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ORIGINAL PAPER

Recovery and Recycling Silica Flux in Submerged Arc Welding – Acceptable Properties and Economical Correlation

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Abstract

This research aims at optimum utilization of waste recycled submerged arc welding slag along with virgin flux in place of pure virgin flux without compromising the quality of welding and effective waste reduction. The related quality aspects, determination of quantum of recycled slag to be used are evaluated through suitable experimentation. The application, process parameters, welding parameters, parent material and filler wires are also changing in line with the job order. In such a dynamic environment weld economy has to be inbuilt through proper mechanism. A suitable mechanism involving optimum usage of spent slag with virgin flux will be ideal in such a dynamic environment An attempt has been made to introduce the waste recycled slag along with virgin flux during Submerged Arc Welding (SAW) of low carbon steel with suitable wire and optimum welding parameters. Varying weight percentage (20, 30,40 & 50 wt.%) of waste slags were mixed and submerged arc welding was carried out; Mechanical testing, Radiography, Ultrasonic tests were employed to ascertain the quality and arrived the optimum mixture of slag and virgin flux. Results revealed that usage of waste slag between 20 and 30 wt.% showcased optimum tensile strength, impact strength, hardness and reduction of cost. However any deviation from the optimum level of recycled slag with virgin flux will deviate from optimum level of quality or profit.

Keywords SAW · Recycled slag · Virgin flux · Mechanical behaviour · Quality aspects

1 Introduction

Industrial revolutions have changed the production techniques and provide comfort zones for the mankind. Technological up gradation and digitalization improved the productivity but accounts variety of unwanted industrial discharges [1–3]. The knowledge and implementation of waste to wealth will be the key solution for enhanced and economical management of industrial waste. The growth rate and development of industries creates several environmental issues which are mostly man-made [4–6]. One such issue is generation of waste and its disposal. Several measures were taken to manage the waste at source and efficient clearance varies according to the type of industry. The most common pollutants arise from sources of air, water and soil leads to challenges. Such challenges faced are globally ecological and its effective control will avoid environmental risks [7–10].

Currently as reported by world steel association during January 2020, around 150 million tons of steel was produced. Every ton of steel produced 0.5 wt. % of welding takes place and consequently the flux usage [11]. Submerged arc welding is a process of metal joining with high heat input and found application in heavy metal fabrication industries. This process produces slag of 0.221 g/mm of submerged arc welding. Another survey reveals around 10,000 tonnes of flux was consumed during the year 2006 [12–14]. Such large quantum of slag produced every year becomes non-biodegradable waste and disposal would be a threat in the future. Submerged Arc Welding is a process by which two work pieces are joined by heating and fusing them with an arc

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between bare metal electrode and the work. The shielding of arc and the molten metal is provided by the granular flux blanket. This process produces high deposition rate welds. The electrode fuses and deposit over the joint and simultaneously flux get fused and covers up the weld puddle and providing the protective medium [15, 16]. The protection of weld pool from atmospheric exposure prevents oxidation and ensure sound weld. In this process substantial amount of flux gets converted in to slag while reacting with the fused metal. A significant amount of molten flux also gets attached with the slag and goes as waste [17, 18]. Overall flux wastage in the form of slag (spent flux) and dust is very significant and this paper attempts to recover the slag and explains the technique used and quality standards achieved while arriving optimum slag usage for cost benefit. SAW slag finds limited scope in land filling and civil construction activities but the rest possess environmental issues and discarding will be a costly affair. Formation of slag may not be avoided but ways and means of utilizing it properly to the advantage of production process will enhance the economy and profit. So any attempts in this line will be a welcoming change. Such changes can be brought in the form of recovery or recycling of generated slag to reduce wastage of resources, pollution and economy. Conversely land filling with slag causes decrement in the soil fertility, this attribute the formation of several waste land [19, 20]. Civil and construction industries accounts for partial usage of slag in their application. Over the period slag is dumped in open area causing environmental issues. The size shape and projected particles of the slag creates problem for the humans and cattle. However the complete recovery of slag may not be possible to the fullest extent but partial usage will be qualitatively and quantitatively a viable solution to address the issue. Attempts towards usage of 100% slag will be a costly affair and may not be economical and warrants only limited addition of slag usage considering the economic front [21–25].

Table 1 Chemical composition of the virgin flux

Flux constituent	SiO_2	TiO_2	MgO	CaO	MnO	Al_2O_3	CaF_2
	15		31		31		18

Singh et al. studied the effect of flux composition on element transfer by using agglomerated flux while joining mild steel plates using SAW, reveals that carbon and manganese contents were transferred from weld metal to slag. The amount of element transfer varies but depends on flux chemistry, metal slag reaction, and dilution [26]. Prachya peasura investigate the effect of SAW process parameter over the mechanical properties of A283 grade pressure vessel steel. Results

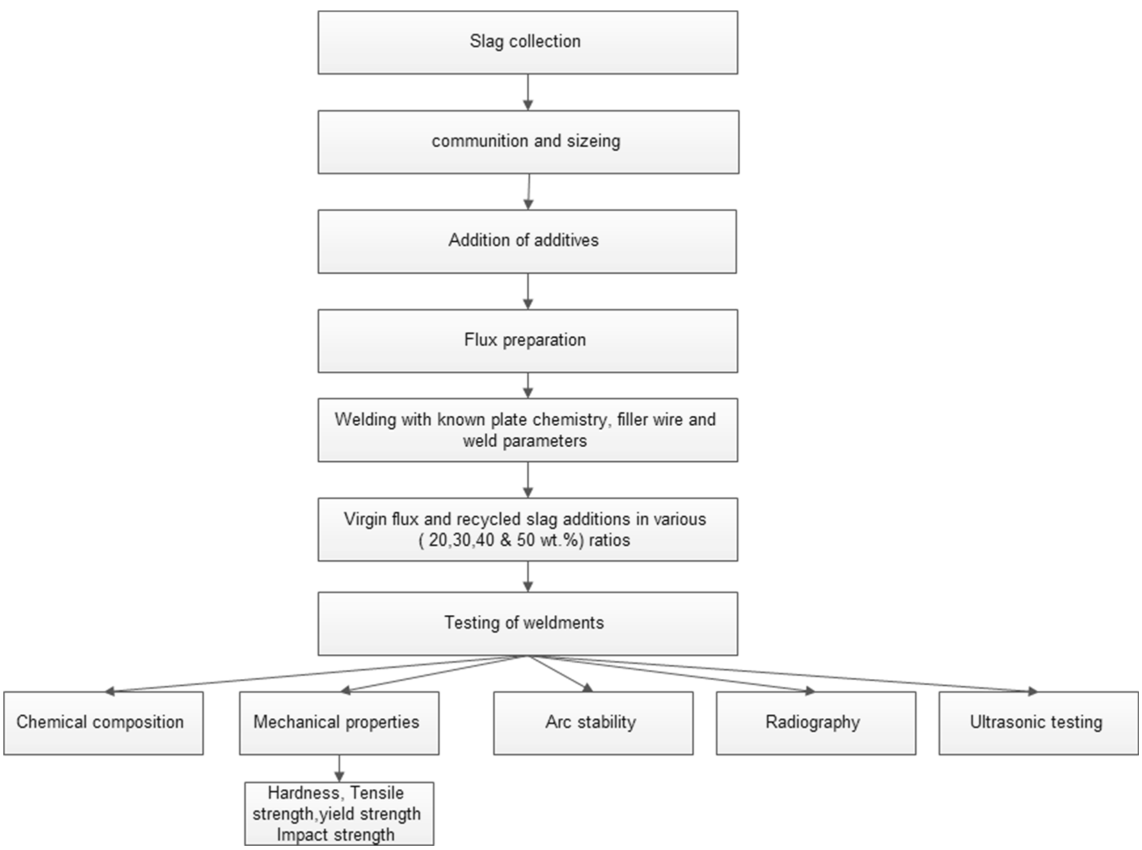


Fig. 1 Methodology for submerged arc welding on optimum slag flux ratio

Table 2 Mixing proportion of virgin flux and recycled slag in weight %

Recycled slag: virgin flux	20:80	30:70	40:60	50:50
Designation of mixing proportions	RS20	RS30	RS40	RS50

revealed that welding current, voltage and travel speed significantly affect the mechanical properties. He also arrived optimum SAW parameters using response surface methodology [27]. Ana Ma paniagua Mercado and co-workers developed SAW on AISI 1025 Steel and investigate the mechanical and microstructural properties on varying flux composition. Results reveals that TiO_2 bearing flux have shown better strength and exhibits acicular ferritic microstructure [28]. Singh et al. investigate the collected slag during SAW, processed, mixed with additives and flux. The recycled flux is used to weld and mechanical properties and x-ray test was carried out and found satisfactory results [29]. Jatinder Garg et al. recycled the SAW flux on cladding stainless steel plates and studied corrosion aspects. Microstructural aspect, grain size, ferritic content and concluded a significant cost reduction in using recycled flux [30]. In survey of literature clearly indicates the need for optimum usage of slag while designing the flux for submerged arc welding applications. Submerged arc welding is taking place in different places depending upon the application and also in specified work environment. A suitable mechanism involving optimum usage of spent slag with virgin flux will be ideal in such a dynamic environment. In this approach the usage of spent slag in various proportions and arriving an optimum spent slag usage is envisaged and confirming to various quality parameters. A study has been carried out using recycled slag in various proportions with basic agglomerated flux on welding of low carbon steel with EM12K. to arrive optimum usage of flux. Necessary mechanical testing were carried out along with radiography and ultrasonic test to ascertain the quality.

2 Experimentation

2.1 Materials and Methods

In past decades, SAW slag materials were found to be dumped in yards, land filling activities which possess eco-friendly issues and land pollution. Attempts were also made to use slag in cement mortar and masonry applications of civil engineering. However the actual recycling of slag in welding industries has not gained momentum. An approach has been made to introduce recycling of slag in welding industries without compromising its weld quality. During SAW process, the flux material, while welding gets converted into liquid flux and reacting with base and weld metal and protecting the weld pool from atmospheric contamination viz. oxides, fumes, UV emission etc. and also aids in metal transfer to the weldment. In this process ultimately flux is converted into slag. The slag also consists of unfused flux adherent to top surface which can be reused.

In this proposed research work, a systematic approach of collecting the slag at the generation sites from the similar applications. Thus the collected slags are processed through ball mill and magnetic separator for sizing and separation of iron particles. This followed by sieving and sizing (Fig. 1). These powdered slags are sintered at 400°C for 3 hrs. before any further operation to avoid combined moisture. Simultaneously the virgin flux material as illustrated in Table 1 is mixed with basic ingredients of powdered slag as per the Table 2. The flux used in this approach is the combined silicate flux. The slag generated using virgin flux is termed as silicate slag. While introducing the recycled slag along with virgin flux there is need to quantify the content of the slag to virgin flux. Out of available quantification techniques wt.% is consider to be the best representation [30, 31].

Both virgin flux and recycled slag are mixed in a double cone blender and mixed for 30 min and mulled in a wet mixer along with 10% sodium silicate binder and mixed thoroughly, thus mixed mass was subject to agglomeration using the granulator and pelletized. These pellets are subject to drying, heating and sintering for removal of adherent and adsorbed moisture. The sizing of flux is carried through suitable sieve shaker and packed in double lined High Density Poly Ethylene bags with proper labelling on the bag. Low carbon steels which predominantly exhibit better strength to weight ratio and used in structural application is selected as base plate. The 5 mm thick plate with single V groove edge butt joint welding was used. Herein EM12K is the wire designated for a carbon steel plate, basic flux combination. This solid wire with a nominal 0.12% carbon, 1% manganese and 0.1 to 0.35% silicon capable of achieving an ultimate tensile strength of 60 k.p.i. (415 MPa), a Charpy-V impact strength

Table 3 Elemental composition of low carbon steel:

C	Mn	Si	P	S
0.170	1.260	0.265	0.027	0.02

Table 4 Chemical composition of welding wire EM12K

C	Mn	Si	S	P	Cu
0.108	0.986	0.21	0.014	0.012	0.17

Table 5 Selected welding parameters for SAW process

Welding current, I amps	Voltage, V volt	Travelling Speed V, mm/ minute
450	30	400

of 27J at -50°F (-46 °C) in the post weld heat treated condition which finds application in pressure vessels, structural and bridge fabrication, boiler and pressure vessels, storage tanks etc. is used in this experiment.Table 3 depicts the welding parameters that are selected based on welding experts opinion from industries. Welding parameters are generally determine for adequate fusion of base metal and filler wire which leads to optimum strength and quality. These parameters will be further selected based on the plate thickness, wire speed and flux. Inspite of handbooks which illustrates the optimum welding parameters for particular chemistry, thickness of base plate welding wire and flux. The optimum welding parameters are arrived based on the few experimental trial and error method followed by discussions with industrial users.

Designated flux RS20, RS30, RS40 and RS50 are used for experimentation. Each designated flux is subject to following testing procedures (Table 4). The following tests were employed to assess the weld quality as per AWS and appropriate standards suitable for such test. Though there are number of test that can be employed in accessing the quality and soundness of the weldment but the following tests were suitable and employed for quality assessment.

Chemical composition of base plate and wire are illustrated in Tables 5 and 6. However during welding the weld metal forms with melting of plate, flux and wire and related dilution and chemical changes taking place and simultaneous formation of slag. Slag chemistry will thus affect the weld metal chemical composition and its mechanical properties. So the element composition of weld metal which plays a vital role was carried out using EDAX. The most important parameters to determine the soundness of the weldment are mechanical properties viz. Hardness, Tensile, yield and impact testing. Likewise ultrasonic testing and radiography testing determine the qualitative assessment of the soundness. All such parameters are evaluated and values are reported suitably and analysed. The results based on three experimental values were considered and the average values are reported in the results [32].

3 Result and Discussion

3.1 Element Confirmation of Recycled Slag

The weld metal element confirmation is analysed using Energy-dispersive X-ray spectroscopy (EDAX) and found the presence of carbon, manganese and silica. The weld metal was analysed for every incremental slag addition and found the reduction in manganese and silica (Fig. 2). Basically the manganese is the deoxidizer and content of the manganese will drastically reduce as the RS values increase. This fact is owing to exposure of weld metal to the atmosphere and thereby oxidation and loss of manganese and silica.

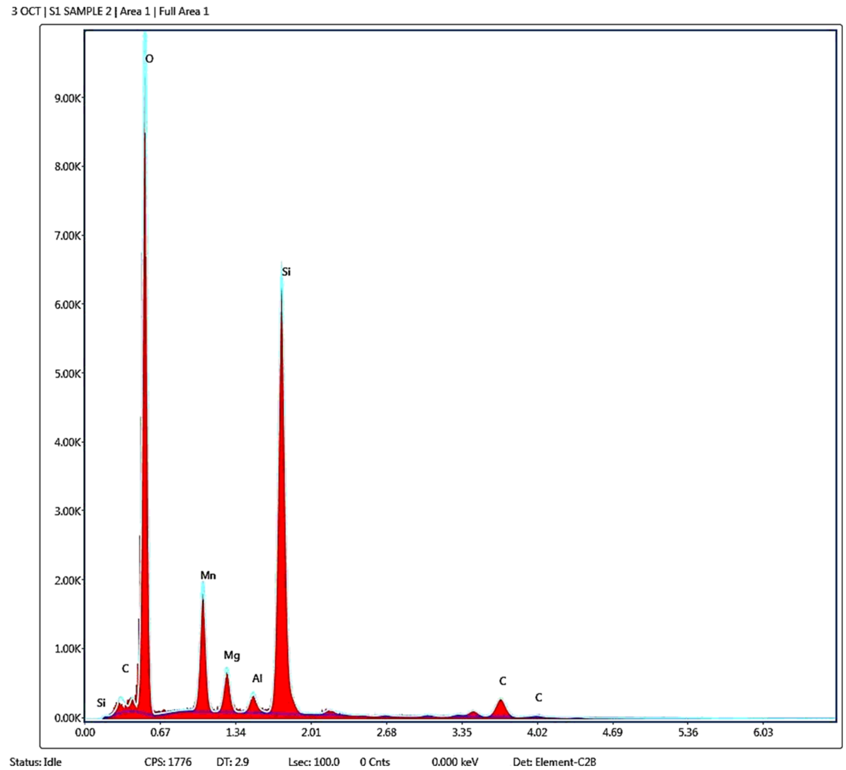
3.2 Arc Stability of Recycled Slag

The Fig. 3a-b illustrates the variation in arc stability against the varying slag flux mixture. Arc stability is determined by deviations in welding current and voltage during welding process. Flux generally helps to make the arc initiating process simpler and it can affect arc stability by comprising materials of various ionization potential in the liquid flux. Thus the materials in the flux constituents contribute either positively or negatively on stabilizing the arc. The arc stability is measured in terms of voltage and current during the welding process. As it's a continuous process the abnormality exhibited in terms of surge current and voltage was considered as contributions to the instability of the arc. The slag flux mixture designated as RS20, RS30, RS40 & RS50 are exhibiting variations in ionization potential and thus affects arc stability. The variations in voltage and current are measured in digital form and the number of variations with respect to mean voltage and mean current are plotted against the respective flux samples. The Fig. 3a-b illustrates both current and voltage varies abnormally as the slag constituents increases in the flux samples viz. RS20 to RS50 employed for welding purpose. This deviation against the mean voltage and current clearly indicates the absence of arc stabilizers when the slag constituent's increases in the samples employed for welding purpose. As the reuse of slag increase the arc stabilizers tends towards minimum or null. In general, higher the ionisation potential, hotter is the arc. This is because of ionised particles returning to work surface and liberating the higher energy of ionisation. As the percentage of slag increases the

Table 6 Testing of weldment

Sl.no	Testing method	Means of testing
1	Mechanical behavior	Hardness, Tensile, yield and impact testing
2	Non destructive testing	Ultrasonic/ Radiography
3	Element confirmation	EDAX

Fig. 2 EDAX of weld metal



effective scavenging and protection of the atmosphere gets reduced because of the higher percentage of slag and hence the ionisation potential to remove an electron from atom of the shielding gas which is produced by the flux and arc striking & smoothness of the arc become inferior compare to higher percentage of virgin flux in the recycled slag. The arc stability is dynamic and erratic due to absence of poor constituents of arc stabilisers in flux materials as the percentage of recycled slag increases [33–35].

3.3 Hardness of Weldment with Various Ratios of Recycled Slag

Figure 4 shows the higher hardness values on the base metal than HAZ and weld metal. It reveals the difference in cooling rate exhibited by the base metal, HAZ and weld metal [36]. Particularly it is true in the case of weld metal as the efficiency of flux blanket coverage on weld metal reduces cooling rate. In the case of weld metal the severity of coverage of remelted

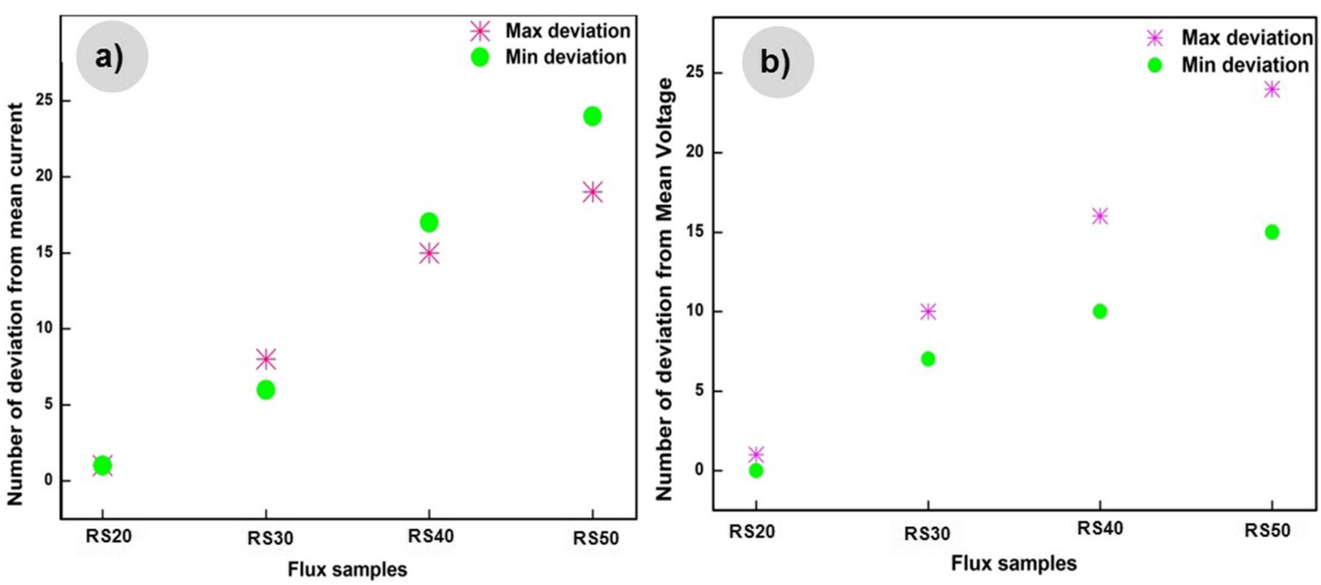


Fig. 3 Arc stability characteristics with respect to: (a) current (b) voltage

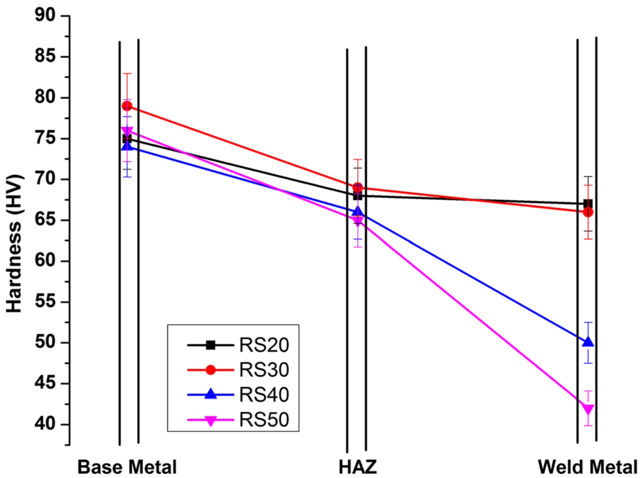


Fig. 4 Hardness of base plate, HAZ & weld metal with respect to recycled slag addition

flux on cooling rate varies from RS20 to RS50. Hardness exhibited on the weld metal by various recycled slag combination shows, at a lower percentage of reused slag shows better hardness and it drops drastically with respect to increasing order of recycled slag combination in virgin flux. Addition of recycled slag exhibits highly oxidizing characteristics in nature and forms metal oxides hence no metal transfer. This results inadequate effective liquid slag formation and expose the weld metal to atmosphere.

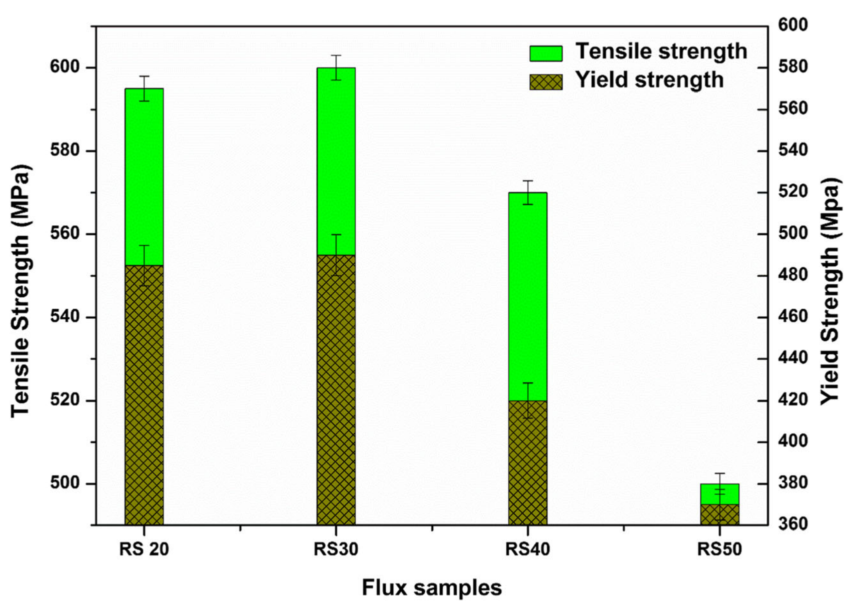
3.4 Tensile Behaviour of Weldment with Various Ratios of Recycled Slag

Tensile and yield strength of the weldment with various flux samples are tested under ASTM E8M standard. In the present study the tensile strenght value and yield stregth exhibits from moderate to very poor values as the recyled slag constitents increases (Fig. 5). At lower percentage of recycled flux addition, the tensile strength exhibited by the specimen is near normal strength as the percentage of recycled slag increases the tensile strength decreases gradually to drastic reduction. It is mainly due to inadequate coverage of weld metal by flux constituents there by increasing oxides, nitrides and slag inclusion. Added to this the deoxizer and transfer of elements viz. manganese and silicon, which contributes for tensile strength becomes ineffective and thus exhibits reduction in tensile and yield strength. This may also leads to vacancy formation, voids and porosity at higher percentage of recycled slag additions. The inclusion of slags and oxides in the weld metals leads to discontinues surface thereby reduction in tensile strength.

3.5 Impact strength of weldment with various ratios of recycled slag

Impact strength of weldment was studied by adopting ASTM E23 standards. Figure 6 depecit the average values(Three experiments) of impact stregth of the weldment. The lower values of yield leads to necking region, development of crack edge at necking region and micro seperation are instrumental in determining area under the stress strain diagram and such microsepration is continuous and the crack edge prograte as the load increase and failure occurs and thus impact values get reduces. In general ddislocations can move through the crystal grains and can interact with each other. Grain boundaries often hinder their transmission, creating a dislocation pile-up at the boundary and thereby making the material harder to deform.The Hall-Petch relation (law) gives a quantitative description of an increase in the yield stress of a

Fig. 5 Tensile behaviour of weldment with various ratios of recycled slag



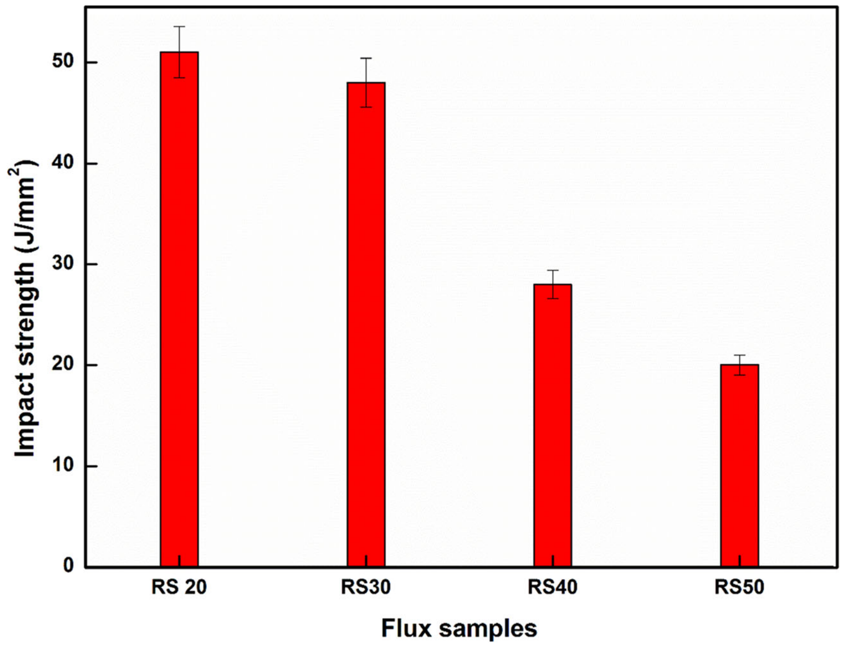


Fig. 6 Impact strength of weldment with various ratios of recycled slag

polycrystalline material as its grain size decreases. This relationship is based on dislocation mechanisms of plastic deformation: grain boundaries hinder the movement of dislocations. The absence of dislocation arresters like intermeattalic components and grain boundries causes large strain on visco plasticity results in cumbersome three dimensioal stresses which results and paves way for permature failures and reduction in toughness.

3.6 Radiography Testing of Weldment

The weldments obtained with various samples of recycled flux were tested for soundness using radiography. 50 HZ portable xray radiography from 100 to 450 ma was utlized to conduct the radiographic test. The precautionary measures like isolation, dosimeter test, usage of lead coverage at approriate places were employed. The radiography test

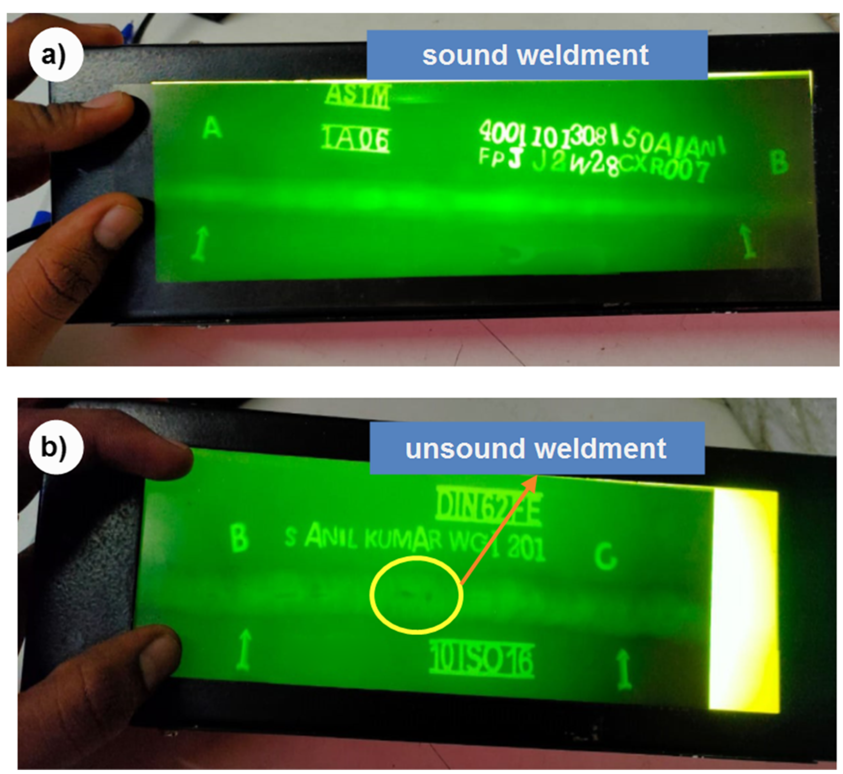


Fig. 7 Radiography showing (**a**) sound weldment (**b**) unsound weldment

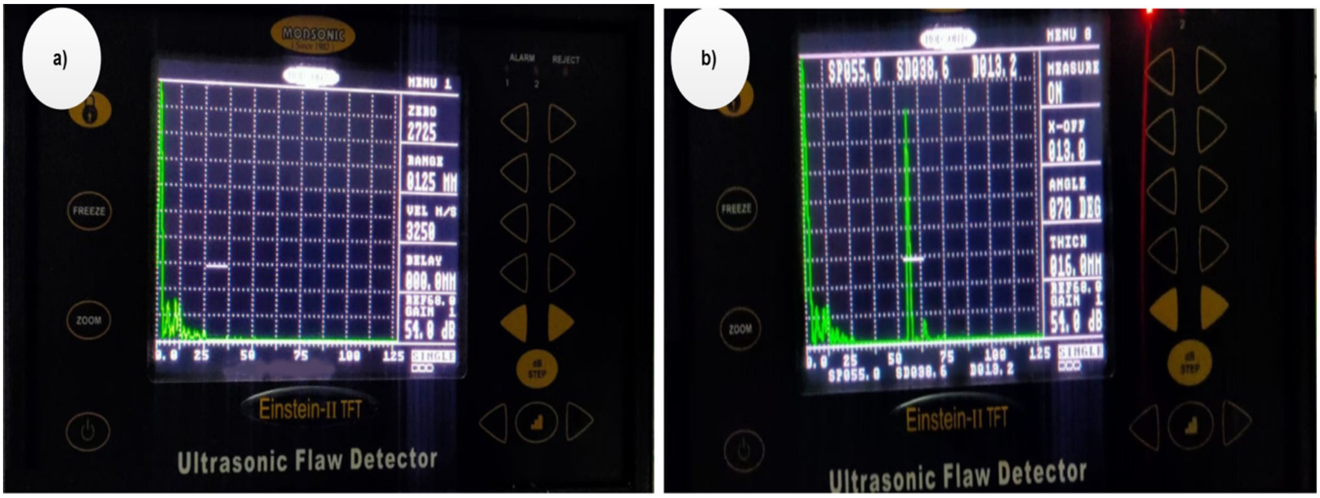


Fig. 8 Ultrasonic testing showing (**a**) sound weldment (**b**) unsound weldment

was employed as per EN 1435 standard to carry out soundness test and the obtained exposed film as shown Fig. 7a-b. The radiograph illustrates no flaw in Fig. 6a. whereas in Fig. 6b. shows dark spots and discontinuity which represents flaw in the form of porosities. The x-ray passes through the flaw and darken the xray film and becomes dark spot, this represents the presence of flaw. The presence of pores and flaws inside the weldment will be revealed only by the radiography test in the form of exposure to xray and there by darkning the radiographic films. The intesity of dark spot illustarate the size of flaw and discontinuity.

3.7 Ultrasonic Testing for Weldment

Ultrasonic testing of weldment was carried out using EN 1714 standard and the results are depicted in Fig. 8a-b. The ultrasonic waves produced and calibrated initally with the help of V1 plate before testing. Then the ultrasonic waves are passed through transducer into the weld metal. The probe over couplant was moved from one end of the weld to other end longitunally. The flaw at appropriate place was indicated by the ultrasonic signals displayed in the form of flaw echo (Fig. 7b) and its location is indicated by the origin of peak in x axis and confirms the presence of flaw.

Fig. 9 Overview of the cost and quality aspects in recycled slag

3.8 Cost Consideration in Recyled Slag

Figure 9 illustrates the influcening factors for overall cost reduction and corresponding quality standards in weldment while using recycled slags. In the present study following processes contributes toward cost of recyled slag are as follows.

(i) Collection of slag – since it is collected over a period from one single factory the cost involed is negligible.
(ii) Processing the slag (crushing, powdering, blending, Addition of potassium silicate, aggloramation, peletaizing, sintering and sizing) - since it's a basic processing step and all the ingredents under go the same treatment, so no additional cost involved.
(iii) Quality layout- acceptance levels of mechanical properties, Element confirmation, ultrasonic and radiography quality are laid down based on the compromise struck between the quality requirement and cost reduction. This is considered as acceptance parameter to arrive the optimium recycled slag. Based on the compromise the quality standard and profit margin will be arrived.
(iv) The above process can be applied to any SAW environment for cost reduction and assuring the minimum weld quality.

At the acceptable quality level based on the prametric study carried out shows 20 to 30 wt.% of recyled flux contributes the maximum quality without affecting the acceptable level of quality. The deveiations either side will have to comprmise on either quality or cost.

4 Conclusion

In the present study focuing on the usage of waste various slag virgin flux percentage on SAW with low carbon steel combined with EM12K wire has been carried out. Arc stability, ultrasonic and radiographic testing, mechancial properties like hardness, tensile strength, yield strength, impact strength were carried out to assess the optimum usage of recyced slag and the following observations are made:

1. The limited study indicate 20 to 30 wt.% of slag results the optimum properties and sound weldment there by providing the maximum reduction in the cost.
2. Any deviation above or below 20 to 30 wt.% of the slag affects either quality or cost.
3. The increase in usage of slag beyond 30 wt.% in the flux causes poor arc stability, poor mechancial properties and unsound weldments.
4. The usage of slag within 20 wt.% in the flux causes improved arc stability, good mechancial properties and sound weldments but the profit margin will be less.
5. The study favours usage of generated slag in a dynamic jobbing environment along with virgin flux and contribute for optimum properties and cost reduction, This study paves way for recycling of slag and waste management in a dynamic jobbing environment.

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