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Steel Welding Compatibility with Submerged Arc Welding: A Review

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Abstract **Low carbon steel has functional characteristics in broad diversity of applications such as nuclear reactor vessels, heat exchangers, oil industry tubular and components of chemical processing units. Since long time, Components have been used in such industries often required joining of materials with higher thickness. There are many welding methods consistent for low carbon steel welding. Along with various welding methods, Submerged Arc Welding technique is recognizable for high thickness welding .In this paper, Submerged Arc welding method and the effect of process parameter on quality of welding have been reviewed with various researches and discussed in detail because of its inbuilt benefits such as good strength of the joint, higher metal deposition rate, and good surface look. Owing to the above desired properties, this welding process is widely used in the manufacture of pipe lines, pressure vessels, and off-shore structures. Welding flux almost half of the cost in submerged Arc welding process. This welding process is frequently chosen because it offers high fabrication rate, high melting effectiveness and easiness of automation. The review is related with factors affected the quality of weld in low carbon steel by Submerged Arc Welding and hope that it is very supportive for finding the best welding circumstances for structural steel.**

Keywords — submerged arc welding, low carbon steel and flux.

I. Introduction

In Submerged Arc Welding method, the arc and the melted weld metal are protected by a covering pocket of molten flux and a film of unfused coarse flux particles. The arc is exactly submerged in flux, so the process is comparatively free of powerful radiation of heat and light in almost distinctive open arc welding processes and the resulting welds are very clean. Like in Gas Metal Arc Welding process, Submerged Arc Welding process possess continuous solid wire electrode which is consumed to generate filler metal.

The arc currents are normally high as (500A to 2000A). The usefulness of energy transfer from electrode to work piece is high (generally over 90%), Losses from convection, radiation, and spatter are less. The deposition rate is high and weld reliability is excellent.

Cost cutting and output enhancement in welding process can generate significant impact on competitiveness of a range of production industries. Arc efficiency welding time and joint preparation are important parameters dominating the cost and productivity of the weld. The preferred amount of weld diffusion should be achieved in a single pass the welding speed will be the major factor that determines the welding time. The arc effectiveness finds good penetration as well as efficiency of quality welds. Thickness of the part is also vital in mounting the preferred penetration.

II. Literature Review

A. Review Stage

[1] Fatih Uzun et al. used ultra low, low and medium carbon steel and SAW process for his experiment to find the effect of carbon content and submerged arc welding process on hardness of carbon steels. He reported that welding process increase the hardness. Rapid heating and cooling periods cause the formation of a locally hardened zone around the weld beam. Hardness (%) increases in ultralow carbon steel is higher than low and medium carbon steel.

[2] A. Vedrtnam et al. Using stainless steel as a material with SAW process he found that input weld parameters volt, current, weld speed and nozzle to work distance significantly affect the response variables Bead width, Bead height, and Hardness selected for the study. He pointed out that an increment in voltage increases the bead width but decreases the bead height, Increment in current result-in increment in bead height and no change in bead width. The increment in welding speed result-in decreased bead width and height. With an increment in the nozzle-to-plate

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distance, the bead width decrease, but bead height increases. The bead hardness increases with current but voltage and travel speed do not have a significant influence on the hardness. He also suggest the effect of diameter of electrode on weld profile and hardness can be evaluated in the further study

[3] Aditya Kumar Rathi has done research using IS2062 steel using SAW and suggested the effect of voltage, trolley speed, wire feed rate, electrode diameter, and flux on weld on Bead height (reinforcement), bead width and depth of penetration. He has found that reinforcement height is most affected by electrode diameter, depth of penetration is highly influenced by electrode diameter (D) and wire feed rate and hardness of weld bead maximum affected by voltage.

[4] P. Sahare and S. K. Pradhan et al. has carried experiment on windmill turbine using SAW using mild steel S355 grade. He has conducted his experiment considering Welding current, voltage, Standoff distance (Distance between work and blasting nozzle), and Travel speed as input parameters and measured Temperature and Repair result (%) is using Ultrasonic Testing. He found optimal values of input and output Process parameters and also pointed out that out of all welding parameter, arc voltage and current affects the temperature most and hence need to be optimized.

[5] M. Sailender et al. He has experimentally examined number of sample low carbon steel in normal SAW and using CO2 with SAW conditions. Using voltage, wire feed rate, welding speed and nozzle to plate distance process parameters and measured weld penetration depth, reinforcement height, HAZ-width, and the dilution % of weld metal in to base metal. He suggested that weld speed is the major significant variable than others input variables remaining parameters has smaller effect. While, HAZ width and HAZ area are remain almost unchanged in both the case. He also proved that 'purged' welding condition outputs are better to 'as-weld' welding condition and it also supported by scanning electron microscope (SEM) images. He also suggest that Limited literature is available on SAW of low carbon alloy steel welding process

[6] T. Rajkumar et al. experimentally examined the effect of input parameters voltage, current and welding speed on tensile strength of mild steel plate IS2062, using SAW. In his test result he has found the maximum tensile strength at an optimum combination of current, voltage and welding speed at 380A, 28 V and 45 m/hrs. He also found that voltage has maximum influence on mild steel joint where current and welding has mild and least effect. He observed in SEM image and observed the fine grains of pearlite and ferritic structure with moderate precipitates. This joint has very good mechanical and corrosion resistant properties.

[7] Pankaj Has experimentally investigated the effect of varying the basicity index of flux on mechanical properties of structural steel (% C =0.25) sing SAW process. He has applied five different combination of flux having basicity index 1.10-2.35. He used combination of various fluxes CaF2, CaO, Na2O, MnO, SiO2, Al2O3, MgO, TiO2, FeO. He found that, with increment in basicity index, weld geometry like Bead width, Bead reinforcement, Penetration and mechanical properties like hardness, Tensile strength and toughness are decreases.

[8] Timothy Odiaka et al. has investigated effect of varying voltage, current and addition of titanium powder (two grade, one is pure and other is Ti 6–2– 2–2–2 alloy) on tensile strength of AISI 1008 mild steel using butt and lap joint and SMAW process. Tensile strength were measured for all the samples and Optimum value 22V, 120A for butt joint and 23V, 215A for lap joint using pure Ti powder and 24 V, 130 A using butt joint and 26 V, 215 A using lap joint using Ti 6–2–2– 2–2 alloy. However he also added that none the selected parameters proved significant because none of the 'p' value found less than 0.05. This is all due to small range of parameters. so he conclude that L4 orthogonal array may not be suited to determine the significance of process parameters for GMAW of mild steel, it is sufficient for optimizing the welding process.

[9] Prasanta Majumder et al. has investigated on IS2062 mild steel by varying Voltage, Speed of arc travel, electrode feed rate and electrode stick out length as input parameters, Same times the steel samples are preheated by MIG welding and Muffle furnace to 100ºC to check the effect on output parameters Penetration depth, Reinforcement height, Bead width and Hardness (BHN). He conclude 1, Depth of weld penetration, HAZ and bead width increased at higher heat input in both the conditions of preheating 2, weld penetration and bead width is found better in weldment which were preheated by MIG welding 3, Reinforcement and HAZ appeared better in the weldment which were preheated in muffle furnace 4, Micro-hardness decreases with increasing heat input irrespective of pre-heating techniques. He also determined the optimum value of process parameters. Higher-the-better criterion has been selected for penetration and hardness and the lower-the-better criterion has been selected for bead width and reinforcement.

[10] Aditya kumar et al. has investigated on Mild steel plate by varying the flux combination using alloying elements NiO ,MnO and MgO at two different level of voltage and measured hardness and impact strength. He suggests the best combination of input value for both hardness and impact strength at 32 and 34 volt. The importance of flux alloying elements for both output were also suggested. Finally he conclude, hardness mostly reliable on MnO and MgO where in case of impact strength MnO and MgO

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played significant role, on the other hand NiO is not as much effective as the former two.

[11] Ravinder Kumar et al. has investigated the effect of current, voltage and travel speed with SAW using SS 316-L steel alloy steel, on dilution rate and area of penetration. He found current is the dominant parameter to increases the dilution rate while voltage and travel speed found lesser effect on it. While in case of penetration area travel speed play major role, with increases in travel speed, penetration area fall sharply. Overall both dilution rate and area of penetration increases with increase of current and voltage and decrease with increase of travel speed.

[12] M. Mohammadijoo, S. Kenny, J.B. Wiskel, D.G. Ivey, H. Henein. has experimental investigated on 'X70 micro alloyed steel' using cold wire feeding with regular SAW process by varying different input parameters like Cold wire position, Heat input rate, voltage, travel speed, cold wire angle, cold wire feed speed and measure the effect on bead width, penetration depth, HAZ area and reinforcement area and micro hardness. HE found no significant effect on bead geometry but found the effect on of variation in cold-wire parameters. Which significantly affected micro-hardness of the weld metal and HAZ.

[13] Sumit Das Lala et al. has found hardness at three various zones like reinforcement, Weld zone and HAZ on mild steel IS2062 grade A using SAW and combined MIG+SAW using input parameters for MIG Voltage, Current and Arc Travel Speed and for SAW Arc voltage, Welding speed, Stick out length. He found in Most of the cases hardness is at higher level weld with SAW alone compared to MIG+SAW.

[14] Siddharth chaudhary et al. has experimentally found the effect of combination flux of CaO, Al2O3, TiO2, and MgO and voltage variation on mild steel. He measured impact strength and hardness of welded samples and find optimum flux, hardness and impact strength.

[15] Rudra Pratap Singh et al. have found the effect of varying current, voltage, feed and welding speed using mild steel with SAW machine on weld hardness. He found the optimal input parameters for maximum and minimum hardness value. Trained ANN has been used to predict the hardness of weld. Predicted data has been compared with experiment data and found almost similar result. From the result it is said that ANN can successfully be used for prediction of Mechanical prosperities of welding.

[16] Muhammad Asad Ahmad et al. have designed experiment based statistical approaches to optimize submerged arc welding process parameters by selecting SAW process and ASME SA516 grade 70 (medium carbon steel) for optimization. He has used Signal to noise (S/N) ratio analyses to find significant effects of main parameters on selected output. Othogonal factorial method (OFM) is used for modeling the responses. ANOVA and desirability analyses (DA) are used for optimization. Based on larger is the better he found the optimum value of response like UTS Hardness Deposition rate, Reinforcement height and Bead width. So under similar welding condition and given certain material this approaches can be used to find best quality of weld.

[17] Serdar Karaoglu et al. have conducted Sensitivity analysis to optimize submerged arc welding process parameters using mild steel. He has used multiple curvilinear regression analysis and 3^3 factorial designs mathematical model to find the effects of voltage, current and welding speed on bed width, reinforcement height and penetration. He found the experimental reading and based on mathematical model, data responses are calculated and the accuracy of the actual value compared and validated successfully with calculated data. The conclusion has been made that bed width is very sensible parameters followed by penetration and reinforcement height against current, voltage and speed sensitivity.

[18] Sachchida Nand et al. have investigated effect of addition of metal powder in conventional SAW process using SAE 1020 (mild steel) plate. Keeping heat input rate constant during experiment, he found improvement in metal deposition rate, Vickers hardness. Yield strength, UTS, and % elongation as compared conventional SAW process.

19] Brijpal Singh et al. have found the effect on addition of CaF2, FeMn and NiO in flux with mild steel using SAW process. He measured bed width, reinforcement height and penetration by varying the three content. He investigated that addition of CaF2, FeMn and NiO in flux has significant effect on bed width, reinforcement height and penetration.

[20] Abhijit Bhowmik et al. have conducted Feasibility Study SAW on MS Plate IS 2062 Grade B at Zero Degree Celsius and heat input as a input parameter. They measured weld bead width, HAZ width, depth of penetration and reinforcement at 0^o as well as 30^o temperature and found SAW is feasible at 0^o temperature without preheating the base metal. Weld bead width, HAZ width, depth of penetration and reinforcement increased with increased in heat input. Only penetration increases higher at 30^o compared to 0^o.

III. DIFFERENT WELDING PROCESS

A. SAW Process

Figure-1 shows the principles of SAW Process. The filler material is bare, continuous wire electrode, feed to the joint combined with a stream of fine-grained flux, which is feed from a flux hopper. The resistance of the electrode should be very less as possible to assist welding at a high current. The arc generate in a cavity, which is away from the arc

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itself, is packed with gas and metal vapor. The top of the cavity is shaped by melted flux.

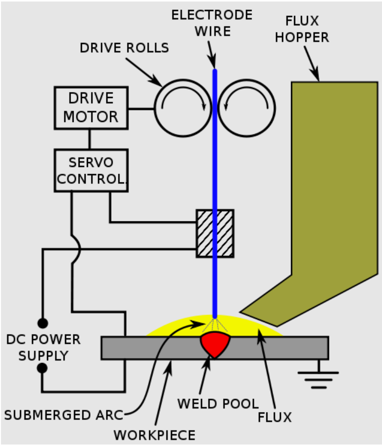

Figure-1. Schematic of SAW process

B. B. Shield Metal Arc Welding

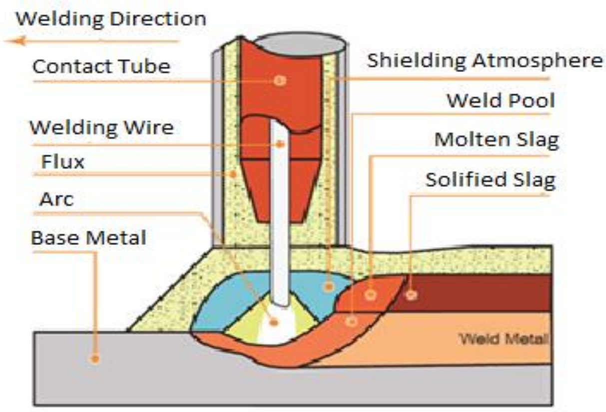

Figure-2 Schematic of SMAW process

Figure-2 shows the solidified weld metal and the solidified flux, it covers the weld in a thin coat and it must be removed. So here not all the flux is completely used. The excess flux can be drawn up and used again. The flux also has a thermal insulating effect and so it reduces heat losses from the arc. That's why; more input energy is present for the welding process itself. The thermal efficiency is higher and the welding rate is faster. It is found that SAW has higher thermal efficiency than Shield Metal Arc Welding (SMAW).

IV. MOST COMPACTABLE WELDING SAW

A. Low carbon steel

Low carbon steel is a carbon steel. It has a carbon content of less than 0.023 % by weight. After iron, carbon is the most important element in low carbon steel. Raising the amount of carbon in the composition of steel, results in metal that have low ductility and high strength.

Low carbon steel is the most extensively used materials in profitable and engineering fabrication.

With good machinability, high strength, and high ductility, low carbon steel plate is a safe and gainful fabrication material that serves as the spine of steel fabrication.

When durability and weight savings both are key factors, low carbon steel plates will likely to be used. In spite of the low carbon steel plates, low carbon steel comes in a lot of shapes and sizing it flexible for miscellaneous projects.

There are nine grades of low carbon steel available as per IS2062-2011. For grades E 250 to E 410, there are four sub-categories (A, BR, B0 and C) and for grades E 450 to E 650, there are be two sub-categories (A and BR). Sub-categories A, BR, B0 and C point out necessity of impact test and type of de-oxidation as under: A: Impact test is not necessary, (semi-killed*/killed**) BR: Impact test is optional; if required at normal temperature; (semi-killed/killed) B0: Impact test compulsory at 0°C, (semi-killed/ killed) C: Impact test compulsory at –20°C, (killed)

B. Semi-killed steels

Semi-killed steels are likely partly deoxidized before it pouring into mold and typically it has carbon (C) amount is very in between 0.15 to 0.3%.

C. Killed steels

Killed steels are fully deoxidized in such manner that formation of carbon monoxide (CO) does not exist at all during solidification. The finished product has a harmonized structure and no blowholes. Aluminum is generally added into the ladle or mold as a primary deoxidizer to kill or not happened the creation of carbon monoxide; however, there are some applications where the adding up of aluminum to the finished product is unwanted. We can also add ferroalloys of manganese and silicon or calcium silicide as an alternative of aluminum.

Table 1:Percentage contribution

Grade Designation	C	Mn	S	P	Si	Carbon Equivalent (CE), Max
E250-E650	0.20-0.23	1.50-1.70	0.015-0.045	0.025-0.045	0.40-0.50	0.39-0.55

Carbon Equivalent (CE) =%C+{(%Mn+%Si)/6}+{(%Cr+%Mo+%V)/5}+{(%Cu+%Ni)/15}

Table 2: Mechanical Properties

Grade Designation	Tensile Strength MPa	Yield Stress MPa	Percentage Elongation
E250	410	250	30

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E275	430	275	22
E300	440	300	22
E350	490	350	22
E410	540	410	20
E450	570	450	20
E550	650	550	12
E600	730	600	12
E650	780	650	12

D. Weldability of carbon steel

The weldability of carbon steel is the property that shows the ease with which the material can be welded. Weldability is a function of carbon equivalent estimated from the chemical composition of the steel. Increase in carbon content decreases the weldability of carbon steel. Thus, high carbon steel has low weldability.

Table 3:Carbon steel characteristics

Carbon equivalent (CE)	**Weldability**
Up to 0.35	Excellent
0.36–0.40	Very good
0.41–0.45	Good
0.46–0.50	Fair
Over 0.50	Poor

E. Welding Electrode

The electrodes diameter used in SAW mostly ranges from 1-5 mm. The electrode wire is supplied from the roll through a contact tube connected to the power source. Electrode wire is made of steel is mostly copper coated because It protect from atmospheric corrosion and increase the current carrying capacity.

F. SAW Flux

Role of fluxes in SAW is similar to coating in stick electrodes of SMAW. The functions are protection of weld pool from shielding gases. SAW fluxes can manipulate the weld metal composition considerably in the form of addition or loss of alloying elements via gas metal and slag metal reactions. Few hygroscopic fluxes are normally baked at 250 to 300°C for 1-2 hours to remove the moisture. There are four types of common SAW fluxes.

Manufacturing steps of these fluxes.

Fused fluxes: raw constituents are mixed, melted, quenched, crushed, screened and graded.

Bonded fluxes: raw constituents are powdered, dry mixed, bonded with K/Na silicates, wet mixed pelletized-crushed and screened

Agglomerated fluxes: produced in same way to bonded fluxes but ceramic binder in place of silicate binder.

Mechanically mixed fluxes: from above fluxes any two types are mixed in desired ratios.

The first type of flux, usually consist of different types of oxides and halides such as MnO, SiO2, CaO, MgO, Al2O3, TiO2, FeO, CaF and Sodium/Potassium Silicate. For high quality weld joints of high strength steel to be used for critical applications halide fluxes are used while oxide fluxes are used for developing weld joints of non-critical applications. Some of oxides such as MgO,CaO, CaF2 ,BaO, Na2O, MnO, KO, etc. are basic in nature (donors of oxygen) and few others such as SiO2, TiO2 , Al2O are acidic (acceptors of oxygen). Depending upon relative amount of these acidic and basic fluxes, the basicity index of flux is decided. The basicity index of flux is calculated by the ratio of the sum of (wt. %) all basic oxides to all non-basic oxides.

V. CONCLUSION

SAW process has been widely used in heavy metal construction work of mild and medium carbon steel of thickness 10mm or more.

SAW welding can be possible from zero to normal room temperature [20], metallic and non metallic element additive in flux can improve the weld bed geometry and mechanical/metrological properities of weld and reduce the number of weld pass.[19][18], by increase in heat input we can increases the weld geometry and development of mathematical model can reduce the experimental setup [17]. A statistical model is proved and can be used for optimization other welding process parameters [16].optimization technique can be used to optimized SAW welding process parameters[16],[15]. A neural network can be trained for finding out best welding parameters [15]. SAW can be used to improve surface hardness [14]. Addition of cold wire will improve the mechanical prosperities [12]. As the voltage increases weld bed width increased but depth of penetration decreases. Dilution rate and area of penetration are increases with increase of current and voltage and decrease with increase of travel speed. Current is the dominant parameter to increases the dilution rate [11]. In the matter of additive in flux, Hardness mostly reliable on MnO and MgO where in case of impact strength MnO and MgO played significant role [10]. Preheating technique can also be applied to improve weld geometry [9]. With increment in basicity index, weld geometry like Bead width, Bead reinforcement, Penetration and mechanical properties like hardness, Tensile strength and toughness are decreases [7]. Voltage has maximum influence on mild steel joint where current and welding has mild and least effect [6]. Use of purging gas with SAW can improve weld bed geometry [5]. Depth of penetration is

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highly influenced by electrode diameter (D) and wire feed rate and hardness of weld bead maximum affected by voltage [3]. Voltage increases the bead width but decreases the bead height, Increment in current result-in increment in bead height and hardness [2]. Welding process increase the hardness. Hardness (%) increases in ultralow carbon steel is higher than low and medium carbon steel.

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