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Experimental Investigation on Hardness of Submerged Arc Welding Slag Recycling for Stainless Steel Welding

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ABSTRACT

Submerged arc welding uses a granular flux that is converted to slag during welding. The generated slag is treated as waste that contains residues of minerals and is non- biodegradable. Due to its non-biodegradable nature, it creates an environmental problem, hence needs safe disposal. A huge amount of land and cost is incurred for its safe disposal. The study was undertaken to reduce these problems with submerged arc welding slag. For recycling SAW slag, Agglomerated fluxes were prepared by mixing different amounts of alloying element and deoxidizer (by hit and trial) to the milled slag and using potassium silicate as a binder. It was found that the addition of SiO2 (8%), Cr2O3 (4%), TiO2(3%), MnO (2%) gave the desired weld chemistry, according to ASTM A 240 for SS 304. The weld performance was checked after obtaining the desired weld chemistry by performing different tests like the Tensile test, Charpy test, Microhardness survey. The ferrite morphology was studied after looking at the microstructures captured by an optical microscope. The ferrite content of the weld was also measured through the Feritscope FMP-30.It was observed that recycled slag showed comparable arc stability and slag detachability to fresh flux. The ultimate strength of weld with recycled flux was 559.36MPa which is more than the tensile strength of the base metal (SS 304) and comparable with fresh flux. The cost incurred in recycling is 54.62% less than the fresh flux, Hence, it can be concluded that recycled flux can be a good replacement for fresh flux in the industries at a reduced cost.

Keywords- Submerged arc welding, Flux, Filler material, Hardness

Introduction

The submerged arc welding process is the type of fusion welding process that uses a continuously moving electrode towards the workpiece. The granular flux is used in submerged arc welding, which is kept in the hopper and flows through the nozzle ahead of the weld pool. When the arc is generated between electrode and workpiece, the flux melts and form molten slag. The molten slag is lighter than weld metal, as a result, it floats on the surface of the molten weld pool, protects the weld from atmospheric contamination. The slag formed during welding must be removed after welding. Submerged arc welding is mechanized as well as a hand held. SAW having a duty cycle of 100%, maybe operated at a very high current up to 2000A and arc voltage between 25 volts to 40 volts (Phillips, 2016). In submerged arc welding multiple electrode wires can be used, resulting in a very high deposition rate. Due to the very high deposition rate, SAW is widely used in the area where a thicker plate or thicker section is to be welded in a minimum number of passes. The range of thickness that can be easily welded lies between 3mm to 100mm (Sridhar, Biswas, & Mahanta, 2019). The amount of molten slag and weld pool generated, during welding restricts the SAW process to a horizontal position only. The process parameters should be carefully selected for a proper weld. The schematic diagram of submerged arc welding is shown in Figure 1.1.

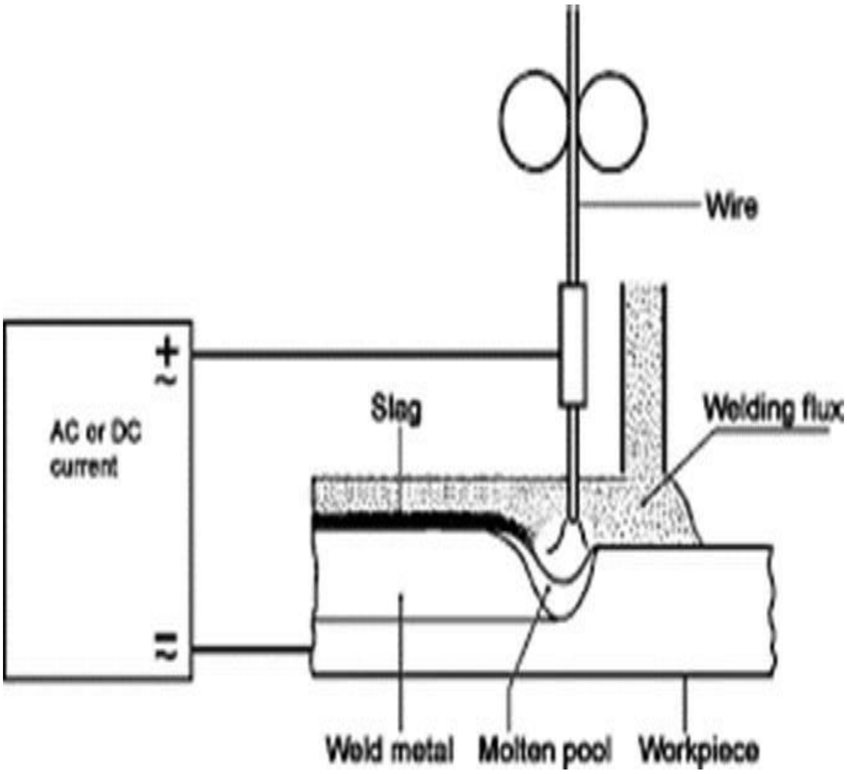


Figure 1. 1 Schematic diagram of submerged arc welding

Advantages of Submerged arc welding

- Huge weld deposition rate.
- The amount of smoke and fumes generated during welding is minimized.
- Absence of arc radiation.
- It is easy to change weld properties by changing flux constituents.
- Availability of automatic SAW machines so, the less-skilled worker can also perform welding.
- Thick metal can be welded in a minimum number of passes.

Limitations of Submerged arc welding

- Only flat position welding can be performed.
- It is not easily portable.
- Post welding, there is a requirement for slag removal.
- Only Suitable for welding of a thicker section, not for a thin section.
- It uses flux which can easily absorb moisture and will create weld defects.
- There is a requirement of a flux recovery system that adds complexity.

Applications of SAW

- SAW mostly find application in welding of thick metal in pressure vessel, marine vessel, and offshore structures (Choudhary, Kumar, & Unune, 2019)**.**
- It is used for welding weld ship structures and thick-walled stainless-steel piping (Nam, et al., 2018)**.**

Equipment for submerged arc welding

Following are major equipment for automatic submerged arc welding Welding power source

a) Welding nozzle

b) Flux hopper

c) Wire feeder and control mechanism

d) Travel mechanism

e) Control panel

Literature review

To have a clear understanding of what researchers found in the previous research and to find the research gap, it becomes important for researchers to go for a detailed literature review.Slag is the sprout of submerged arc welding, being non-biodegradable, their complete recycling is required to be done. A suitable methodology should be developed so that the complete recycling of SAW slag can be possible. Researchers are trying their best to recycle SAW slag for the last couple of years. Every researcher tried their way to recycle SAW slag like

a) Utilization of SAW slag in bricks and ceramics manufacturing.

b) utilizing the pure slag for welding, cladding.

c) some also tried welding by mixing slag waste with virgin flux.

d) complete recycling of SAW slag for the welding operation.

A detailed discussion of the literature reviewed under subcategories discussed above are discussed below under the heading of Utilization of SAW slag as a building material, Reutilization of SAW slag for welding, Use of Slag-flux mixture for welding, and Thorough recycling of SAW slag for welding.

Utilization of SAW slag as a building material

(**Ramesh, Gandhimathi, Nidheesh, Rajakumar, & Prateepkumar, 2013**) studied the feasibility of welding and furnace slag in Low-cost construction work having a good amount of compressive strength. In the manufacturing of the concrete block fine aggregate was replaced with waste, like welding slag and furnace slag in different percentages like 5 percent, 10 percent, and 15 percent. Cement, concrete, and slag were fixed for the preliminary study. The building materials were tested for compressive strength as per IS code and was found an increase in compressive strength when slag was used for making the concrete block. After 28 days, the optimum compressive strength of concrete was found to be 41 N/mm^2 for 5 percent welding slag and 39.7 N/mm^2 for 10 percent replacement of furnace slag. The findings showed that for practical purposes, 5 percent of welding and 10 percent of furnace slag replacement with sand was very efficient.

(**Ananthi & Karthikeyan, 2015**) Instead of using fine aggregates in the making of concrete, attempted to use industrial waste such as bottom ash and welding slag. The chemical composition of such waste in concrete was determined by X-ray diffraction technology and with the aid of a scanning electron microscope, their morphology was also examined. A compression test was conducted to test the strength of the prepared samples and found that the compressive strength of concrete with up to 10% of industrial waste mixed was found to be much higher than regular concrete.

(Ganga & Rajkohila, 2015) replaced some percentage of sand by the fused SAW slag, in the preparation of concrete. SAW slag, fine aggregate, coarse aggregate, cement, and water were mixed in a certain proportion to prepare M25 grade concrete. In the preparation of concrete, SAW slag replaced coarse aggregate in 10 percent,20 percent,30%, and 40% in a different sample. samples were prepared, for testing the compressive strength, tensile strength, and flexural strength, having a dimension of 150 mm cubic specimen, the cylindrical specimen having a length of 300 mm, and a flexural beam of 500×150×150 mm size respectively. The samples were prepared after the age of 7 days and 28 days from each composition i.e. 10%, 20%, 30%, and 40% SAW slag. The result of compressive strength of original concrete without SAW slag and that prepared with SAW slag mixing were compared, at age of 28 days, and was found that compressive strength reduces by 12.85% when 30% SAW slag replaced coarse grain aggregate.

(Francis & Abdel Rahman, 2016) Used metallurgical and agricultural wastes, like submerged-arc welding slag (SAWS) and rice husk (RH) wastes together with glass cullet, to find the feasibility of SAWS, in the production of lightweight porous glass- ceramics that could be useful for technical purposes. At different dosages of husks up to 20 percent, the effects of temperatures and RHs concentration on the porosity and water absorption of porous glass-ceramics have been addressed. It was observed in the result that glass-ceramics obtained on mixing glass cutlet with slag and 20% rice husk at 100- degree temperature had a porosity of 67.76% and water adsorption of 42 percent. The results presented a good way to treat submerged-arc welding slags, transforming them through a simple powder technology and sintering process into useful porous and usable glass-ceramic products

Reutilization of SAW slag for welding

(Singh, Singh, & Gargan, 2011) made an effort, without any further processing, to reuse the slag after crushing it. Two distinct specimens were prepared using fresh flux and crushed slag, keeping all the other conditions/parameters same. After the weld deposition, their quality was compared and was found that weld deposited using the crushed slag did not show any remarkable change in physical appearance. It was also found after the chemical composition analysis that the chemical composition was not lying in the range, according to AWS code. As an extension of their analysis (Garg, 2011), tried to compare the Bead geometry and microhardness, obtained by fresh flux and crushed slag. Significant variation was noticed in the bead geometry and microhardness of the specimens.

Use of Slag-flux mixture for welding

(Dobránszky, Németh, & Biczó, 2014) used slag-flux mixture varying slag percentage from zero to 40% in their experiment. Submerged arc welding was performed using all

slag-flux mixtures into a groove of the specimen having a dimension of 55×10×7.5 mm. After performing the spectroscopy, it was observed that slag-flux mixture up to 40% can give good weld properties without affecting the quality of weld metal. Researchers also discussed that slag-flux mix up to 40% have good slag detachability and arc stability.

After passing spectroscopy, Charpy impact toughness at -20 degree centigrade, and the tensile test was performed on the deposited weld metal and found that slag-flux mixtures up to 40% can give weld of good mechanical properties. They also illustrated that using the slag-flux mixture as flux can reduce wastage and cost as well.

(Somal, Singh, Singh, & Singh, Feb 2016) studied the effect of different amounts of slag and fresh flux mixture, on bead appearance, slag detachability, microstructural examination, and chemical analysis to find the matching composition according to standard. In the experiment, the weld bead was prepared with a different slag flux mixture. In the first trial, they started with a fresh flux containing a slag mix of 20%, then remaining flux with 40% slag mix, and in successive experiments, slag mix of 60%,80%, and 100% was taken to deposit weld bead on mild steel plate of size 200×100×12. It was found that if 60% of the slag is mixed with fresh flux, then a sound weld bead can be obtained. They also found that slag flux caused a significant reduction in sulphur and phosphorous which resulted in an improvement of impact toughness. The microstructure analysis was also done of the weld, prepared with the different slag-flux mixture, the almost similar microstructure was seen in bead deposited using different slag and flux mixture.

(Gupta, Sapra, Singla, & Gora, 2013) observed the effect of slag and flux mixture on mechanical properties and microstructure. Three fresh fluxes were prepared by mixing chemicals like CaF2, CaO, Na2O, MnO, SiO2, Al2O3, MgO, TiO2, FeO in different proportions using the agglomeration method, named the flux as A, B, C having the basicity index of 1.2, 1.3 and 1.5 respectively. The slag was mixed into the prepared flux A, B, C in the percentage of 10,20 and 30 respectively. The total number of beads deposited on the mild steel plate was 16 by these mixtures. The tensile test, impact test, microhardness survey, and microstructural analysis were done of all 16 beads. It was observed that ultimate tensile strength and hardness showed a decreasing trend, with an increase in the basicity index. It was also found that the addition of slag into prepared flux reduces the tensile strength, microhardness, and impact strength.

(Thirunavukkarasu, Kavimani, Gopal, & Das, 2020) experimented to find out the optimum percentage of slag mixture in virgin flux without compromising with the properties of the weld bead. In the different run of experiments, the researcher mixed the slag into virgin flux in the percentage of 20,30,40 and 50, to prepare weld bead on low carbon steel using welding wire EM12K at a current 450A. Different NDT was performed such as ultrasonic and radiographic to check the soundness of the weld bead. Mechanical testing like hardness, tensile, and impact testing was also carried to analyse, whether it is matching standard or not. It was concluded that weld with the slag-flux mixture, in between 20% and 30% gave an optimum result, but slight variation from the recommended percentage resulted in the poor weld. It was recommended that for the optimum cost-saving the proper slag-flux mixture between 20% to 30% should be taken for weld deposition.

Thorough recycling of SAW slag for welding

(Garg & Singh, 2016) recycled the submerged arc welding slag successfully for stainless steel cladding. In the experiments the weld chemistry of the cladding material was found by spectroscopy; it was found to match the ASME specification. The different types of tests on the cladding materials were conducted like Corrosion test, bend test, microhardness to find whether the cladding material will serve the required purpose. In the corrosion test, it was found that the resistance offered to corrosion by cladding material using fresh flux and recycled flux were comparable. By performing a bend test, it was found that the weld possesses good ductility and good bonding with the base metal. Microhardness of the cladding material was found good up to 350 VHN. The required properties of flux like arc stability and slag detachability were equivalent to that of fresh flux. The most important conclusion drawn was the cost-saving, it was found that the cost of recycled flux is 73% less in comparison to fresh flux available in the market. Subinox- 309L was used as an electrode for cladding on the Base metal SA 516 Grade 70.

(Nimker & Wattal, 2020) tried to recycle the submerged arc welding slag by mixing different deoxidisers in the slag. The flux prepared were used to deposit the weld on mild steel and also using fresh flux F7AZ and EH 14 wires. The weld chemistry was analysed to match the chemical composition according to AWS A 5.17, after meeting the required chemical composition, a series of the experiment were conducted to test whether the bead obtained is acceptable or not. Weld bead obtained using recycled passed all that series of an experiment like a tensile test, impact test. It was found that weld bead obtained using recycled slag has almost equal properties to that of weld bead obtained using fresh flux.

EXPERIMENTATION

The current chapters deal with the process used in the recycling of SAW slag and the test performed for evaluating the performance of weld deposited using fresh and recycled slag. The approach adopted for recycling has also been presented in form of flow chat.

Welding Equipment used for experimentation

TORNADO SAW M 800, manufactured by **Ador Fontech Ltd.**, was the submerged arc welding machine used for welding throughout the experiment. It is an automatic machine with a 100% duty cycle and an IGBT (Insulated Gate Bipolar Transistor) Inverter power source.

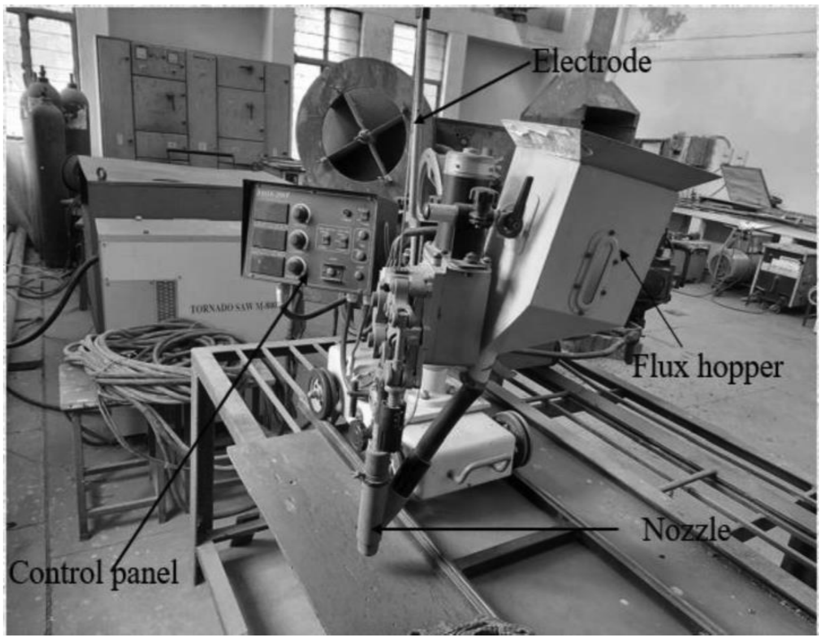
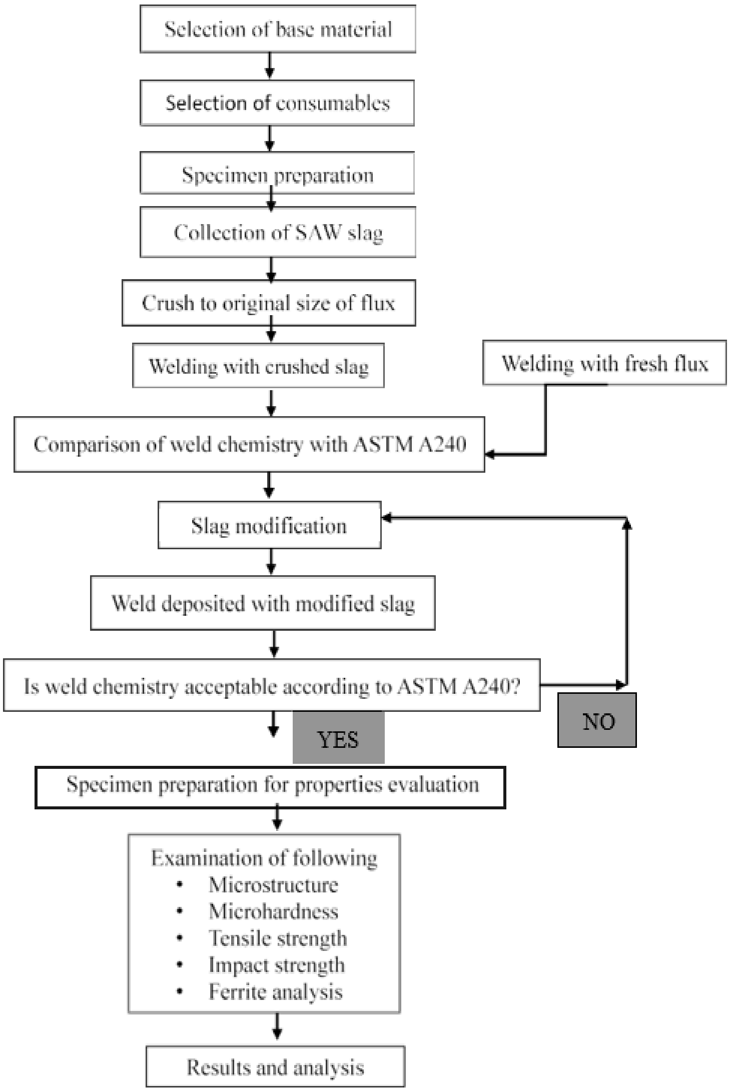


Figure 3. 1 TORNADO SAW M-800

TORNADO SAW M-800, shown in Figure 3.1 is available in the advanced welding lab of SLIET, which was used for welding throughout the experiment. On the control panel, three nobs are attached, from which three important parameters like voltage, current, and welding speed was controlled according to requirements. Forward and reverse welding both can be done through TORNADO SAW M-800 by simply pressing the switches available on the control panel. As we can see from Figure 3.1 flux hopper end and the wire feed end are the same i.e at the nozzle, to control the proper feed of flux surrounding the electrodes to protect the weld bead. The trolley moves on the rail while welding

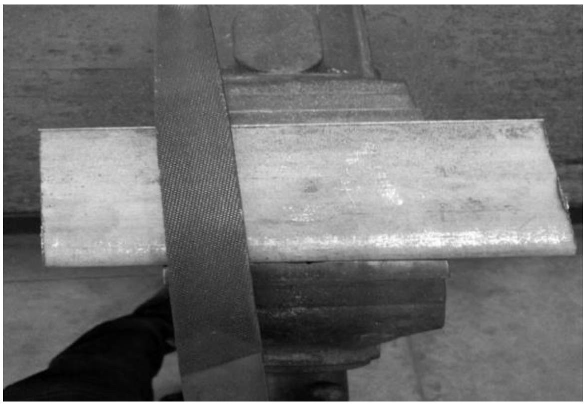
Methodology

The careful decision of plan of experimentation was taken to achieve a good result, it reduced the time of successful completion of the project undertaken. The methodology adopted for the desired result is presented schematically below.



Selection of base material

As per the literature review, it was found that recycling of SAW slag for stainless steel welding is yet to be explored. So, In the experiment, an austenitic steel SS 304 was selected as a base material for which recycling was done. SS 304 has a wider range of applications from cryogenic metal (e.g. For LNG transmission and storage) to a higher temperature i.e. in petrochemical industries, and also from the corrosive environment to the normal environment. So, developing the recycling methodology of SAW slag for SS 304 will result in greater savings in cost as well as a greater amount of slag waste reduction as well. SS 304 used as a base material in the experiment was procured from M.R. Metal, Ludhiana. The base material was tested for its chemical composition at Accurate Metallurgical Laboratories, Ludhiana.



Specimen Preparation

SS 304 procured from M.R. Metal, Ludhiana was a big plate having a dimension of 2400mm×100mm×12mm so, it was cut into the required dimension of 200mm×100mm×12mm as shown in Figure 3.3 by power hacksaw available in Fitting Shop at SLIET, Longowal.

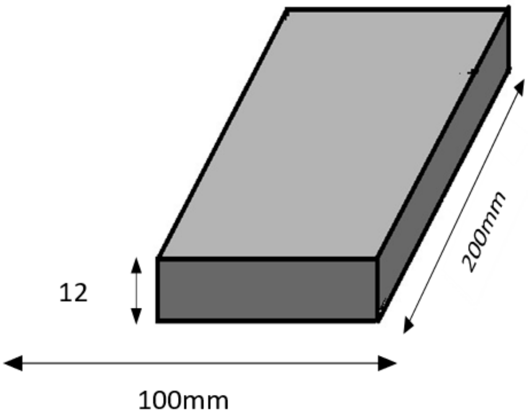


Figure 3. 3 Schematic diagram of the workpiece with dimensions

After cutting to the required dimension of 200×100×12mm^3 edge finishing was done to remove burr before making a groove angle on the plate as shown in Figure 3.4.

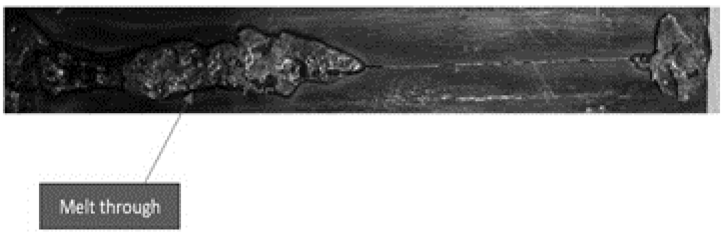


Figure 3. 4 Edge finishing

RESULTS AND DISCUSSION

The welding was performed using filler wire ER 308L keeping the same process parameters in all the trial runs. There was the only variation in the composition of the agglomerated flux as shown in Table 3.2 in each trial run to meet the composition requirement according to ASTM A240. Before going for actual trial runs to meet the composition requirements, there were several trials to find the optimum root face required to minimize melt through as shown in Figure 4.1 with proper fusion up to the root. It was found that when the root face was kept 2 mm at the selected process parameters then the melt through was less with the adequate fusion up to the root, hence Selected.

Figure 4. 1 Melt through

After achieving the objective of the root face, the trial started to meet chemical composition requirements according to ASTM A240. The chemical composition of the weld joint with fresh flux, pure slag is presented in Table 4.2 and that obtained in each trial during recycling as discussed in the previous chapter is presented in Table 4.3.

TENSILE TEST RESULTS AND ANALYSIS

The tensile test of the specimens prepared from weld with recycled flux and fresh flux was carried out according to the ASTM E8M. The minimum tensile strength requirement for SS 304 according to ASTM A 240 is 515 MPa and the tensile strength as mentioned by the catalog of GEEFLUX 303 X GEE SAW 308L should lie in between 560-670. The tensile test results ity (68 %) are presented in Table

4.4. Three tensile test samples as shown in Figure 4.8 were tested from each i.e. three from weld of recycled flux and three from the fresh flux and the mid result between highest and lowest is presented in form of a table and graph below.

Table 4. 4 Tensile test results

Sample Types	Ultimate strength	Breaking strength	% Elongation
Recycled flux test piece	559.36 MPa	246.44 MPa	25
Fresh flux test piece	576.94 MPa	198.28 MPa	21.87

It can be observed from the table that the magnitude of the tensile strength of specimen from the recycled flux and fresh flux are greater than that of the tensile strength of base metal according to ASTM A 240. However, the percentage elongation was reduced, this may be because the austenite grains are increasingly subdivided by ferrite dendrites; shear deformation is retarded. This leads to high strength and low ductility and a phase- boundary failure propensity (Gugelev, 1969). In the experiment two passes were used to fill the groove, this may be another reason for low percentage elongation because as the number of passes increases, there is a decrease in percentage elongation (Gowrisankar, Bhaduri, Seetharaman, Verma, & Achar, 1987).

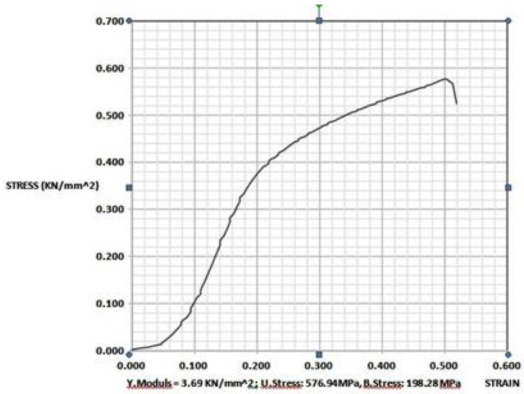


Figure 4. 6 Stress-strain curve in case of fresh flux specimen

Figure- Stress-strain curve

CONCLUSIONS AND FUTURE SCOPE

1) A methodology for the recycling of slag produced during submerged arc welding applications for stainless steel welding was carried out and was successfully developed.
2) The percentage of C, Si, Mn, S, P, Cr, Ni in the recycled slag weld was 0.025, 0.390, 1.49, 0.020, 0.028, 18.36, 8.98, respectively, which is within the acceptable boundaries of the ASTM A240 specifications.
3) The ultimate tensile strength of the weld with recycled flux was 559.36MPa, which was higher than the minimum tensile strength requirements according to ASTM A240.
4) The average of the ferrite contents in the fusion zone of the recycled flux was 5.14% which is good for providing resistance against the solidification cracking.
5) The microhardness variation across the weld with recycled flux and fresh flux was found to be similar.
6) Arc stability and slag detachability with the recycled flux was found good and comparable with that of fresh flux.
7) The Dual-phase microstructure consisting of austenite and ferrite was observed from the micrograph of the samples with fresh and recycled flux.
8) The cost of the recycled flux was 54.62% less than that of fresh flux cost available in the market. It suggests that recycling of slag generated during submerged arc welding of stainless steel welding is economically feasible.
9) The joint efficiency of weld with recycled flux was 108.61%, so it can be concluded that weld joint with recycled flux has more strength than the base metal.
10) Acceptable bead geometry was obtained using recycled flux having a slightly wider bead compared to weld with fresh flux.

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