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Novel Method of Productivity Improvement and Waste Reduction Through Recycling of Submerged Arc Welding Slag

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Abstract

The traditional welding flux is costly and the flux used in Submerged Arc Welding (SAW) generates wastages known as Slag. It is generally thrown away as a waste after use. This poses the problem of storage, disposal, and environmental pollution and needs landfill space apart from exhaust of non-renewable resources. If by recycling the used flux can be reused in product yielding same quality parameter as the new flux, then the cost of the input will go down significantly. However, this requires extensive trial and error experimentation because it is often difficult to know how the slag ingredients interact after recycling to determine the operational characteristics of the recycled flux and the final performance of the welded structure. Keeping this in mind an experiment has been conducted in a manufacturing unit with small investment. As far as possible weld qualification tests were performed using recycled flux to get it to be qualified in a National Accreditation Board of Laboratories in the final products made from recycled slag. While comparing, it was indeed revealed that the product has better chemical analysis, dye penetration test, radiography, mechanical tests and metallurgical investigations than the product from new flux. Cost analysis of recycled slag per 100 kg was calculated and compared with the equivalent fresh flux available in the market according to the principle of market value method or reversal cost method. It is similar to the technique of by product revenue deducted from production cost. The cost analysis has revealed in terms of % of saving that it could be to the extent of 70.73%.

Keywords: Submerged Arc Welding, Flux; Recycling, Reuse; Waste Reduction.

1. Introduction

Welding is a complex multi-disciplinary technology requiring permanent modernization of manufacture with new machines, permanent education of workers, and introduction of most recent manufacturing processes. Productivity in fusion arc welding processes can be increased in several ways. Application of numerous welding technologies in fabrication and maintenance processes covers wide range of industrial cases from steam generator to aircraft to high precision equipment of almost every industrial sector.

Among the different Arc welding processes, Submerged Arc Welding (SAW) process finds wide industrial application due to its easy applicability; high current density and ability to deposit a large amount of weld metal using more than one wire at the same time. It is highly emphasized in manufacturing because of its natural qualities such as easiness in controlling process variables, high quality, deep penetration, smooth finish, capability to weld thicker sections and prevention of atmospheric contamination of the weld pool.

The flux used in SAW after use generates wastages of Flux i.e., which is known as Slag. It is generally thrown away as a waste after use. This poses the problem of storage, disposal, and environmental pollution and needs landfill space apart from exhaust of non-renewable resources. The flux is very costly and, if the used flux i.e. slags can be reused in product yielding same quality parameter as the new flux then the cost of the input of SAW will go down significantly.

Considering this view, an experiment has been conducted in a manufacturing unit with small investment on the additional arrangements for recollection of generated slag. The slag was collected and mixed with additives and subsequently used in the sample.

Weld qualification tests were carried out using recycled slag to get it qualified in a National Accreditation Board of Laboratories in the sample of final products made from recycled slag. Comparison discovered that the product has better chemical analysis, dye penetration test, radiography, mechanical tests and metallurgical examinations than the product from new flux.

Submerged Arc Welding is basically an arc-welding process in which the arc is concealed by a blanket of granular and fusible flux. The physical properties of flux are important considerations in SAW for improving welding properties. SAW is an economical method for producing tools and machine parts with required surface properties, particularly resistance to wear and corrosion.

The source of heat for SAW is obtained from the arc generated between a bare solid metal in the form of a

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consumable wire or strip electrode and the work piece. The arc is maintained in a cavity of molten flux or slag that refines the weld metal and protects it from atmospheric contamination. Alloy ingredients in flux attempt to enhance the mechanical properties and crack resistance of the weld deposit. Therefore, as Flux is one of the essential ingredients of SAW, it is of utmost importance to select SAW Flux properly in order to improve weld quality.

Since, the development of the SAW process, there has been attempts by technologists and researchers to increase its productivity and to decrease the welding cost. The cost of the flux is a major part of the total welding cost for the SAW process[1]. It has been estimated that, in general, one kg of flux is consumed for every kg of weld metal deposited. Flux consumption increases with an increase in arc voltage. About 2500 tonnes of flux are being used every year in India alone. After welding, such a large quantity of flux becomes slag and that is treated as waste. The slag is then disposed-of. The basic question is whether the slag can be recycled or not. If, Cost-effective recycling of slag is possible, it will not only overcome the problems of storage and disposal, but also save non-renewable resources.

2. Objective of this Study

Adityapur Industrial Area is the industrial hub of Jharkhand state in India. There are many small and medium industries in which SAW facilities are available. They cater to the needs of many original equipment manufacturers by supplying qualitative products. But on the cost parameters most of the ventures are unable to compete with the competitors. On the other hand, there is always a pressure from the customer to reduce some percentage of cost as an effort of continual improvement. This study has been conducted in a small industry, where SAW facilities are available and with the support of top management of the organization. The monthly output of slag is approximately 700 – 1000 kg at present and with the commissioning of 2nd phase the quantity will be approximately doubled.

In order to fulfill the major objective, slag was recycled and the characteristics of recycled slag were evaluated by performing weld qualification tests, chemical composition, mechanical properties and metallurgical investigations. At the same time, the evaluation of weld metal were carried out to justify other aspects like:

1. To find out means and ways about possibility of recycling SAW slag.
2. To compare the weld metal chemistry achieved with recycled slag against laid down requirements of available AWS and ASME specifications.
3. To find out Mechanical as well as Chemical parameters either they match with available international specifications range or not
4. To witness and observe aesthetic appeal of beads possible without any visual defects or not.
5. To study the stability and slag detachability with the recycled slag.
6. To reduce the wastages of Slag
7. To protect the environment from pollution.
8. To contribute to the improvement of global quality of life through use and innovation in welding and joining technologies

3. Literature Review

SAW process was developed by the E O Paton Electric Welding Institute[1] in Russia, during the second world war, and it was used for many different applications during that time, most notable for its use on the T34 tank. Submerged Arc Welding is just what its name says. Desire for the mankind to improve the quality of life, conserve the natural resources, protect the environment etc. has been the major driving force for innovations in the field of materials and their application. In this regard, a major advance in systematizing the study of welding flux was begun by Christensen and Chipman[2] who investigated acidic coatings on shielded metal arc electrodes. Others following[3-5] have made similar studies on SAW fluxes. Since, the development of the SAW process, there has been attempts by technologists and researchers to increase its productivity and to decrease the welding cost. The cost of the flux is a major part of the total welding cost for the SAW process. It has been estimated that, in general, one kg of flux is consumed for every kg of weld metal deposited. Flux consumption increases with an increase in arc voltage. About 2500 tonnes of flux are being used every year in India alone[6].

Waste reduction is an important issue in today's context. The main objective of the waste reduction is to minimize waste while the resource management aims to maximize the utilization of resources. According to Mitra and Eagar [7] the alloying elements lost in slag on welding by flux are Mn upto -0.30 Pct, Si upto -0.31 Pct and Cr -4.83 Pct. Hence, the basic question is whether the slag can be recycled or not. If, cost-effective recycling of slag is possible, it will not only overcome the problems of storage and disposal, but also save non-renewable resources because. But, very few efforts have been done to study and validate the use of slag after recycling.

Generally the industrial firms are reluctant to provide information on quantity and composition of waste for fear of show cause from regulating authorities. The quantum of waste generated reflects the inefficiency of the organization. The Government of India through national committee of science and technology works on the projects of recycling and gives solutions. The director general of supplies and disposal regulates on supplies and disposals. Similarly, Metal Scrap Trade Corporation and Minerals and Metal Trading Corporation have suggested some procedures for the manner of disposal and market analysis. Organization for the economic co-operation and development has advocated to consider safety, efficiency, cost effectiveness, waste minimization and feasibility to industries ,while selecting a specific technique for system and /or component recycling[8].

3.1. Recycling of SAW Slag

SAW fluxes are granular, fusible mineral compounds of various proportions and quantities, manufactured by several different methods. In addition, some fluxes may contain intimately mixed metallic ingredients to deoxidize the weld pool. Any flux is likely to produce weld metal of somewhat different composition from that of the electrode used with it due to chemical reactions in the arc and sometimes to the presence of metallic ingredients in the flux. A change in arc voltage during welding will change the quantity of flux interacting with a given quantity of electrode and may, therefore, change the composition of the weld metal. This latter change provides a means of describing fluxes as ''neutral,'' ''active,'' or ''alloy.''

From the review of Specification No AWS 5.17[9]for carbon steel electrodes and fluxes for submerged arc welding A99, the types of fluxes are neutral fluxes, active fluxes, alloy fluxes, crushed slags and closed-loop, crushed slags

Neutral fluxes are those, which will not produce any significant change in the weld metal chemical analysis as a result of a large change in the arc voltage, and thus, the arc length. The primary use for neutral fluxes is in multi pass welding, especially when the base metal exceeds 25 mm in thickness. The considerations as suggested by AWS 5.17[9] that neutral fluxes contain little or no deoxidizers. They rely on the electrode to provide deoxidation. Single-pass welds with insufficient deoxidation on heavily oxidized base metal may be prone to porosity, centerline cracking, or both. It maintains the chemical composition of the weld metal even when the voltage is changed; it is not always true that the chemical composition of the weld metal is the same as the chemical composition of the electrode used. It is used to maintain the weld metal chemical composition through a range of welding voltages, weld properties. Strength level and impact properties can change changes in other welding parameters such as depth of fusion, heat input, and number of passes.

Active fluxes are those, which contain small amounts of manganese, silicon, or both. These deoxidizers are added to the flux to provide improved resistance to porosity and weld cracking caused by contaminants on or in the base metal. The primary use for active fluxes is to make single pass welds, especially on oxidized base metal.

The considerations as suggested by AWS 5.17[9] that Active fluxes contain some de oxidizers, the manganese, silicon, or both, in the weld metal. The active flux will vary with changes in arc voltage. An increase in manganese or silicon increases the strength and hardness of the weld metal in multi pass welds but may lower the impact properties. For this reason, the voltage may need to be more tightly controlled for multi pass welding with active fluxes than when using neutral fluxes. Some fluxes are more active than others. This means they offer more resistance to porosity due to base-metal surface oxides in single-pass welds than a flux, which is less active, but may pose more problems in multi pass welding.

Alloy fluxes are those, which can be used with a carbon steel electrode to make alloy weld metal. The alloys for the weld metal are added as ingredients in the flux. The primary use for alloy fluxes is to weld low alloy steels and for hard facing.

Christensen[10] has classified fluxes into three types namely manganese silicate, calcium silicate and basic. For each flux he characterized the amount of Mn, Si, and O transfer by two variables. The variables are the initial or nominal manganese content and an operational parameter. Kubli and Sharav[11] showed that the oxygen content of submerged arc weld metal decreases with increasing flux basicity.

Slag formed during the welding process is subsequently crushed for use as a welding flux is defined as crushed slag. This is different from a recycled flux, which was never fused into a slag and can often be collected from a clean surface and reused without crushing.

Slag generated by a fabricator from a specific brand of flux under controlled welding conditions and crushed for subsequent reuse by the same fabricator is defined as closed-loop, crushed slag. Closed-loop, crushed slag, or blends of closed-loop, crushed slag with the original brand of unused flux ensure better control of input material by virtue of the inherent partnering of the fabricator with the crusher.

If blending of slag with unused flux is done, changes in the original brand of unused flux or in the blending ratio can affect the quality of the final product.

It is reported that TITUS Steel Company[12]has been reclaiming slag for fabricators in the USA. The Paton Electric Welding Institute of Ukraine [13] has also reported the development of a technology for recycling of slag.

However, from the available literatures it is evident that the first attempt at recycling of SAW Slag was reported by Alfred Beck and Jackson[14]. 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 slag.

Beck and Jackson [14] further revealed their finding that if it is processed properly and according to code requirements, recycled slag could be reliably used as a substitute to fresh flux. They further emphasized a saving up to 50% of the total cost of purchased flux by recycling the slag.

Devis and Baily[15] established that fused calcium silicate flux, which has fully reacted during manufacturing, produces no change on reheating. Such a flux contains no readily oxidizable material and can be recycled.

A few researchers have also explored the possibility of using a mixture of fresh flux and slag. Research carried-out by Livshits et al[16]has shown the possibilities of using pulverized slag crust mixed with iron filings for hard facing applications. They additionally confirmed that this process is efficient and cost-effective.

Moi et al[17] and Pal et al.[18] found that of mixture containing up to 20% fused slag in fresh flux produces no change in weld metal chemistry.

Milichenko et al[19].have proposed a new method for preparing alloying fluxes for hard facing by enriching the flux with ferro-alloys.

Their[20] has proposed empirical equations for computing the alloy content of the weld metal. In spite of the fact that from the available literature of Singh and Pandey [21], it was found 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. Pandey et al.[22] found that an acceptable bead geometry can be achieved using recycled slag and have claimed a saving of 68.6% using recycled slag.

Many other investigators like Farias et al[23], Du Plessis et al.[24] and Kanjilal et al[25] tried to understand the role of each flux ingredients on the weld-metal properties and operational characteristics of the process by varying only the individual flux ingredient in a given flux system observed that this approach by its very nature failed to take into account the simultaneous variation of the flux ingredients as well as their interaction effects.

The significant interactions effect of flux ingredients has been reported previously by Lau et al[26], and Kanjilal et al[27] further stress that this assessment of flux ingredient interaction has been recognised as increasingly important in welding flux design, where it may be necessary to determine the combined synergetic and antagonistic effects of many flux ingredients.

The need for the reduction of the number of experiments has been the concern of welding flux researchers and manufacturers. Although modeling tools can not completely eliminate experiments, it can drastically reduce the number of experiments. Quintana et al[28].observed that a reduction in the number of experimental welds from 30 to 5 in GMAW leads to about 80% energy savings. Obviously the benefits of the reduction in the number of experimental welds would be higher by the time the savings on materials, labour and time are considered.

According to Ademola et al[29] to arrive at an optimum flux composition and mitigate the problems of the traditional approach, an alternative approach is to develop mathematical models through effective and strategic planning, design and execution of experiments. With the availability of such models, the formulation of welding flux can be based on quantitative footing. According to them, such an approach minimizes the expenditure of time, labour and materials.

The steps/ procedures have been suggested by NIST/SEMATECH[30], Gunaraj and Murugan[31], and Allen et al[32]to follow while planning and conducting welding flux research in the subject mixture experiments typically involving the following, which could also be implemented for recycling of slag:

- Define the objectives of the experiment
- Select the flux ingredients and where necessary any other factor to be studied e.g. process variables
- Identify any constraints on the flux components or other factors in order to specify the experimental region
- Identify the response variables to be measured
- Propose an appropriate model for modeling the response data as functions of the flux ingredients and other factors selected for the experiment
- Select an experimental design that is sufficient not only to fit the proposed model but which allows a test of model adequacy as well
- Conduct the experiment as per the design matrix
- Measure and record the responses
- Develop the mathematical models
- Calculate the coefficients of the polynomials
- Check the adequacy of the model developed
- Conduct the confirmatory test
- Present the main and interaction effects of the different ingredients on the responses
- Use the model to predict the combination of flux ingredients that will give the desired response
- Perform actual experiments with the designed flux
- Analyze the results

The efficacy of the methodology in welding flux research has been demonstrated by Kanjilal et al[33-36] Their paper presents a brief discussion on mixture design. The procedure of mixture experiment, the analytical model forms and the sequence of model fitting are discussed but not fully developed. Areas of welding flux research where the various mixture designs may be useful are suggested.

Most recently Kaveh et al[37] have developed a methodology of recycling of slag obtained from the application of powder in submerged arc welding used in low carbon steel grade st 37. Their research highlights finding a method for recycling such wastes by making use of phases assessment systems (X-ray diffractometery XRD), chemical composition assessment systems (X-ray fluorescence XRF), phases type and form assessment system (Scanning electro microscope SEM), and carbon and sulphur value assessment system (Strolein system) and by using separation, formulation, and ceramic sintering

A quantity of information is also available in the www.recycleflux.com[38]in which recycling and disposing methodologies have been given.

In view of the strong support found from review of available literature for the slag recycling, one common recommendation witnessed that SAW Slag can be recycled with adding certain quantities of additives.

4. Plan of Experiments

After going through the books, reference materials and reviews from journals, holding detailed discussions with the Welding Experts, Shop Personals, and Inspectors, it was formally decided to take up the study. It was decided to gather the information of SAW as far as possible. Side by side it was decided to evaluate and generate the data related to mechanical properties and chemical properties of the raw material being welded. This was decided in view of the facts that welded material property is the main issue in this case to be dealt with. If the alternate methods are able to match the mechanical as well as chemical properties, the alternate material can be used. It was decided that methodologies of reusing the slag is the best option, if possible, in least cost than the fresh flux

4.1. Experimental Set up

The experiment was conducted in the company abbreviated as ABC to keep confidentiality of the company. The industry has modern SAW facility having following specification.

- Model: Auto weld 1000 I
- Input power (kva): 44
- Current range (Ampere): 60-1000
- Input supply: 380-440 v, 3 Phase, 50 Hz supply

The job is fixed at the desired position and the SAW torch moves forward or backward on the tractor, which runs through parallel rails The inbuilt features of the tractor used were 120Volts rated input Voltage, Wire diameter 1.6 to 6 mm with scratch or retract arc starting method, 100-1500 mm/min speed, 200-4500 mm/ min wire feed rate, 0-80 mm vertical adjustment, ± 30 mm horizontal adjustments with 45^0 inclination of the welding torch as well as the welding head. The flux hopper was suitably mounted along with spool holder arrangement.

4.2. Process adopted to Recycle the Slag

A systematic approach is needed to recycle the total system waste. SAW process is carried out in the plant facility where more than one material is used. The slag may contain oil, mill scale, chips, dust and other consumables. Hence, the collection of slag requires much attention. Various strategies have been proposed to reduce the wastages through recycling like; moisture and oil must be removed from the compressed air used in the re-cycling system. Addition of additives must be done with the proportion as they remain in the new flux. Foreign material such as mill scale must be removed by a suitable system, such as sieving.

As a generator, one have "cradle-to-grave" responsibility for the hazardous waste produced. Below is a short outline of the adopted recycling procedures.

- Project Initiation

Assigning project specific job numbers was of critical importance in initiating a project. Job and lot numbers were utilized to track all materials as they moved through the processing.

- Temporary Storage

Depending upon the requirements of the job, the material was moved to temporary storage or drop boxes placed on site.

- Representative Sample and Document Procurement

Throughout blasting operations, spent abrasives will be accumulated in the containment facilities. When sufficient volumes of spent grit have been accumulated, representative samples of the material will be collected. Depending on actual volumes of waste generated, collection of several samples for analysis may be indicated.

- Testing and Designation

Selecting applicable chemical analysis for a waste stream was critical to waste recycling because selection of the wrong analysis could generate added costs. Hence, appropriate tests were carried out and once tested; the material is designated based on characteristic criteria.

- Disposal or Recycling Recommendation Once the material was designated an appropriate disposal or recycling facility was recommended.
- Transportation

Once the spent slag waste has been accepted for recycling or disposal the material was transported to the facility depending upon its designation.

- Decontamination

The drop boxes were used for slag materials. They were thoroughly cleaned and decontaminated prior to use. Records were also maintained on this operation.

- Chain-of-Custody Documentation

Throughout the entire handling of the material, chain-of-custody documentation has been maintained. This enabled tracking everything in the process: identification, storage, testing, designation, transportation, and disposal/recycling facilities.

The specific waste collection and recycling strategies adopted have been summarized and presented below

- Design of economic basis to facilitate separation at source
- To provide every organization with a set of four standard bins to separately collect the metallic, plastic, paper and other miscellaneous waste. The bins should be designed properly.
- Design the appropriate collection system
- Incentive to encourage segregation of waste at source
- Timely collection of waste
- Selection of representative sample and documentation
- Disposal or Recycling Recommendation
- Use appropriate technology to recycle
- Insure its ultimate use, and
- Compare the recycling cost with fresh one

Traditionally, no slag is reused in the submerged arc welding. The aim was to test whether slag can be recycled and used further in the production or not. To test this theory a plan of investigation has been made. The detail plan of investigation has been shown in Fig. 1. The various steps are;

1. Welding with fresh flux
2. Welding with pure crushed slag
3. Comparison of weld metal chemistry
4. Processing of slag
5. Weld qualification test with recycled slag
   - Chemical test for chemistry of weld metal
   - Test plates for radiography
   - Mechanical testing, and Metallurgical investigations.

4.3. Welding with Fresh Flux

Three Mild steel sample weld pads were prepared and welded with fresh flux. A weld pad sample is shown in Fig.2. The original fresh flux used was F7AZ which was use in combination with EL-8 filler wire of 2 mm thickness. The welding parameters and other conditions were in accordance with AWS-SFA 5.17. Preheat is essential for heavy mild steel weldments and alloyed metals to assure good mechanical properties. Multiple pass welds require an interpass temperature equal to the preheat temperature until the weld is completed.The interpass temperature was maintained by six program control unit which controlled and memorized the current, voltage, welding speed and temperature. The ideal parameters specified in AWS-SFA 5.17, and parameters maintained are tabulated in Table 1.

4.4. Welding with pure slag

Slag waste was crushed and meshed to the granular size like that of the original flux. Three weld pads similar to Fig.2 have been made with pure slag maintaining same parameters given in table 1 using crushed slag with EL-8 wire in accordance with AWS SFA 5.17 for chemical analysis of weld metal.

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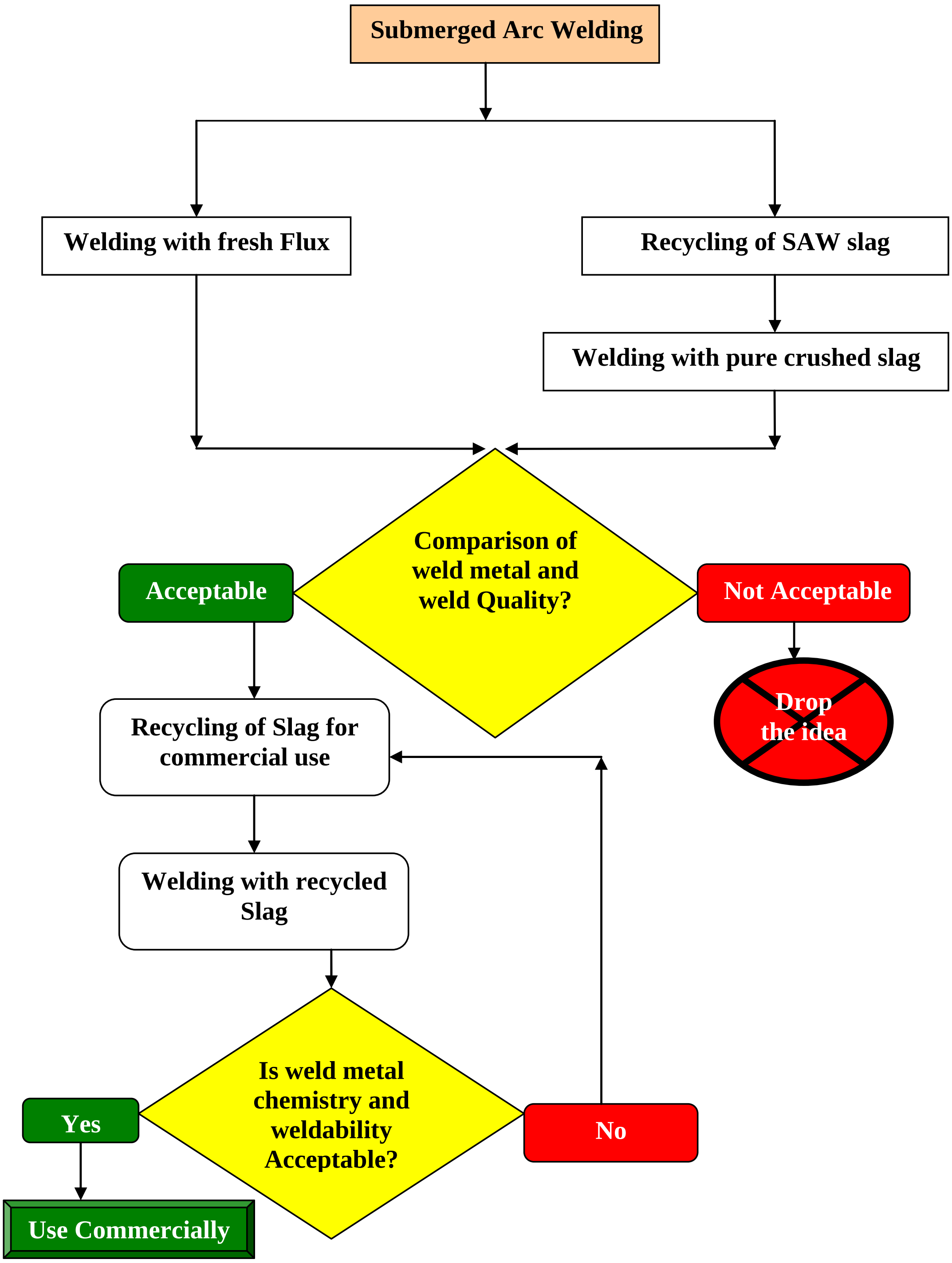

Fig.1 Process flow diagram for recycling of slag

Table1 Specified parameters and maintained parameters in sample pieces

Sl No	Parameter	Unit	Specified parameter range or Chosen	Maintained parameter
1	Current	Ampere	300-400	360
2	Voltage	Volts	26 - 30	30
3	Travel speed	mm /sec	5-6	5
4	Pre heat temperature	^{0}F (^{0}C)	60- 325^{0}F (15-165^{0}C)	250^{0}F (122^{0}C)
5	Inter pass temperature	^{0}F (^{0}C)	275- 325^{0}F (135-165^{0}C)	300^{0}F (150^{0}C)
6	Electrode size	mm	2	2
7	Flux	Granular	F7AZ	F7AZ
8	Position of welding		Flat	Flat
9	Material		Suitable	IS 2062
10	Thickness	mm	Not specified	10

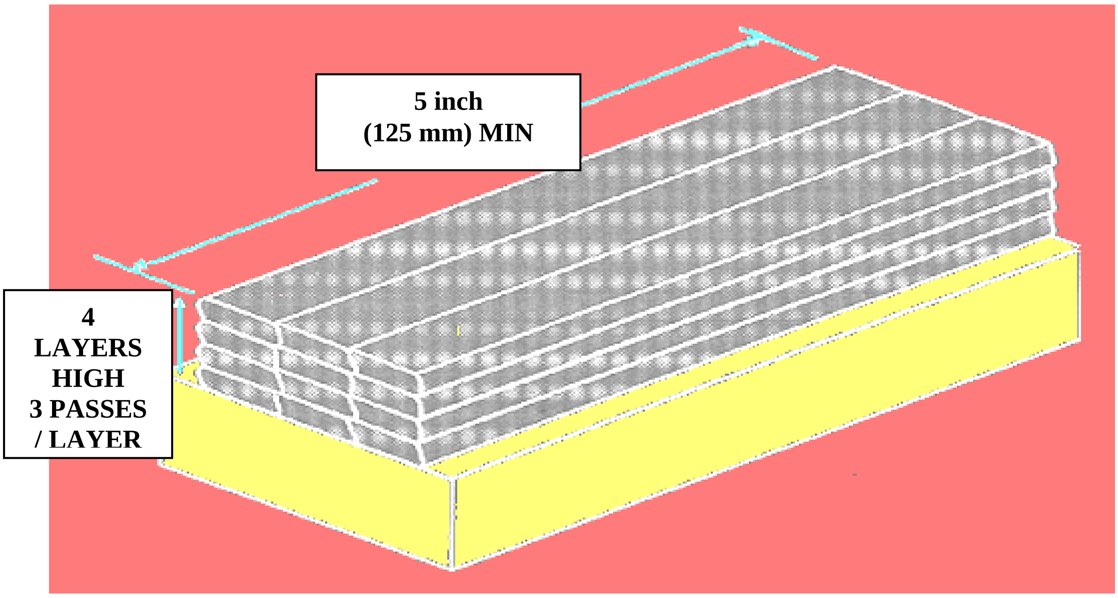

Fig.2 Weld pad for chemical analysis of weld metal [9]

5. Recycling / Modification of slag

Slag formed during the welding process that is subsequently crushed for use as a welding flux is defined as crushed slag. This is different from a recycled flux, which was never fused into a slag and can often be collected from a clean surface and reused without crushing. Crushed slag and blends of crushed slag with unused (virgin) flux may be classified as a welding flux under this specification, but shall not be considered to be the same as virgin flux. Although it is possible to crush and reuse submerged arc slag as a welding flux, the crushed slag, regardless of any addition of virgin flux to it, is a new and chemically different flux. This is because the slag formed during submerged arc welding does not have the same chemical composition or welding characteristics as the virgin flux. Its composition is affected by the composition of the original flux, chemical reactions which occur due to the welding arc, the base metal and electrode compositions, and the welding parameters.

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 mm mesh screen to form small pellets.

These pallets 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 separated to the required grain size and termed as recycled slag.

6. Welding with Recycled Slag

For welding with recycled slag El-8 filler wire was chosen and 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. The modifications were used in different combination of additives and each time 3 samples weld pads were made. Five possible combinations of weld pads were made. As such total 15 numbers of weld pads were made using recycled slag. The modifications were repeated until acceptable chemistry of weld metal was achieved.

The weld pads were similar to 2 and maintained same parameters given in Table 1.

Chemical composition of weld metal deposited with fresh flux, pure crushed slag and with recycled slag was critically analyzed and compared with AWS requirements for deciding further course of action. The chemical composition analysis of weld metal was carried out in a national accreditation board of laboratories with a spectrometer. The reported findings have been presented and are recoded in Table2.

Table 2. Comparison of chemical composition of weld metal

	C	Mn	Si	S	P
AWS requirement	0.05 – 0.15	0.80 – 1.25	0.1 – 0.35	0.03 Max	0.03 Max
With pure slag	0.025	0.541	0.128	.023	0.028
With fresh flux	0.053	0.646	0.216	.028	0.0327
With recycled slag	0.072	0.812	0.178	.026	0.029

Trial runs along with corresponding chemical composition of weld metal have been shown in Table 3.

Table 3. Chemical composition of trial weld pads in different combination of recycled slag.

Trial No	Additives in % of Slag	C	Mn	Si	S	P
1.	$CaCO_3$+SiO_2 = 7.1% F-Mn + F-Ti = 5.2 %	0.054	1.74	0.277	.025	0.042
2.	$CaCO_3$+SiO_2 =10.1% F-Mn + F-Ti =2.6%	0.087	0.428	0.142	.029	.0276
3.	$CaCO_3$+SiO_2 =10% F-Mn + F-Ti =4.2%	0.070	0.557	0.140	0.025	.0237
4.	$CaCO_3$+SiO_2 =10% F-Mn + F-Ti =5.8% F-Si = 1%	0.061	0.683	0.136	0.026	.0271
5.	$CaCO_3$+SiO_2 =10.3% F-Mn + F-Ti =7.26% F-Si = 2%	0.075	0.832	0.199	0.025	.030

7. Weld Qualification Tests and Results

To determine the performance of recycled slag different weld qualification tests have been carried out. Once acceptable chemical composition of weld metal was achieved with recycled slag, following tests were performed to ascertain its performance.

7.1. Preparation of Sample For Different Tests

Three test assemblies each with fresh flux, pure slag; and recycled slag were prepared considering the specification of AWS SFA 5.17. The dimensions of test assemblies are maintained as shown in Fig. 3(a), Fig. 3(b) and Fig. 3(c) and Table 5.

7.2. Testing of Assembly

Test assemblies were subjected to visual inspection, dye-penetration test and radiography before cutting for specimens meant for mechanical testing. Tensile and impact specimens were machined and tested in accordance with AWS SFA 5.17. Results of mechanical test are shown in Table4.

Table 4 Results of mechanical properties testing

Heading	YS N/ mm^2	UTS N/ mm^2	% Elongation	Charpy Impact J (at 0° C)	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

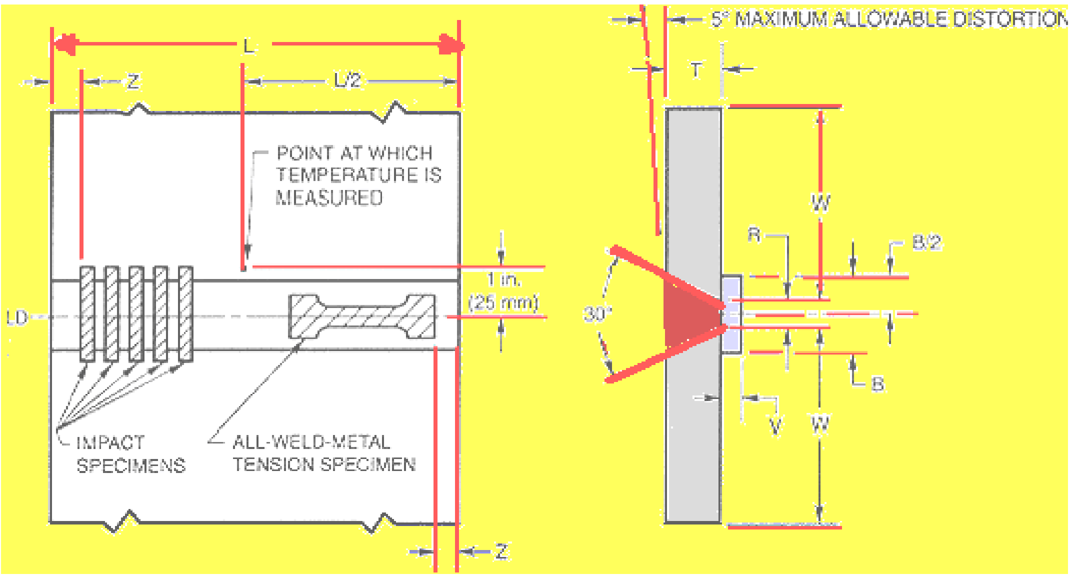

Fig 3(a) Joint configuration and location of test specimen

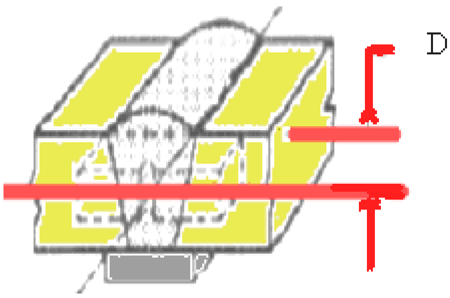

Fig 3(b) Location of impact test specimen.

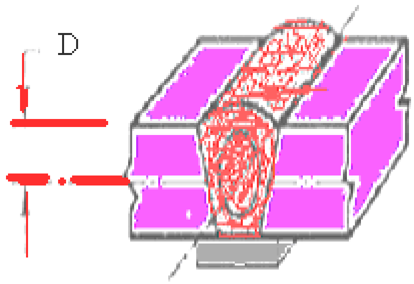

Fig 3(c) Location of all weld metal tension test specimen.

Table 5. Symbols and dimensions in inch and mm for samples as per fig 3(a), 3(b)and 3(c).

Letter Symbol	Dimensions	Inch	mm
L	Length(min)	12	305
T	Thickness	1±1/16	25±1.5
W	Width(min)	5	127
V	Backup Thickness	1/2±1/16	13±1.5
D	Specimen Centre	3/8±1/32	9.5±1.0
B	Backup Width(min)	2	50
R	Root Opening	1/2±1/16	13±1.5

7.2.1. Visual Examination

All three types of test specimens (assemblies) were visually inspected during and after welding. During welding with pure slag, it was observed that undercuts have occurred along the sidewall of groove, which, were later removed by grinding. Slag detachability was poor.

No such problems were experienced during welding with recycled and fresh available flux. Stable arc was observed from the voltmeter. No under cut, surface porosity, and pockmarks were observed on the welded test assemblies. The bead was smooth and its appearance was good.

7.2.2. Dye-penetration Test

After removal of the reinforcement with the help of a grinding machine and dressing it, dye-penetration test was carried out on all the test assemblies to detect porosity and surface cracks. First with the cleaner the weld surface was cleaned, dried and then die penetrant was applied over the surface. 15 minutes time was allowed to enter the penetrant. The excess penetrant was then removed by soft and clean cotton .A developer was then applied to the surface. The developer acted as a blotter and drew out a portion of the penetrant from the flaws and the flaws were immediately detected. Scattered porosity was observed on the test sample deposited with pure slag. No surface defect was observed on the test assemblies prepared with fresh flux and recycled slag.

7.2.3. Radiographic Test

X-ray radiography was used to detect defects in the samples. It was observed that test assembly prepared with pure slag was unsatisfactory 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 inclusion may be due entrapment of slag in under-cuts as slag detachability was poor. Slag entrapped in sidewall under-cut may lead to 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.

7.2.4. 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 2. Recycled slag with EL-08 wire combination confirms to AWS SFA A5.17; F7A0-EL8 classification, which is equivalent to Mergearc[1] SAF-6 flux. As per this classification, for this flux (Recycled slag)-wire combination minimum yield strength, ultimate tensile strength and % elongation required are 360 N/mm^2, 420 N/mm^2 and 20% respectively, which was 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.

7.2.5. Impact Test

In evaluating the test results, the highest and the lowest values obtained have been discarded as dictated by AWS 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^{o}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 ^{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.

7.2.6. Micro Hardness

Change in microstructure, grain growth, hardness and residual stress in a weldment are very much dependent on the temperature distribution, peak temperature and cooling rate. Fig.4 compares the micro-hardness survey carried on the cross section of weld bead deposited with pure slag, fresh flux and recycled slag respectively. It has signified that the hardness achieved with recycled slag was more than achieved with pure slag and similar with fresh flux. Increased amount of C, Mn and Si through recycled slag resulted in higher hardness.

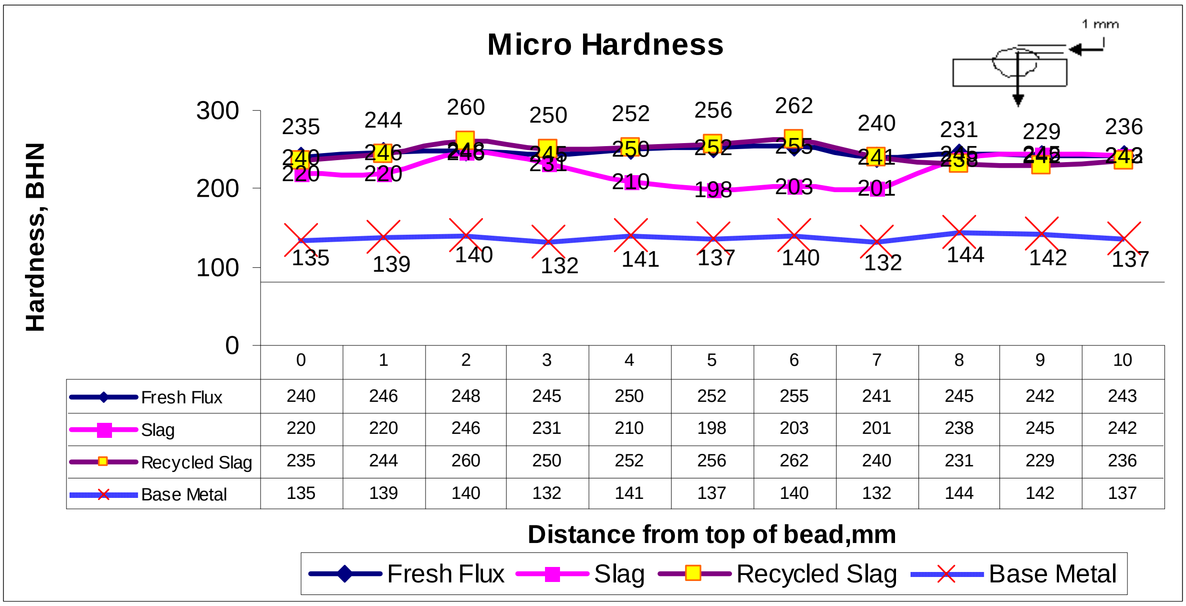

Fig. 4 Micro-hardness survey across the beads

7.2.7. Fractography

Scanned electron micrographs of the fractured tensile test specimens could be seen from Fig 5 and 6 belonging to the weld metal deposited with pure slag and recycled slag respectively. Both the micrographs illustrated ductile mode of failure. However, Fig.6 pointed toward larger dimple size and consequently indicated higher energy absorption before fracture, which, further supported the results of tensile and impact tests. The theoretical relation is that larger the dimple size, higher the energy absorption. It can be attributed to the increased amount of carbon, manganese and silicon in the weld metal deposed with recycled slag.

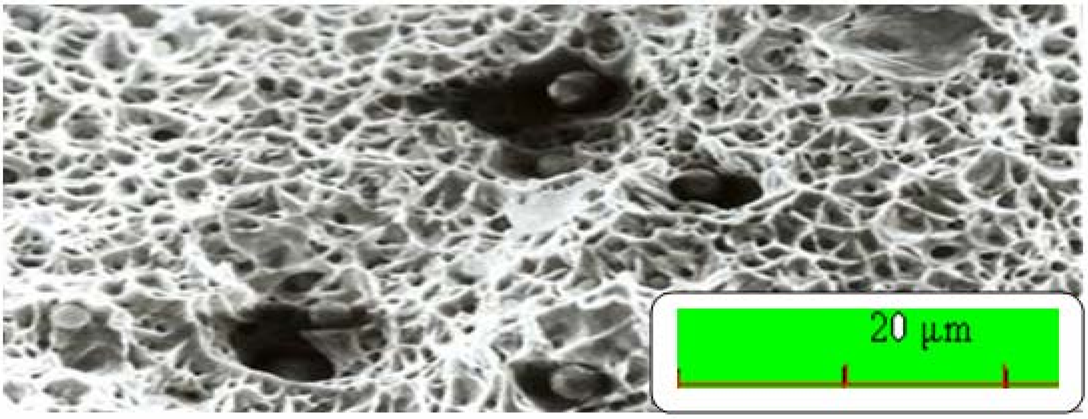

Fig 5. Scanning electron micrograph of the fractured tensile sample of weld metal deposited with pure slag.

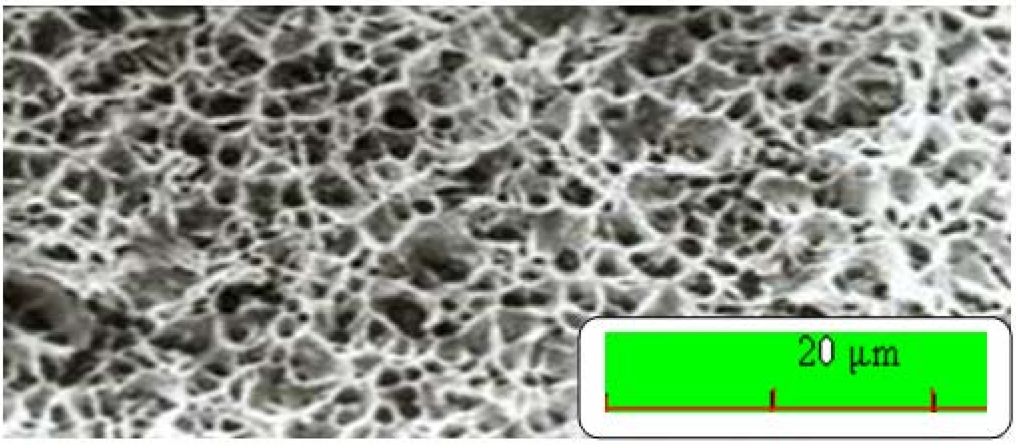

Fig. 6 Scanning electron micrograph of fractured tensile sample of weld metal deposited with recycled Slag.

7.2.8. Metallurgical examinations

For metallurgical analysis 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, Fig 8 and Fig.9.

The presence of columnar grains with grain boundary ferrite and islands of polygonal ferrite could be seen from the microstructure of weld metal deposited with pure crushed slag. Ferrite side plates were also observed. The presence of significant volume fractions of grain boundary ferrite and polygonal ferrite can be attributed to the very low percentage of carbon (0.025%) in the weld metal deposited with pure slag.

The microstructure of weld metal obtained with recycled slag (Fig.9) indicated that the average width of columnar grains is smaller. In addition, the amount of grain boundary ferrite has reduced, the crystallite size within the columnar grains was smaller, and there was more acicular ferrite. This decrease in primary ferrite could be attributed to the increased percentage of carbon (0.08%).

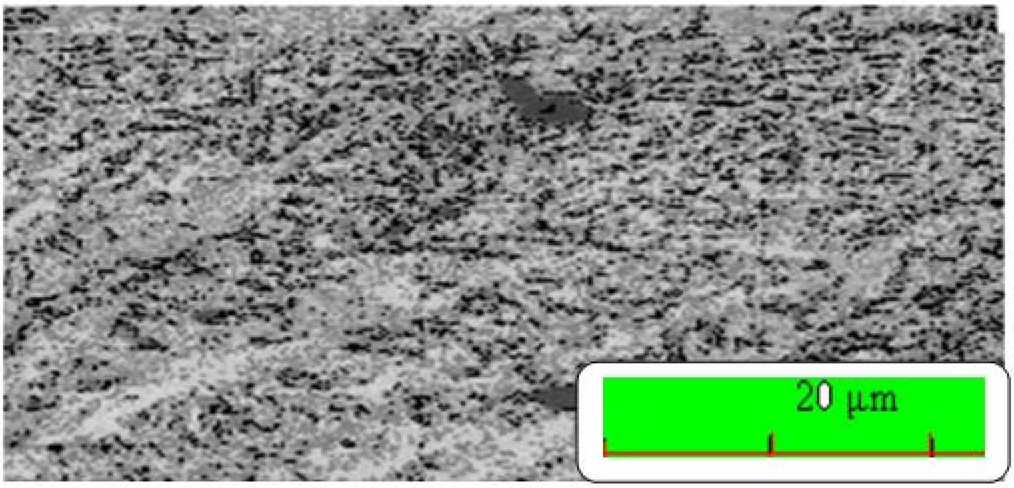

Fig.7 Microstructure of weld metal deposited with pure flux

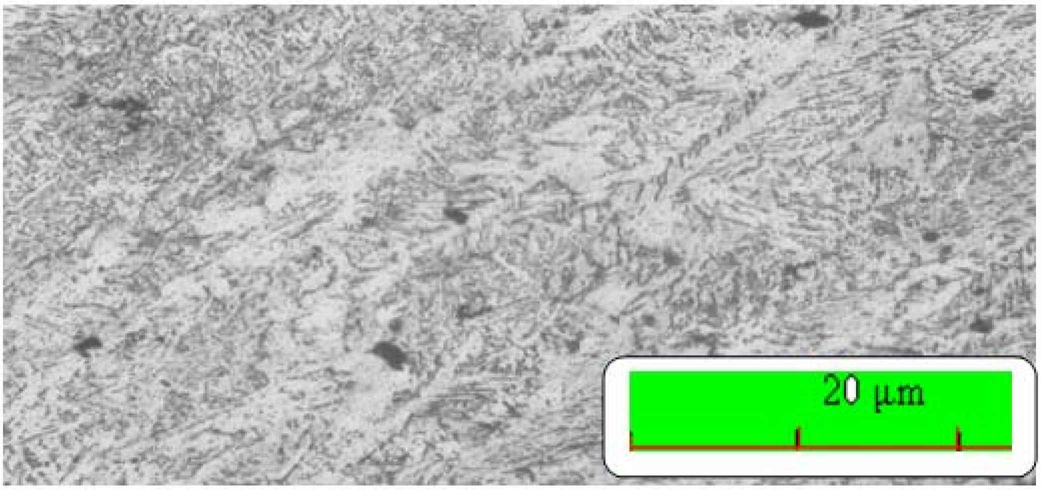

Fig. 8 Microstructure of weld metal deposited with pure slag

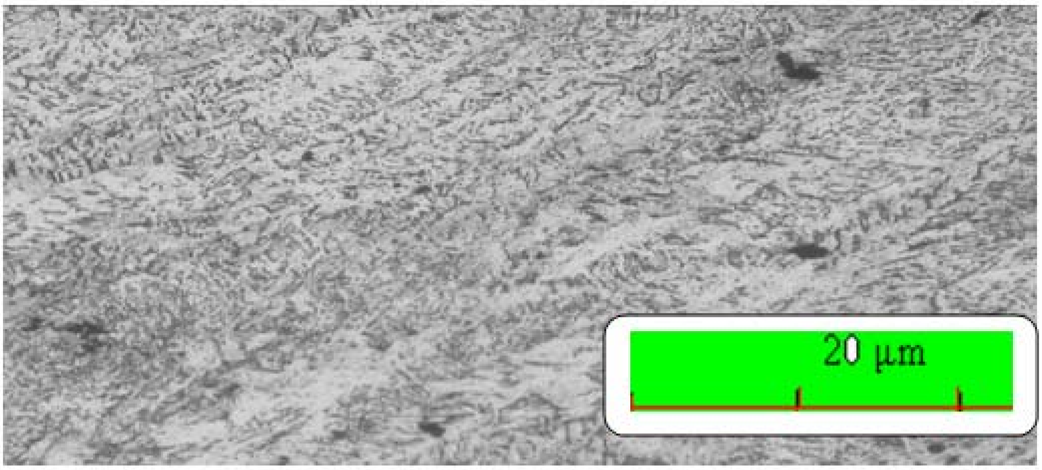

Fig. 9 Microstructure of weld metal deposited with recycled Slag

8. Cost Analysis

By products are difficult to cost because a true cost is indivisible. But, Cost analyses can provide estimates of what a program's costs and benefits are likely to be, before it is implemented. It also helps improve understanding of program operation, and tell what levels of intervention are most cost-effective. Considering these view, Cost analysis of recycled slag per 100 kg was calculated and compared with the equivalent fresh flux available in the market according to the principle of market value method or reversal cost method. It is similar to the technique of by product revenue deducted from production cost. These certainly enable the company to decide a certain level of services to a specific number of clients at specified costs.

Simple mathematical calculations have been carried out gathering market value of the raw materials and additives which are coupled with the manufacturing cost. Labour costs are considered according to the current rates set by the local governing authorities. As per the standard norm being followed by the company overhead and profit are considered at 10% and 12 % respectively. The detail conversion cost per 100 kg was thus obtained which was compared with the fresh flux available at a price from the local market. Approximately, 71 % saving has been reported. Although, no relative significance of the environmental impact cost have been considered and calculated. This recycling will save lots of environmental hazards and pollution, which have adverse effect on the quality of life. The detail analysis has been done and presented in Table 6.

Table 6. Cost breakup of recycled slag and fresh flux per 100 kg

Sl No	Cost Head	Material Specification	Process description	Cost	% of Cost
				US Dollar	
1	Raw Material Slag	Slag	Cost of Slag used inclusive of Transportation charges	1.10	2.63
2	Additive	Ferro Manganese	Cost of additive used	8.80	21.03
3	Additive	Ferro Silicon	Cost of additive used	6.05	14.46
4	Additive	Ferro Titanium	Cost of additive used	6.60	15.77
5	Additive	Calcium Carbonate	Cost of additive used	0.47	1.13
6	Additive	Silicon Oxide	Cost of additive used	0.39	0.92
7	Binder	Potassium Silicate	Cost of binder used	3.30	7.89
8	Processing		Sintering Cost	3.30	7.89
9	Crushing and Milling Cost		Crushing and Milling of Slag with additives	2.97	7.10
10	Labour Cost		Cost of Labour employed in the job	45.00	107.53
11	Sub Total			33.97	
12	Over Head @ 10 %	On 1 to 11		3.40	
13	Profit @ 12%	On 1 to 12		4.48	
14	Conversion cost per 100 kg Recycled slag			41.85	
15	Actual Market Price of fresh flux			143.00	
16	Saving			101.15	
17	% Saving			70.73	

9. Discussion.

Slag can be re-cycled successfully and the following guidelines should be adopted for slag re-cycling and its subsequent use. A locally applicable slag purification and recycling arrangement has been developed.

The following recommendations have been done for obtaining better results from the use of recycled slag.

1. During continuous welding operations unused slag can be recycled and returned to the flux hopper for re-use.
2. Slag and metallic particles should be removed from the recycled slag and discarded prior to using recycled slag.

3. Fines should be removed from recycled slag. Excessive levels of fines will impair the welding performance and degrade the weld bead appearance.
4. Slag should be used mixed with additives and binder re-crushed and processed as flux for welding operations.
5. Following a break in welding operations any unused recycled slag should be removed from the welding machine hopper and stored in a heated hopper (250-300°F, 120-150°C) for a maximum period of 24 hours.
6. This slag should then be mixed with twice its volume of new flux prior to reuse.
7. Care should be taken when using forced air recycling systems to ensure that such systems use only dry air and that the slag particles are not damaged or degraded by using high air flow rates (which can result in the formation of large quantities of dust). Only dry air must be used in forced air recycling systems to prevent moisture pick up by the slag. Compressed air systems used for operating power tools should not be used for flux recovery as they may contain oil lubricant.
8. During the manufacturing process SAW Wires are baked at a high temperature and following manufacture the flux coating has low moisture content. Prior to use with recycled slag proper care has to be taken. SAW Wires should be left in their unopened original moisture proof hermetically sealed containers and stored in a dry area. Once the container is opened, the deep sealing lid should be replaced as the lid provides an effective barrier to moisture ingress. Once the container is opened, the electrodes should be stored in a cabinet equipped with either a desiccant or heated to 10-15ºF (6-8ºC) above the highest expected ambient temperature or both.

10. Conclusions

The weld metal properties in this research are determined either in the as-welded condition or after a post weld heat treatment [one hour at 1150°F (620°C)], or both. Most of the weld metals are suitable for service in either condition, but the research does not cover all of the conditions that such weld metals may encounter in fabrication and service. Procedures employed in practice may require voltage, amperage, type of current, and travel speeds that are considerably different from those specified in the submerged arc welding standards. It has been observed a fluctuation of ± 8% from specified ranges.

In addition, differences encountered in electrode size, electrode composition, electrode extension, joint configuration, preheat temperature, interpass temperature, and post weld heat treatment can have a significant effect on the properties of the joint. Within a given electrode classification, the electrode composition can vary sufficiently to produce variations in the mechanical properties of the weld deposit in both the as-welded and post weld heat-treated conditions. Post welds heat-treatment times in excess of the 1-hour used for classification purposes in this specification.

From the research of the nontraditional approach in reducing cost through scientific involvements in recycling saw slag, the following conclusions can be drawn.

1. SAW slag can be recycled.
2. SAW slag recovery program should not be carried out without testing to prove the recycled product will have no detrimental effect on the weld deposit.
3. Weld metal chemistry achieved with recycled slag was within the acceptable range of AWS SFA 5.17-89 / A5.17M-97.
4. The mechanical properties of weld metal were acceptable as per AWS SFA 5.17-89.
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 recycling of SAW slag is a feasible alternative to buying new flux for saw process users. It provides economic benefit to companies and allows them to environmentally responsible.
8. The use of recycled slag is economical by 70.73% in the present rate of consumables.

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