# Utilization of Slag as a useful flux in submerged Arc Welding

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## ABSTRACT

Slag generated during submerged arc welding is normally thrown away as a waste. This poses the problem of storage, disposal, environmental pollution and needs landfill space apart from exhaust of non-renewable resources. Reusing of slag will not only solve these problems but also be economical. In the present work an attempt has been made to recycle the submerged arc welding slag as a useful flux in the same submerged arc process. Fused slag was processed by replenishing it with suitable alloying elements /deoxidizers, and by agglomeration. This replenished slag is referred to as recycled slag. Recycled slag in combination with EL-8 filler wire was used for welding. The properties of weld metal deposited with recycled slag were evaluated. The mechanical properties were satisfactory and fulfill AWS (American Welding Society) requirements. The chemical composition of weld metal was within the acceptance range of AWS. The test plates cleared the radiographic test. Cost analysis indicates that it is economically viable to use the recycled slag.

## INTRODUCTION

Since the development of the submerged arc welding (SAW) process there have been attempts by technologists and researchers to increase its productivity and to decrease the welding cost. Flux contributes a major part towards welding cost in submerged arc welding. Flux is converted into slag during welding which is a waste now. About 2500 tonnes of flux was consumed in India alone in year of 1982 (Visvanath 1982) which has risen to 10000 tonnes in the year of 2006 (Honavar, 2006). Such a large quantity of flux, after welding, becomes slag waste and has to be disposed-of.

Land-fill space is required to dump the slag waste. It is non bio-degradable and will not decay with time. Being brittle and glassy material it cannot be used as a filling material in building construction. Disposal cost will increase apart from environment pollution. Non renewable resources may get exhausted due to continuous mining. It is not possible to stop the generation of slag because it is a by-product of the process but slag can be reused as a flux in the same submerged arc process. Recycling of slag will not only overcome these problems, but also save non-renewable resources. Furthermore, the slag can be processed according to one's requirements i.e. for hard facing applications. Recycling may be economical compared with fresh purchased flux.

## LITERATURE SURVEY

The first attempt of recycling the slag was made by Alfred Beck in 1959 (Harbert's web site). He used a closed loop recycling process and started practicing this in 1963. However, the response from industry was very poor, because of stringent AWS and ASME codes, combined with the reluctance of fabricators to use a recycled product. By 1996 AWS and ASME codes were amended to permit the use of recycled flux. The Paton Electric Welding Institute of The National Academy of Sciences in Ukraine also reported the development of a technology for recycling of slag. TITUS Steel Company (TITUS steel's website) has been reclaiming slag for fabricators in the USA. Beck and Jackson (1996) found that if it is processed properly and according to code requirements, recycled slag can be reliably used as an alternative to fresh flux. They further claimed a saving up to 50% of the total cost of purchased flux by recycling the slag. Devis and Baily (1982) found that fused calcium silicate flux, which has fully reacted during manufacturing, produces no change on reheating. Such a flux contains no readily oxidiszable material and can be recycled. In another investigation Pandey et al. (2005) found that acceptable bead geometry can be achieved using recycled slag.

Some researchers have also explored the possibility of using a mixture of fresh flux and slag. Experiments carried-out by Livshits et al. (1960) have shown the possibilities of using pulverized slag crust mixed with iron filings for hard-facing applications. They further claimed that this process is efficient and economical. Moi et al. (2001) and Pal et al. (2001) found that of mixture containing up to 20% fused slag in fresh flux produces no change in weld metal chemistry. Milichenko et al. (1963) have proposed a new method for preparing alloying fluxes for hard facing by enriching the flux with ferro-alloys.

From the available literature it was founds that slag is being recycled by some companies but they are professional recyclers and have not disclosed the methodology, may be due to commercial reasons. So it was planned to process the slag to act as a flux in the same submerged arc welding process. Slag was processed and termed as recycled slag. Recycled slag was used as a flux in these investigations. The chemical composition, mechanical properties and metallurgical investigations on weld metal were carried out. The cost of processed slag was calculated and compared with the cost of equivalent fresh flux available in the market.

## PROCESSING OF SLAG FOR RECYCLING

The plan of investigation has been shown in Fig. 1. The various steps for processing the slag are;

- ☐ Welding with fresh flux
- ☐ Welding with pure crushed slag
- ☐ Comparison of weld metal chemistry
- ☐ Modification of slag

## WELDING WITH FRESH FLUX

A weld pad as shown in Fig. 2 was prepared with original fresh flux F7AZ in combination with EL-8 filler wire. The welding parameters and other conditions were in accordance with ASME-SFA 5.17. The chemical composition of weld metal was carried out with a spectrometer and is recoded in Table 1.

## WELDING WITH PURE SLAG

Slag waste was crushed and meshed to the granular size of the original flux. A weld pad similar to one explained above, under similar welding conditions was prepared using crushed slag with EL-8 wire in accordance with ASME SFA 5.17 for chemical analysis of weld metal. Chemical composition of weld metal as revealed by spectrometer is shown in Table 1.

## COMPARISON OF CHEMICAL COMPOSITION

The Chemical composition of weld metal deposited with fresh flux and pure crushed slag was critically analyzed in relation to in order to modify the slag.

## MODIFICATION OF SLAG

Based on the information (loss or gain of elements) provided by above experiments, slag was modified. Under these modifications slag was crushed and subsequently milled in ball mill to convert into powder form. Alloying elements/deoxidizers were added and mixed mechanically in a ball mill for 30 minutes so that the ingredients could form a homogeneous mixture. 20% solution of potassium silicate binder was added to wet the dry mixed powder, wet mixed for 15 minutes 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 were sintered at 850 $^{0}$C for two hours in a muffle furnace. Sintered mass was then crushed and sieved to the required grain size and termed as "recycled slag". Recycled slag in combination with EL-8 filler wire was used for preparation of chemical pad. Chemical composition of weld pad was checked with a spectrometer and compared with AWS requirements. These modifications were repeated until acceptable chemistry of weld metal was achieved. Trial runs along with corresponding chemical composition of weld metal have been shown in Table 2. Trial number 5 as indicated in Table 2 gave acceptable composition of weld metal along with good bead appearance and hence selected for further investigations.

## WELD QUALIFICATION TESTS

Once acceptable chemical composition of weld metal was achieved with recycled slag, following tests were performed to ascertain its performance

- ☐ Test plates for radiography and mechanical testing
- ☐ Metallurgical investigations
- ☐ Cost analysis

## ALL WELD TEST ASSEMBLY

Three test assemblies each with pure slag, fresh flux and recycled slag respectively were prepared. The dimensions of test assembly are shown in Fig. 3. Welding parameters and other conditions for these test assemblies were as dictated by ASME SFA 5.17. Test assemblies were subjected to visual inspection, dye-penetration test and radio-graphy before cutting for specimens meant for mechanical testing. Tensile and impact specimens were machined and tested in accordance with ASME SFA 5.17. Results of mechanical test are shown in Table 3.

## VISUAL EXAMINATION

Test assemblies were visually inspected to detect surface porosity, undercuts, pock marks, surface finish, ripples etc. before cutting for specimen meant for mechanical testing.

## DYE-PENETRATION TEST

After flushing out the reinforcement with the help of a shaping machine and subsequently grinding, dye-penetration test was carried out on all the test assemblies to detect porosity, surface cracks.

## RADIOGRAPHY

All the test assemblies were subjected to radiographic test before cutting for specimen meant for mechanical testing. Evaluations of weld radiographs were as per 9.25.2 of AWS D1.1-88.

## TENSILE TEST

Three all-weld tensile test pieces were removed from each test assembly for tensile testing. The locations of these samples are shown in Fig. 3. Tensile test was performed on 'Hounsfield Tensometer'. The average of three readings was taken. The results of tensile testing have been recorded in Table 3.

## IMPACT TEST

Five all-weld samples from each test assembly were removed for charpy impact testing. The locations of these samples are shown in Fig. 3. Among the five values of the impact strength, the lowest and highest values were discarded and average of other three was taken for the evaluation of the impact strength. The results of impact test have been shown in Table 3.

## MICRO-HARDNESS

Micro-hardness survey was carried on the cross section of weld beads deposited with pure slag, fresh flux and recycled slag respectively. Fig. 4 compares the micro hardness of weld bead deposited with pure crushed slag, fresh flux and recycled slag.

## FRACTOGRAPHY

Scanning electron micrographs of the fractured surface of tensile test pieces of the weld metal deposited with pure slag and recycled slag respectively were captured and shown in Fig. 5-6.

## METALLURGICAL INVESTIGATIONS

For metallurgical investigations and micro-hardness survey beads on plates were deposited at 0.8 KJ/mm heat input. Microstructure of weld metal deposited with pure slag, fresh flux and recycled slag has been shown in Fig 7-8.

## RESULTS AND DISCUSSION

## CHEMISTRY OF WELD METAL

Chemical composition of two weld pads along with AWS requirement is shown in Table 1. Chemical composition of the weld pad prepared with pure slag shows lesser amount of carbon, silicon and manganese and also not as per AWS requirement. As there were no deoxidizers available in the slag, which have already been exhausted, and due to presence of oxygen, the above elements might have been lost by oxidation. As the modified slag was replenished with sufficient amount of deoxidizers/alloying elements, the chemical composition of weld metal (trial number 5, Table 2) improved and is within the acceptable range of AWS.

## VISUAL EXAMINATION

Test assemblies were visually inspected during and after welding. During welding with pure slag undercuts were observed along the sidewall of groove, which were removed by grinding. Slag detachability was poor for the first three passes and was self detaching there after. No such problems were experienced during welding with recycled and fresh flux. Stable arc was indicated by the pointer of voltmeter fitted on the welding equipment. No under cut, surface porosity and pockmarks were observed on the test assemblies prepared with recycled slag. Smooth beads with good appearance were obtained.

## DYE-PENETRATION TEST

After flushing out the reinforcement with the help of a shaping machine and subsequently grinding, dye-penetration test was carried out on all the test assemblies to detect surface defects such as porosity and cracks. Scattered porosity was observed on the test assembly deposited with pure slag. No surface defect was observed on the test assemblies prepared with fresh flux and recycled slag.

## RADIOGRAPHY

Test assembly prepared with pure slag failed in radiography. Porosity, slag inclusion and lack of fusion were observed. Porosity may be due carbon dioxide gas formed in molten pool by oxidation of carbon, as deoxidizers have already been exhausted. Slag inclusions may be due to entrapment of slag in under-cuts as slag detachability was poor for first three runs. Slag entrapped in sidewall under-cuts may also lead to the porosity. Test plates deposited with recycled and fresh flux cleared the radiographic test. Evaluations of weld radiographs were as per 9.25.2 of AWS D1.1-88.

## TENSILE TEST

The results of all weld tensile and impact tests of all the test assemblies as well as AWS requirements are shown in Table 3. Recycled slag with EL-08 wire combination confirms to ASME SFA-5.17; F7A0-EL8 classification, which is equivalent to Mergearc SAF-6 flux of (D&H, Secheron). As per this classification, for this flux-wire combination minimum yield strength, ultimate tensile strength and percent elongation required are 360 N/mm$^2$, 420 N/mm$^2$ and 20% respectively, which were achieved with the recycled slag. Fresh flux also fulfilled above criteria. In case of pure slag with EL-08 wire combination, yield and ultimate tensile strength achieved was 320 and 370 $N/mm^2$ respectively which is below the acceptable range. This may be due to lesser amount of alloying elements (C, Mn and Si) content in the weld metal. These results are in good agreement with the chemical composition. These results are consistent with the findings of Kanjilal et al. (2006).

### IMPACT TEST

In evaluating the test results, the highest and the lowest values obtained have been discarded as dictated by ASME codes. According to this code two of the remaining three values should be equal, or exceed, the specified (90 J) energy level and the average of the three should not be less than the required (90 J) energy level at 0°C. This condition was satisfied in case of recycled slag, where as in case of pure slag the average and minimum impact values were 72.9 J and 52.2 J at 0 °C which are un- acceptable. The presence of slag inclusion, porosity and lack of fusion may be the reason for the low impact value. Addition of alloying elements/deoxidizers reduces the level of oxygen as a result decreased amount of non-metallic inclusions. This resulted in improved toughness as in case of recycled slag. The increased toughness of weld metal deposited with recycled slag may also be attributed to the increased volume fraction of acicular ferrite. Dallam et al. (1985) reported that acicular ferrite present in the weld metal is responsible for high toughness. Indacochea et al. (1989) confirmed that acicular ferrite improve mechanical properties and toughness of the weld metal. Thus increased toughness of weld metal deposited with recycled slag is due to increased volume fraction of acicular ferrite.

### MICRO-HARDNESS

Fig. 4 compares the micro-hardness survey carried on the cross section of weld beads deposited with pure slag, fresh flux and recycled slag respectively. It depicts that the hardness achieved with recycled slag is more than achieved with pure crushed slag, and is comparable with fresh flux. The higher concentrations of C, Mn and Si in the weld metal produced by fresh flux and recycled slag resulted in higher hardness, in agreement with the results of Surian et al. (1982; 1985). Bracarense et al. (1991) also observed that increase in manganese and silicon content in the weld produced higher hardness.

### FRACTOGRAPHY

Fig. 5-6 show the scanning electron micrographs of the fractured surface of tensile test specimens of the weld metal deposited with pure slag and recycled slag respectively. Both the micrographs show the ductile mode of failure. However, Fig. 6 indicates larger dimple size and consequently higher energy absorption before fracture which further supports the results of tensile and impact tests. It can be attributed to the increased amount of carbon, manganese and silicon in the weld metal deposited with recycled slag.

### COST ANALYSIS

Cost of recycled slag per 100 kg was calculated and compared with the equivalent fresh flux available in the market.

### CONCLUSIONS

1. Submerged arc welding slag can be recycled after necessary modification.
2. Weld metal chemistry achieved with recycled slag was within the acceptable range of ASME SFA 5.17-89.
3. The radiographs of the groove welds were found acceptable as per 9.252 of AWS D.1.15-88 radiographic standard of dynamic loading.
4. The mechanical properties of weld metal were acceptable as per ASME SFA 5.17-89.

| | |
|---|---|
| Cost of recycled slag per 100 kg: | |
| 1. Material cost | |
| (a) Cost of slag used | Rs 45.00 (Transportation cost only) |
| (b) Cost of additives | |
| Cost of Ferro - Mn and Ferro - Si | Rs 700.00 |
| Cost of Ferro -Ti | Rs 250.00 |
| Cost of $CaCO_3$ and $SiO_2$ | Rs 38.50 |
| Cost of Potassium Silicate (binder) | Rs 150.00 |
| 2. Processing charges | |
| Sintering cost | Rs 140.00 |
| Labour cost | Rs 24.00 |
| Crushing and milling cost | Rs 105.0 |
| Prime cost of recycled slag per 100 kg | 1+2 = Rs 1452.50 |
| Considering 10 % of prime cost as overhead charges and 20% as profit, | |
| Price of recycled slag per 100 kg | Rs 1888.25 |
| Price of equivalent fresh flux available in the market per100 kg | Rs 6000.00 |
| Percentage saving | 68.52 % |

5. Good appearance of beads without any visual defects was observed.
6. Arc stability and slag detachability both were good with the recycled slag.
7. The use of recycled slag is economical by 68.52%.

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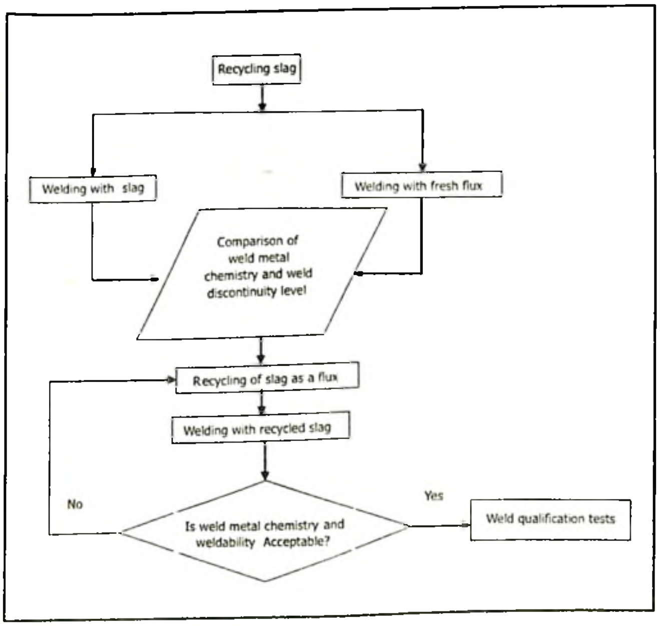



**Figure 1** : Flow diagram for recycling.

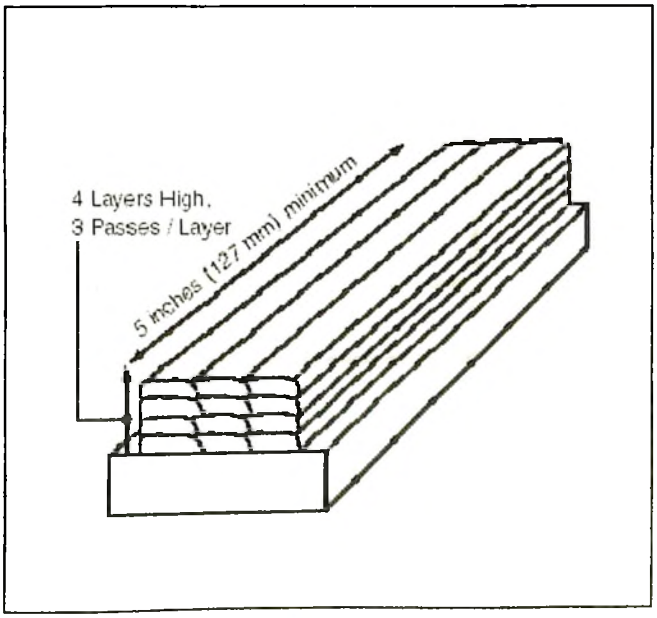



**Figure 2** : Weld metal pad for chemical analysis (ASME SFA-5.17)

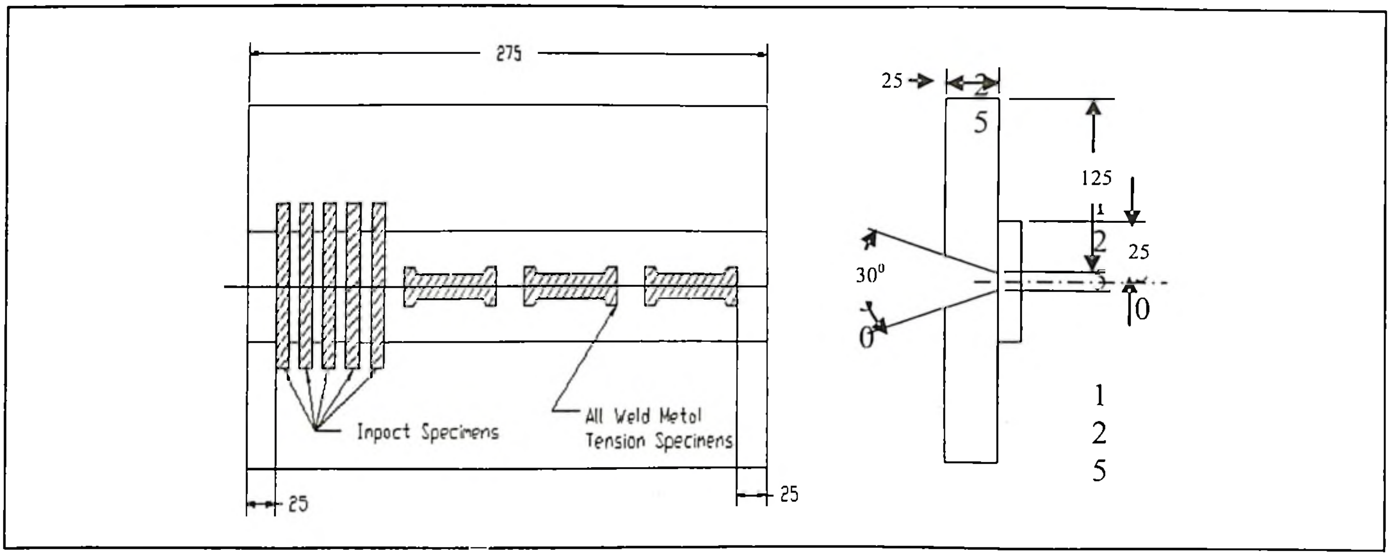
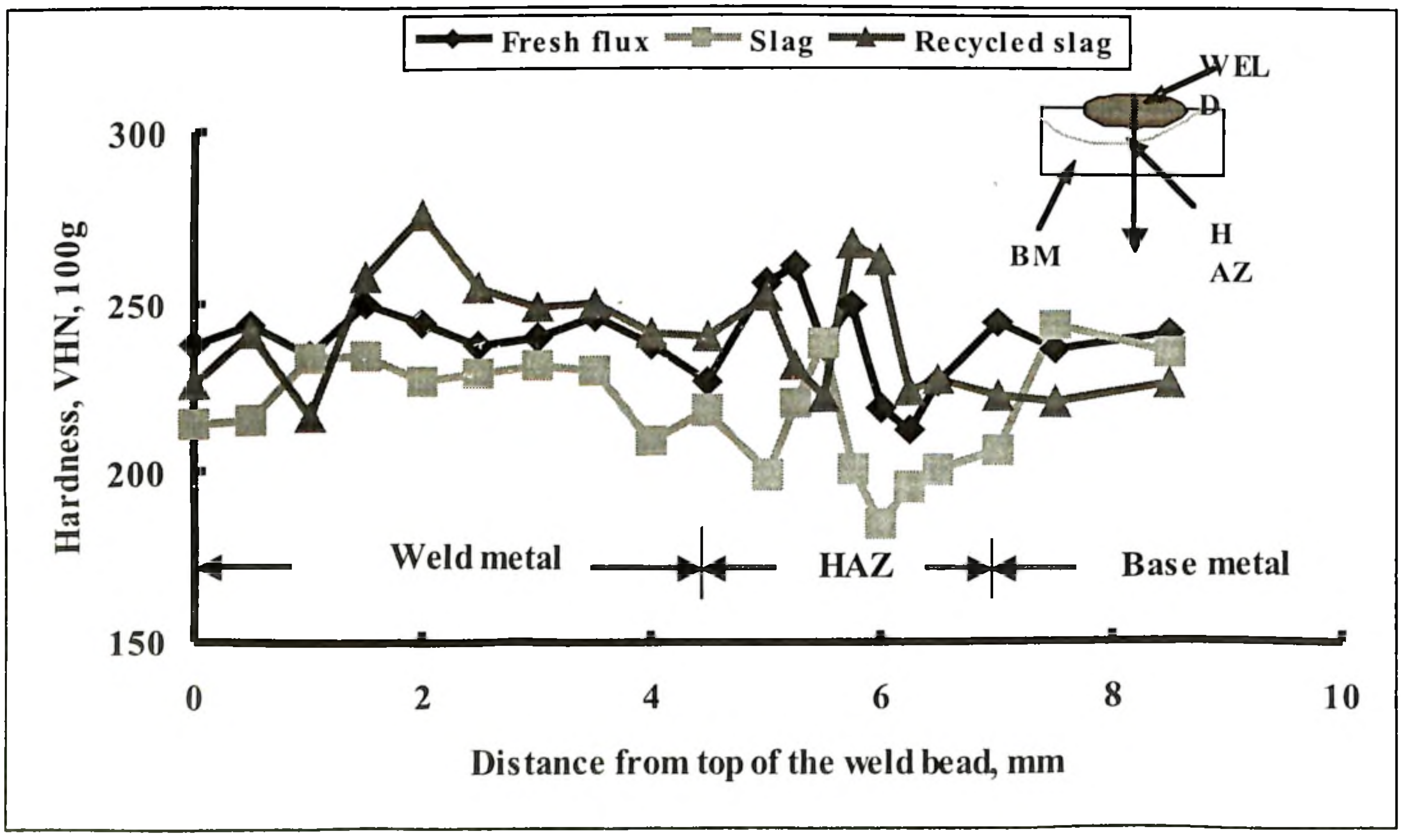



**Figure 3** : Dimensions of all weld test assembly in mm



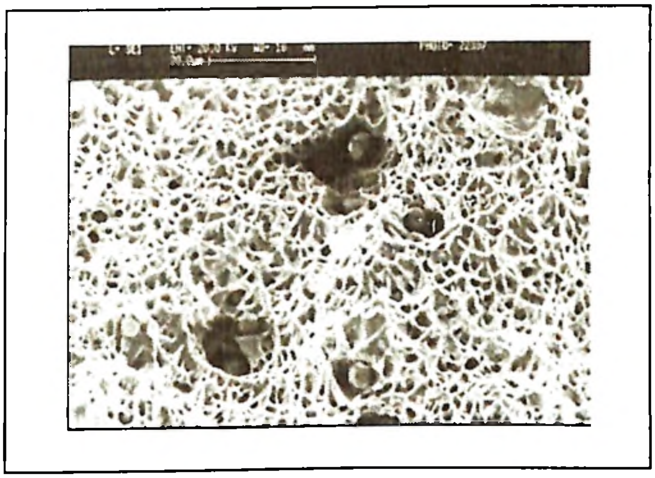


**Figure 5** : Scanning electron micrograph of the fractured tensile sample of weld metal deposited with pure slag

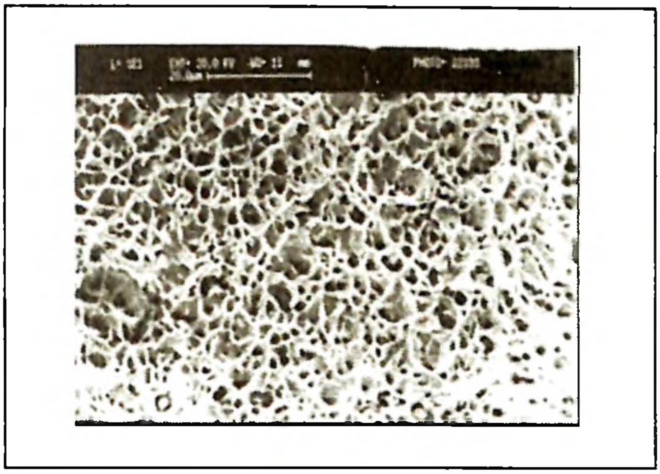


**Figure 6** : Scanning electron micrograph of fractured tensile sample of weld metal deposited with recycled slag.

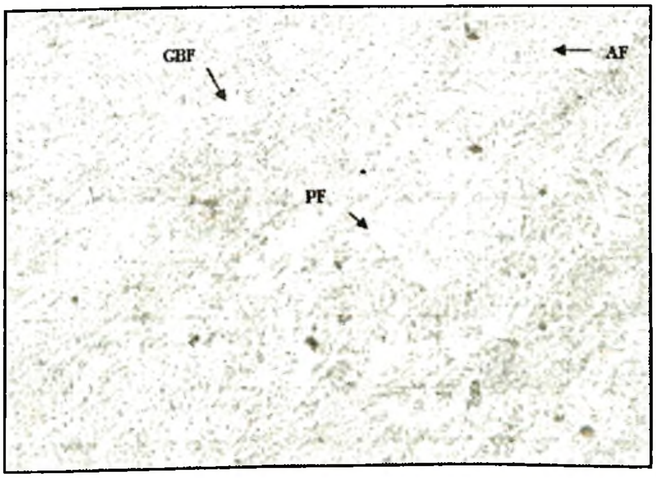



**Figure 7** : Microstructure of weld metal deposited with pure slag (100X) AF- Acicular Ferrite, PF- Polygonal Ferrite, GBF- Grain Boundary Ferrite

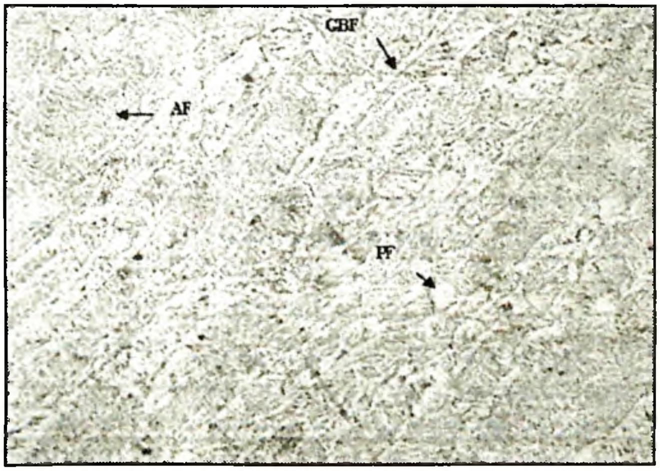



**Figure 8** : Microstructure of weld metal deposited with recycled slag AF-acicular ferrite, GBF- grain boundary ferrite, PF- polygonal ferrite, Nital etch, X 100.

| | C | Mn | Si | S | P |
|---|---|---|---|---|---|
| AWS Requirement | 0.015 - 0.15 | 0.80 - 1.25 | 0.1 - 0.35 | 0.03 Max | 0.03 Max |
| With pure slag | **0.028** | **0.547** | **0.130** | .024 | 0.0272 |
| With fresh slag | 0.052 | 0.637 | 0.211 | .029 | 0.0337 |
| With recycled slag | **0.075** | **0.832** | **0.199** | **.025** | **.030** |

**Table 1** : Chemical composition of weld metal

| Trial No | Additives | C | Mn | Si | S | P |
|---|---|---|---|---|---|---|
| 1. | CaCO3+SiO2 = 7.1%<br>Fe-Mn + Fe-Ti = 5.2 % | 0.054 | 1.74 | 0.277 | .025 | 0.042 |
| 2. | CaCO3+SiO2 =10.1%<br>Fe-Mn + Fe-Ti =2.6% | 0.087 | 0.428 | 0.142 | .029 | .0276 |
| 3. | CaCO3+SiO2 =10%<br>Fe-Mn + Fe-Ti =4.2% | 0.070 | 0.557 | 0.140 | 0.025 | .0237 |
| 4. | CaCO3+SiO2 =10%<br>Fe-Mn + Fe-Ti =5.8%<br>Fe-Si = 1% | 0.061 | 0.683 | 0.136 | 0.026 | .0271 |
| 5. | CaCO3+SiO2 =10.3%<br>Fe-Mn + Fe-Ti =7.26%<br>Fe-Si = 2% | 0.075 | 0.832 | 0.199 | 0.025 | .030 |

**Table 2 :** Chemical composition of trial weld pads

| | YS N/ mm2 | UTS N/ mm2 | % Elongation | Charpy Impact | Radiography |
|---|---|---|---|---|---|
| AWS Requirement | 360 | 420 | 24 | 90 | Must Pass |
| Pure slag | 320 | 370 | 32.7 | 72.9 | Failed |
| Fresh flux | 381.6 | 455.6 | 30.5 | 116.7 | Passed |
| Recycled slag | 423.7 | 525.95 | 34.5 | 109.1 | Passed |

**Table 3 :** Results of mechanical testing