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Development of agglomerated acidic flux for submerged arc welding

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Abstract. A granular flux, which is used in submerged arc welding, plays an important role in deciding the weld metal quality and it may cost up to half of the total welding consumable cost. A significant percentage of the flux gets converted into very fine particles, termed as flux dust, due to transportation and handling. Welding defects like porosity occur if welding is performed without removing these very fine particles from the flux, and if these fine particles are removed by sieving, the cost of welding will be increased significantly. Also if this flux dust is dumped, it creates pollution. The present study has been conducted to investigate the viability of developing an acidic agglomerated flux by utilizing wasted flux dust of the parent commercial acidic flux. The chemical composition and mechanical properties of the all-weld metal, prepared by using the developed acidic flux, were found to be in the same range as that of the weld metal, prepared from parent commercial acidic flux. The radiographic examination of the welded joint, made by developing the flux, was also found to be sound. Therefore the welding cost and pollution can be reduced, without any compromise in weld quality, by utilizing the developed flux, prepared from waste flux dust of the parent flux. Thus the work follows the concept of 'waste to wealth'.

Key words: submerged arc welding, acidic flux, flux dust, tensile strength, impact strength, weld metal.

1. INTRODUCTION

Submerged arc welding (SAW) is one of the most widely used processes for fabrication of thick plates, pipes, pressure vessels, rail tanks, ships, heat exchangers etc. It has become a natural choice in fabrication industries because of its high reliability, smooth finish and high productivity. Parmar [1] stated that it has the capability to weld thicker sections with deep penetration. According to Houldcroft [2] and Brien [3], this process is commercially suitable for welding of low carbon steel, high strength low alloy steel, nickel-base alloys and stainless steel.

A granular material, known as flux, plays a vital role in submerged arc welding. In submerged arc welding, the arc is covered by a flux, which prevents the weld pool from atmospheric contamination. The study of Vishvanath [4] showed that the stability of the arc, mechanical properties of the weld deposit and the quality of the weld are controlled by the flux. It also influences the weld metal physically, chemically and metallurgically. Physically, as demonstrated by Chandel [5], it influences the weld bead geometry and shape relationship, which in turn affects the load-carrying capacity of the weldment. Schwemmer and Williamson [6] have stated that chemically flux affects the weld metal chemistry, which further influences the mechanical properties of the weld metal. Indacochea and Olsen [7] reported how the microstructure affects the properties of the weld metal. It has been reported by Davis and Baily [8] that agglomerated fluxes produce weld deposits of better ductility, alloy transfer efficiency and impact strength as compared with fused fluxes. These fluxes are hygroscopic in nature, therefore baking is essential for good weld metal integrity. Murugan and Gunaraj [9] developed mathematical models to relate the process variables to the weld bead parameters. Datta et al. [10] have performed optimization to determine the amount of waste slag and flux mixture that can be used without sacrificing any negative effect on bead geometry, compared to conventional SAW process, which consumes fresh flux only. So far no work has been performed to develop the flux by using flux dust.

Flux may cost 50% of the total welding consumable cost in submerged arc welding. Due to transportation and handling, approximately 10% to 15% of the flux gets converted into very fine particles termed as flux dust before and after welding. If welding is performed without removing these very fine particles from the flux, the gases generated during welding are not able to escape, thus it may result in welding defects like surface pitting (pocking) and even porosity. On the other hand, if these fine particles are removed by sieving, the cost of welding will be increased significantly. Also if this flux dust is dumped, it will create pollution. The present study has been conducted to investigate the viability of developing acidic agglomerated flux by utilizing wasted flux dust of the parent commercial acidic flux. The chemical composition and mechanical properties of the all-weld metal, prepared by using developed acidic flux, were found to be in the same range as that of the weld metal, prepared from parent commercial acidic flux. The radiographic examination of the welded joint, made by developing the flux, gave also satisfactory results. Therefore the welding cost can be reduced, without any compromise in weld quality, by utilizing the developed flux prepared from waste flux dust of the parent flux. Thus the present work corresponds to the concept of ‘waste to wealth’.

2. EXPERIMENTAL PROCEDURE

In the present study, an agglomerated cost-effective acidic flux was developed by using the flux dust of the parent flux with addition of potassium silicate as binder and aluminium powder as deoxidizer. The two butt-weld joints were made with mild steel as the base plate and backing strip. The solution of potassium silicate binder (900 ml in 550 g of flux dust) was added to the dry mixed powder of the flux dust and aluminium powder (4% of the weight of the flux dust) and it was wet mixed for 10 min and then passed through a 10-mesh screen to form small pallets. Potassium silicate was added as binder for better arc stability. The pallets of the flux were dried in air for 24 h and then baked in the muffle furnace at approximate 700 °C for nearly 3 h. After cooling, these pallets were crushed and subsequently sieved. After sieving, fluxes were kept in air-tight bags and baked again at 300 °C before welding. A constant voltage DC submerged arc welding power source was used for preparing the joints of mild steel plates of the dimensions $275 \times 125 \times 25$ mm^3 using 4 mm diameter wire electrode of grade C (AWS-5.17-80 EH-14). The machine had the provision for controlling the welding wire feed rate and welding speed. DCEP polarity was used throughout the experimentation. The plates were cleaned mechanically and chemically to remove the rust, oil and grease from the fusion faces before welding. The surfaces of the backing plates were also made free from rust and scale. The 12 mm thick backing plates were tack-welded to the base plates. The plates were pre-set so that they remained approximately flat after the welding operation was completed. The inter-pass temperature was maintained in the range of 200–225 °C. The welding conditions, as shown in Table 1, are kept constant throughout the experimentation.

Automelt grade C electrode (AWS-5.17-80EH-14) and M.S backing plate of dimensions $300 \times 100 \times 12$ mm^3 were used. Chemical composition of the mild steel base plate and electrode wire is shown in Table 2. The welding conditions used were 550 A and 38 V and kept constant for all cases. All welds were completed in 12 passes of the weld.

Four-layer high weld pads were made for the acidic-developed agglomerated flux and parent flux following the AWS A5.23-90 standard with the same welding conditions. The chemical compositions of the all-weld metal were evaluated by using spectrometer.

Table 1. Welding parameters

Parameter	Unit	Value
Open Circuit voltage	V	38
Current	A	550
Electrode stick-out	mm	30
Welding speed	cm/min	28

Table 2. Chemical composition of the base plate and electrode wire, %

Element	C	Mn	Si	S	P	Ni	Cr
Base plate	0.21	0.2	0.26	0.028	0.025	0.12	0.43
Electrode wire	0.069	1.86	0.100	0.018	0.023	0	0

The groove welds were laid according to AWS A5.23-90 and welding parameters were maintained as shown in Table 1 using DCEP polarity. The welded plate was cleaned and thereafter the backing plate and crown were removed by machining. The well-cleaned weld plate was radiographed and interpreted according to the standard 9.252 AWS D.1.15-88. The weld plate was subjected to radiographic examination to ascertain weld integrity prior to mechanical testing on radiaogrphy machine Semtinel (Make Global, U.S.A), using gamma rays with 2% sensitivity.

Three all-weld metal tensile test pieces were cut from each welded plate and machined. The tensile tests were carried out on a universal testing machine (Make, FIE-India). Scanning electron microscopy of the fractured surfaces of tensile test specimens was carried out at 10 μm, 20 kV and 1500 X on the microscope (Make JOEL Japan, JSM-6100).

Charpy V notch impact test was carried out to evaluate the toughness of the welded joints at 0 °C. Charpy impact tests were performed on standard notched specimens obtained from the welded joint. The notch was positioned in the centre of the weld and was cut in the face of the test specimens perpendicular to the surface of the plates. Five all-weld metal impact test samples were cut from each welded joint of plates according to the AWS standard A5.23-90. These samples were then fine-polished by the surface grinder. The location of the tensile and impact test specimens in the welded joint assembly is shown in Fig. 1.

Among the five values of the impact strength, the lowest and the highest values were discarded and the average of the three values was taken for the evaluations of the impact strength of the groove welds. The charpy impact tests results, obtained from the weld metal, showed rather good repeatability. The same procedure was applied to the developed flux and commercially available parent flux to investigate the compatibility of the developed flux with the commercial flux.

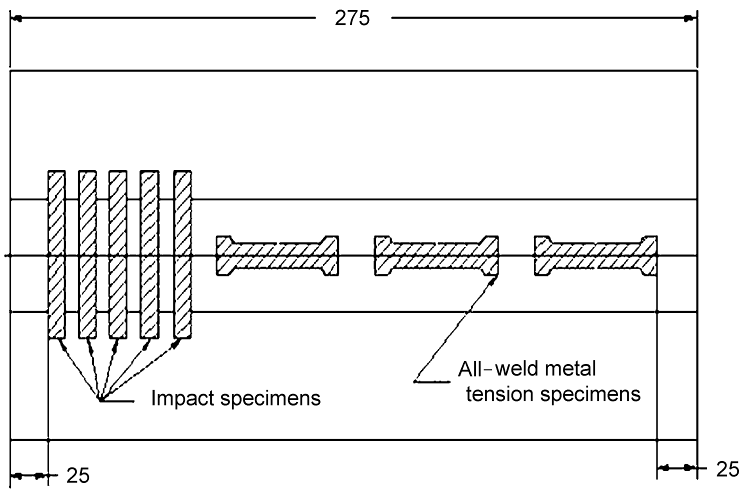

Fig. 1. Location of tensile and impact test specimens on the welded joint assembly.

3. RESULTS AND DISCUSSION

The flux behaviour of the developed acidic fluxes was found to be satisfactory. The bead surface appearance was observed to be excellent and free from any visual defects and is comparable with that of the parent commercial flux. The slag was easily detachable from the welded joint made from the developed flux. As shown in Table 3, the compositions of the all-weld metal of the developed and parent flux are found to be in the same range. However, manganese content of the weld metal, laid by using the developed flux, is slightly lower than the weld metal, laid by using the parent flux. The silicon content of the weld metal, laid by using the developed flux, is higher than the weld metal, laid by using the parent flux.

The carbon equivalent (CEV) was computed from the following equation [[11]]:

$$CEV = C + Mn/6 + Si/24 + Ni/40 + Cr/5 + Mo/4 + V/4,$$

where C, Mn, Si, Ni, Cr, Mo and V represent the carbon, manganese, silicon, nickel, chromium molybdenum and vanadium content in percentage, respectively. Additional potassium silicate binder, which was added for agglomeration of the flux dust, contains silicon dioxide. The silicon dioxide dissociates into oxygen and silicon due to heat during welding. It causes the additional amount of oxygen and silicon content in the weld pool. A study of Lau et al. [[12]] has shown that the additional amount of oxygen results in oxidation of manganese and hence in smaller manganese content in the weld metal laid by using the developed flux as compared to the weld metal laid by using the parent flux. The additional amount of silicon results in the increase of the silicon content and hence the higher silicon content in the weld metal laid by using the developed flux as compared to the weld metal laid by using the parent flux. The radiographs of the welded joint, which were prepared using developed fluxes, were found to be acceptable as per 9.252 of AWS D.1.15-88 radiographic standard of dynamic loading. The average values of the tensile properties, yield strength, ultimate strength, elongation percentage, area reduction percentage and average impact strength/fracture energy of the developed flux as well as of the parent flux are shown in Tables 4 and 5, respectively. The tensile strength and average impact strength of the all-weld metal, obtained by using the developed and parent flux, are reported to be in the same range. However, the tensile strength and impact strength of the all-weld metal, laid by using the parent flux, are slightly higher than the tensile strength and fracture energy of the all-weld metal, laid by using the developed flux. It is attributed to slightly higher CEV of the all-weld metal, laid by using parent flux than that of CEV of the all-weld metal, using the developed flux.

Table 3. Chemical composition of all-weld metal, laid by developed and parent acidic fluxes, %

Element	C	Mn	Si	S	P	Ni	Cr	CEV
Developed flux	0.051	1.52	0.52	0.016	0.017	0.0142	0.048	0.03391
Parent flux	0.058	1.6	0.49	0.018	0.018	0	0.08	0.3610

Table 4. Tensile strength of all-weld metals, laid by using developed and parent acidic fluxes

Flux	Yield strength, N/mm^2	Tensile strength, N/mm^2	Elongation, %	Area reduction, %
Developed flux	500	617	29	65
Parent flux	510	625	25	52

Table 5. Fracture energy of all-weld metals, laid by using developed and parent acidic fluxes

Flux	Fracture energy by different observations, J					
	1	2	3	4	5	Average
Developed flux	70	80	65	68	71	69.96
Parent flux	75	74	98	73	72	74

(a) (b)

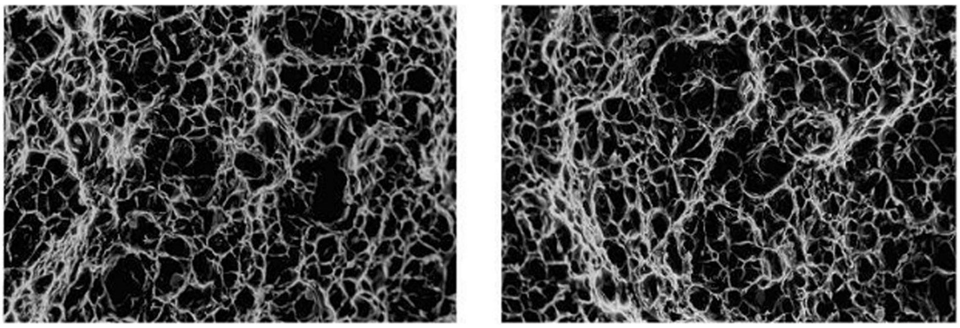

Fig. 2. SEM image (carried out at 10 μm, 20 kV) of tensile fractured surface of weld laid by parent acidic flux (a) and by developed acidic flux (b).

Figure 2 shows the scanning electron micrographs of the fractured tensile test specimens of the weld, laid out with the same parameters, using the developed as well as the parent acidic flux. The micrographs of both specimens show the ductile mode of fracture.

4. CONCLUSIONS

1. The bead surface appearance was observed to be excellent and free from any visual defects and it is comparable with the parent commercial flux.
2. The flux behaviour of the developed acidic flux was found to be satisfactory.
3. The welded joint, prepared by using the developed acidic flux, was found to be radiographically sound.
4. The chemical composition of the all-weld metal, by using the developed flux, is comparable with the all-weld metal, laid by using the respective parent acidic flux.

5. The yield strength, tensile strength and fracture energy of the all-weld metal, laid by using the parent fluxes, are slightly higher than those of the all-weld metal, laid by using the developed flux.
6. Therefore the flux dust can be reused after developing as agglomerated acidic flux without compromising with the quality.

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Aglomereeritud happelise räbusti väljatöötamine kaarkeevituse jaoks

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Räbustis kaarkeevitusel kasutatav granuleeritud räbu on tähtis keevise kvaliteedi seisukohalt, moodustades kuni poole keevismaterjalide hinnast. Märkimisväärne osa räbustist muutub transpordil ja töötlemisel väga peeneks tolmuks. Keevitusdefektid, nagu poorsus, ilmnevad keevises eelkõige väga peene räbu fraktsiooni tõttu, mille eemaldamine sõelumise teel tõstab keevise maksumust. Samas saastab räbutolm keskkonda. Käesolev uurimus on suunatud aglomereeritud happelise räbusti väljatöötamisele, kasutades tööstuslikku jäätmeräbustitolmu. Uuriti uue räbustiga saadud keevismetalli keemilist koostist ja mehaanilisi omadusi ning selgus, et need olid kaubanduslike räbustite kasutamisel saadud keevismetalli omadustega võrreldes samad. Uue räbustiga saadud keeviste röntgenuuringud näitasid keeviste head kvaliteeti. Seega väheneb keevituse maksumus ja keskkonnasaaste.