speed

Increasing trolley speed decreases the weld heat input or vice versa. With an increase in the input energy, grain growth in weld microstructure increases and grain boundaries are reduced in the background. Reduction in grain boundaries locks the movement of dislocations, increases the possibility of dislocation movement as the line defects increase.

On the other hand very high arc voltage and current can increase the chances of defect formation such as burn throughs in the weld which effects the mechanical properties and quality of weld.

When the heat input increases the cooling rate decreases for the deposited weld metal. In the case multiple welds a higher volume fraction of tempered martensite phase [9] is observed. Furthermore, grain coarsening of microstructure in the proximity of the weld zone can also be seen . Preheating before welding decreases cooling rate of the weld which in turn decreases the weld hardness.

C. Arc Stability

The range of welding parameters viz. welding arc voltage, welding travel speed were selected such that the current variation on the analog ammeter was not more than +/- 25 amperes during welding.

D. Slag Detachability and Visual Examination

Test assemblies were visually inspected during and after welding. Slag detachability was poor for the first two passes and was self detaching thereafter.

E. Effect of Variation of Percentage of TiO_2

TiO_2 promotes the formation of acicular ferrite and refines the grains with an increase of ductility and toughness.

F. Weld Bead Geometry

1) Penetration

The decrease in penetration with increase in travel speed can be attributed to fact that an increase in travel speed reduces heat input per unit length causing the reduction in the amount of molten base metal. Hence the penetration decreases.

2) Bead height

The decreasing trend of reinforcement with higher arc voltages can be attributed to the fact that at higher voltage, the arc becomes longer and spreads on a larger surface area resulting in an increase in bead width and decrease in reinforcement.

3) Bead width

The increase in bead width with an increase in arc voltage can be attributed to the fact that voltage increase leads to an increased arc length. Consequently the contact area at parent metal increases thereby distributing the arc heat over a larger area causing an increase in bead width.

TABLE 5: WELD PENETRATION ANALYSIS REPORT OF FLUX 1. VOLTAGE 28V AND SPEED 0.30 M/MIN

	Measure	Type	Actual	Remarks
1	Depth1	Depth	2.77	L1 & U2
2	Thickness1	Thickness	16.00	
3	Penetration1	%Penetration	17.31	
4	Leg3	Length	4.32	U1 & L1

TABLE 6: WELD PENETRATION ANALYSIS REPORT OF FLUX 2. VOLTAGE 28V AND SPEED 0.25 M/MIN

	Measure	Type	Actual	Remarks
1	Depth1	Depth	3.18	L1 & U2
2	Thickness1	Thickness	16.00	
3	Penetration1	%Penetration	19.85	
4	Leg3	Length	5.27	U1 & L1

TABLE 7: WELD PENETRATION ANALYSIS REPORT OF FLUX 3. VOLTAGE 32V AND SPEED 0.25 M/MIN

	Measure	Type	Actual	Remarks
1	Depth1	Depth	3.38	L1 & U2
2	Thickness1	Thickness	16.00	
3	Penetration1	%Penetration	21.11	
4	Leg3	Length	5.20	U1 & L1

TABLE 8: WELD PENETRATION ANALYSIS REPORT OF FLUX 4. VOLTAGE 32V AND SPEED 0.30 M/MIN

	Measure	Type	Actual	Remarks
1	Depth1	Depth	2.98	L1 & U2
2	Thickness1	Thickness	16.00	
3	Penetration1	%Penetration	20.59	
4	Leg3	Length	5.10	U1 & L1

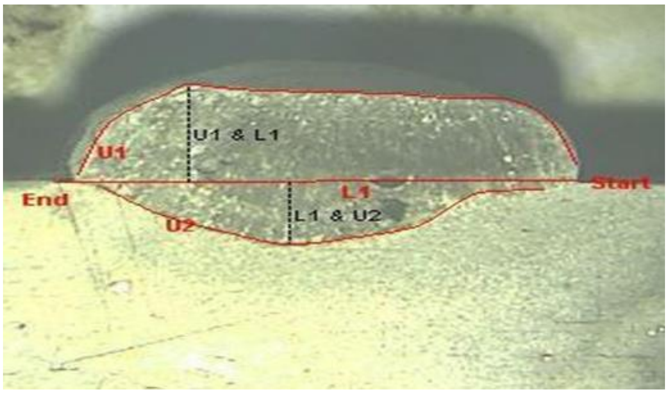

Fig.3 Weld Penetration Analysis of Flux 1. Voltage 28V and Speed 0.30 m/min

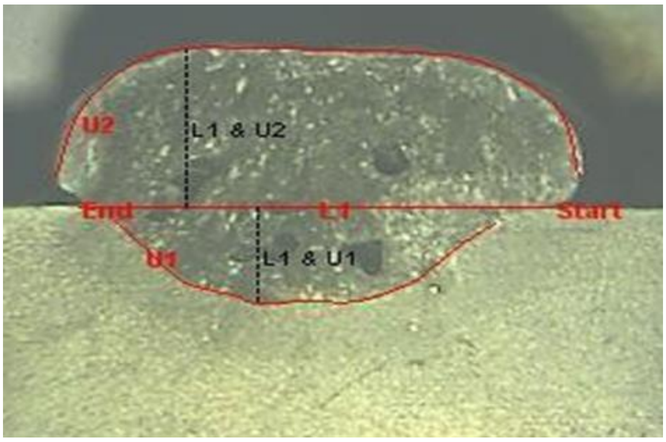

Fig.4 Weld Penetration Analysis of Flux 2. Voltage 28V and Speed 0.25 m/min

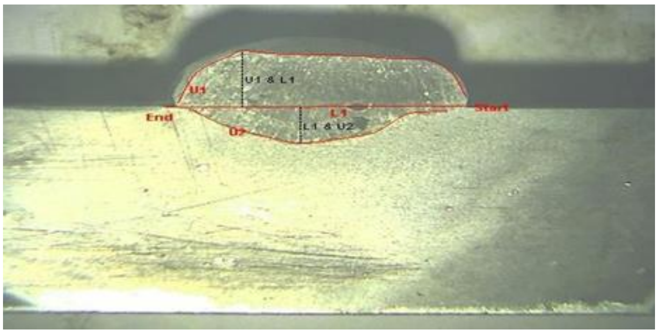

Fig.5 weld penetration analysis of Flux 5. Voltage 32V and Speed 0.25 m/min

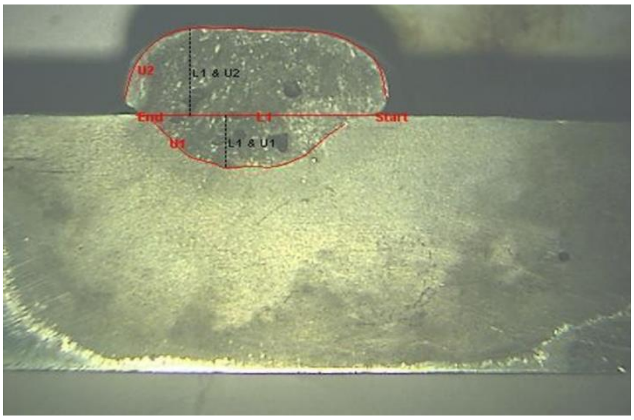

Fig.6 weld penetration analysis of Flux 6. Voltage 32V and Speed 0.32 m/min

V. CONCLUSIONS

A. Rockwell Hardness

The study and analysis of the data obtained during the Rockwell hardness experiments and the computed hardness showed that the hardness of the weldment:-

- Decreases due to decrease in welding speed
- Increases with the decrease in arc voltage
- Slightly decreases with increase in TiO2

B. Impact Strength

The study and analysis of the data obtained during the Charpy impact strength tests and the computed impact strength showed that the impact strength of the weldment:-

- Decreases with decrease in welding speed
- Increases with decrease in arc voltage
- Increases with increase in TiO_2

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