Combined Research of Flux and Welding Parameters and Influence of Chemical Composition and Mechanical Properties of Submerged Arc Welding: A Review

Ram Gopal Verma

(Research Scholar), Department of Mechanical Engineering, Rajshree Institute of Management and Technology, Bareilly, U.P, India

Abstract: **Submerged Arc Welding (SAW) can be employed for an extremely wide range of work piece. The method is suitable for butt welding and fillet welding of such applications as structural members in ship, manufacture of pressure vessels, bridge beams, massive water pipes, thin sheet shells and so on. Rotatable designs based on statistical experiments for mixtures have been developed to predict the combined effect of flux mixture and welding parameters on submerged arc weld metal chemical composition and mechanical properties. Bead-on-plate weld deposits on low carbon steel plates were made at different flux composition and welding parameter combinations. The results show that flux mixture related variables based on individual flux ingredients and welding parameters have individual as well as interaction effects on responses, viz. weld metal chemical composition and mechanical properties. In general, two factor interaction effects are higher than the individual effect of mixture related variables. Amongst welding parameters, polarity is found to be important for all responses under study.**

Keywords- **SAW, Rotatable mixture designs, Mixture related variables, Heat input, Electrochemical reaction and with two area ratio.**

I. INTRODUCTION

Submerged arc welding (SAW) is a process that melts and joins metals by heating them with an arc established between a consumable wire electrode and the metals, with the arc being shielded by a molten slag and granular flux. This process differs from the arc welding processes discussed so far in that the arc is submerged and thus invisible. The flux is supplied from a hopper, which travels with the torch. No shielding gas is needed because the molten metal is separated from the air by the molten slag and granular flux. Direct-current electrode positive is most often used. However, at very high welding currents (e.g., above 900A) AC is preferred in order to minimize arc blow. Arc blow is caused by the electromagnetic (Lorentz) force as a result of the interaction between the electric current itself and the magnetic field it induces. This is a well established and extremely versatile method of welding. Submerged-arc welding (SAW) involves the formation of an arc between a continuously fed electrode and the work piece. A blanket of powdered flux, which generates a protective gas shield and a slag (and may also be used to add alloying elements to the weld pool), protects the weld zone. A shielding gas is not required. The arc is submerged beneath the flux blanket and is not normally visible during welding as shown in figure 2. Submerged Arc Welding (SAW) process was invented simultaneously in U.S.A and U.S.S.R in 1930"s. Submerged arc welding contributes to approximately 10% of the total welding. It is one of the most widely used processes for fabrication of pipes, thick plates, pressure vessels, marine vessels, rail tanks, ships, heat exchangers, offshore structure etc. It is characterized by higher metal deposition rate, deep weld penetration, excellent surface appearance, invisible arc and lower welding skill requirement. It is possible to weld thin sheet of steels at over 5 m/min with minimum emission of welding fume. Apart from joining, this process can also be used for cladding applications to increase corrosion and wear resistance on the surface. Welds produced are sound, uniform, ductile, and have good impact value. This process is commercially used for welding of low carbon steel, high strength low alloy steel, nickel base alloys and stainless steel (Wilson, 1966) [2].

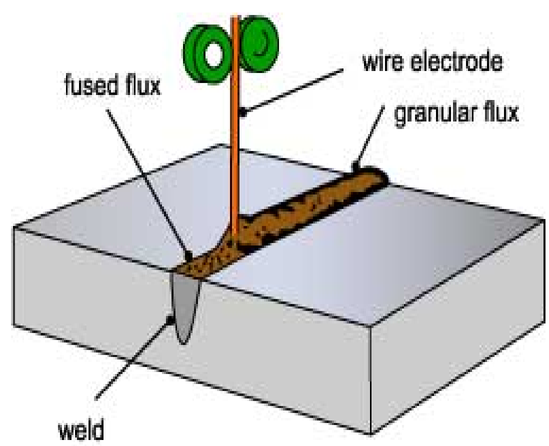

Figure 1: Schematic of submerged arc welding [2]

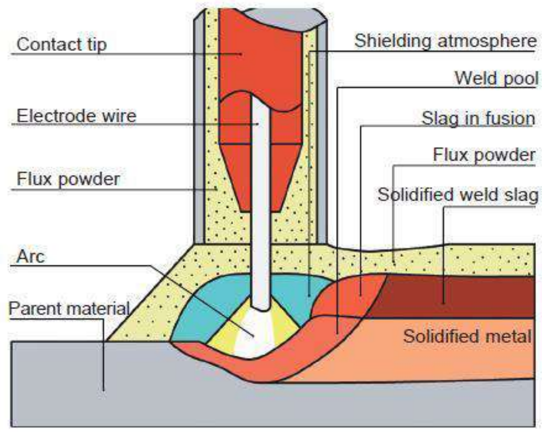

Figure 2: Schematic of SAW [2]

1.1 Components of submerged arc welding

Main components of a submerged arc welding unit are: "The wire electrode reel, the wire feed motor equipped with grooved wire feed rolls which are suitable for the demanded wire diameters, a wire straightened as well as a torch head for current transmission, Figure 2. Flux supply is carried out via a hose from the flux container to the feeding hopper which is mounted on the torch head. Depending on the degree of automation it is possible to install a flux excess pickup behind the torch. Submerged arc welding can be operated using either an A.C. power source or a D.C. power source where the electrode is normally connected to the positive terminal. Welding advance is provided by the welding machine or by work piece movement"[1].

1.2 The principle of submerged arc welding

The diagram below indicates, in schematic form, "the main principles of submerged arc welding. The filler material is an uncoated, continuous wire electrode, applied to the joint together with a flow of fine-grained flux, which is supplied from a flux hopper via a tube.

The electrical resistance of the electrode should be as low as possible to facilitate welding at a high current, and so the welding current is supplied to the electrode through contacts very close to the arc and immediately" above it.

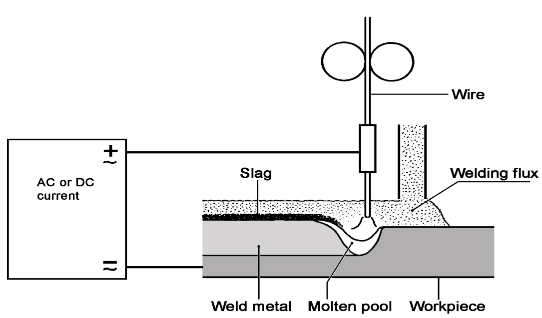

Figure 3: The principle of submerged arc welding [3].

The arc burns in a cavity which, "apart from the arc itself, is filled with gas and metal vapour. The size of the cavity in front of the arc is delineated by unbelted basic material and behind it by the molten weld. The top of the cavity is formed by molten flux. The diagram also shows the solidified weld and the solidified flux, which covers the weld in a thin layer and which must subsequently be removed. Not all of the flux supplied is used up: the excess flux can be sucked up and used again. The flux also has a thermal insulating effect, and thus reduces heat losses from the arc. As a result, more of the input energy is available for the actual welding processes itself than is the case with processes involving an exposed arc. The thermal efficiency is greater and the rate of welding is faster. It has been found that submerged arc welding has a thermal efficiency of about 90 %, as against an approximate value of about 75 % for MMA welding" [4].

1.3 Parameters of the SAW to make the weld joint

Welding data depends on the size of the work piece, "and must be selected to ensure satisfactory penetration and correct shape of the weld. Starting from this basic require- ment, we select the appropriate values of filler wire size, arc voltage, welding current and welding speed" [5].

1.3.1 Arc voltage

The arc voltage is decisive in determining the shape and width of the arc and, to some degree, also in determining its penetration. Too high an arc voltage in an I-joint in flat sheet will produce a wider weld, while in a V-joint, X-joint and fillet radii it will result in a concave weld, with a risk of undercutting and slag that is difficult to remove. On the other hand, too low an arc voltage will result in a high, round weld in I-joints and V- joints, while in X-joints and fillet radii it will result in a convex weld, and which is also hard to de-slag [5].

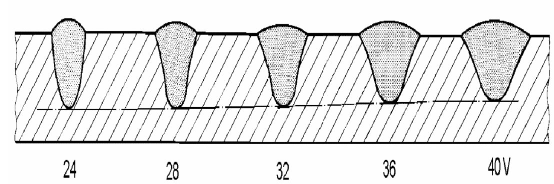

Figure 4: Change in arc voltage affects the shape of weld, welding current is constant [5].

1.3.2 Welding current

Welding current is the "parameter that is of greatest importance for penetration. The current setting depends on the thickness of the metal and the type of joint. The current has no effect on the width of the bead, but too high a current can result in burn- through, while too low a current can result in insufficient penetration with resulting root defects. This means that the welding current, which is proportional to the wire feed speed, affects the deposition rate (the quantity of electrode material melted into the weld per unit of time), so that as the welding current increases, the rate of melting of the filler wire also increases. For a given welding current, the deposition rate will be higher if the filler wire is negative with respect to the work piece than if the wire is positive, but the penetration will be reduced" [5].

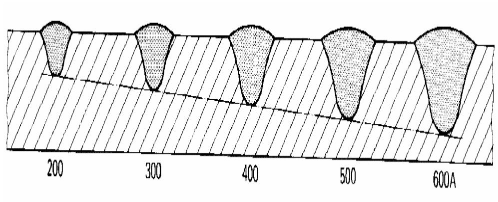

Figure 5: Increasing welding current results in deeper penetration [5].

1.3.3 Welding speed

The welding speed (linear speed along the line of the weld) also affects the penetration. "If the speed is increased relative to the original value, penetration will be decreased and the weld will be narrower. Reducing the speed and increases penetration results in a wider. However, reducing the welding speed to about 20–25 cm/min (depending on the actual value of the current) can have the opposite effect, i.e. a reduction in penetration, as the arc is prevented from transferring thermal energy to the parent metal by the excessive size of the weld pool. If the welding speed is to be changed while penetration is kept constant, it is necessary to compensate by adjustment of the welding current, i.e. to increase or decrease it" [4].

1.3.4 Wire diameter

For a given current, "a change in wire size will result in a change in current density. Greater wire diameter results in a reduction in penetration and, to some extent, also the risk of burning through at the bottom of the weld. In addition, the arc will become more difficult to strike and arc stability will be adversely affected. There is a risk of root defects if too large an electrode is used in V-joints" [6].

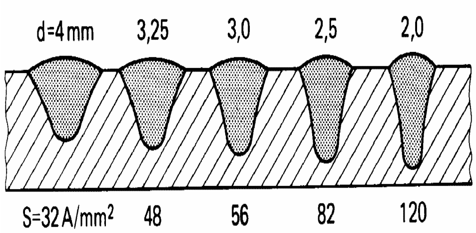

Figure 5: The effect of different wire diameters at constant welding current [6].

II. FLUX USED IN SUBMERGED ARC WELDING

Fluxes used in submerged arc welding (SAW) are granular fusible "minerals containing oxides of manganese, silicon, titanium, aluminium, calcium, zirconium, magnesium and other compounds such as calcium fluoride. The flux is specially formulated to be compatible with a given electrode wire type so that the combination of flux and wire yields desired mechanical properties. It is common practice to refer to fluxes as active if they add manganese and silicon to the weld, the amount of manganese and silicon added is influenced by the arc voltage and the welding current level. The main types of fluxes for submerged arc welding are as shown in figure" [7].

Figure 6: Sample of flux (MSCC**:** Mild steel copper coated**)** [7]

2.1. Research progress in flux

Table 1: Research Contribution in flux and influence of parameters

Research Contribution in year wise
LAU L et al (1986) [1] in this paper, a detailed study is presented of the interactions of Mn, Al and O at the different stages of the welding operation. These interactions have been studied by analyzing the total Mn, Al and O contents, as well as the composition of inclusions formed at the different stages. At the electrode tip and in the arc column, changes in oxygen, aluminum and manganese were dominated by flux decomposition, while at the weld metal stage, slag-metal reactions occurred.
Kanjilal P et al (2005)[5] describe the rotatable designs based on statistical experiments for mixtures have been developed to predict the combined effect of flux mixture and welding parameters on submerged arc weld metal chemical composition and mechanical properties. Bead-on-plate weld deposits on low carbon steel plates were made at different flux composition and welding parameter combinations.
Ana Ma et al (2005)[6] study was conducted on the effect of flux composition for the microstructure and tensile properties of a submerged-arc welded AISI 1025 steel. Three flux compositions were used with a low-carbon electrode. A commercial flux composition was used for comparison. The welding conditions were kept the same. Tension tests were pursued at room temperature. Microstructure and macrostructure of welds were observed with light and scanning electron microscopes (SEM).

Majumdar S.K et al (2006)[7] carried out the rotatable designs based on statistical experiments for mixtures have been developed to predict the combined effect of flux mixture and welding parameters on submerged arc weld metal chemical composition and mechanical properties. Bead-on-plate weld deposits on low carbon steel plates were made at different flux composition and welding parameter combinations. The results show that flux mixture related variables based on individual flux ingredients and welding parameters have individual as well as interaction effects on responses, viz. weld metal chemical composition and mechanical properties. In general, two factor interaction effect are higher than the individual effect of mixture related variables. Amongst welding parameters, polarity is found to be important for all responses under study.
Arun Rehal et al (2012)[9] studied submerged arc welding, because of its inherent benefits such as higher metal deposition rate, good strength of the joint and good surface appearance, is extensively used in the fabrication of pressure vessels, pipe lines and off-shore structures. Welding flux constitutes nearly half of the cost in SAW process. Over the years, development of better welding flux compositions in terms of mechanical properties and productivity, which are economically cost effective too, has caught the eye of many researchers
Krishankant et al (2012)[10] the submerged arc welding (SAW) is a common arc welding process where the total welding cost includes the cost of the flux consumed during welding, SAW is preferable more its inherent qualities like easy control of process variables, high quality, deep penetration, smooth finish. Flux used in submerged arc welding contributes a major part towards welding cost. In the present work, the effect of operating voltage, welding current, welding speed and basicity index on flux consumption has been studied.
Jasvinder Singh et al (2012)[11] discussed the slag generated during submerged arc welding (SAW) is normally thrown away as a waste. This poses the problem of storage, disposal, and environmental pollution and needs landfill space apart from exhaust of non-renewable resources. Reusing of slag will not only solve these problems but also be economical. In the present work an attempt has been made to use the submerged arc welding slag as flux in the same submerged arc welding process. Fused slag was crushed to the desired particle size as that of the original flux.
Rati Saluja et al (2013)[12] describe the large joint areas with fewer passes and minimal preparation with high deposition rates is possible in submerged arc welding. Deposition rates approaching 45 kg/h have been reported this compares to 5 kg/h (max) for shielded metal arc welding. In general, one kg of flux is consumed for every kg of weld metal deposited in submerged arc welding. There are two important parameters in submerged arc welding, the flux and the wire, that may be supplied separately. The arc, end of electrode and molten pool remain completely hidden are invisible being submerged under a blanket of flux. A general problem that may occur is the absorption of moisture by the fluxes during storage. The study revealed to recycle the moisturized flux. Moisturized flux has been processed in such a manner that allows it to be used as a flux. Additionally it is always important and useful to reduce waste and to move towards "ZERO WASTE CONCEPT".
Brijpal Singh et al (2013)[13] the Performance of a welding flux is decided by the physical and chemical properties of its constituents. The flux selected should show a good welding behaviour and the required weld bead geometry. The mechanical properties of a joint are not only decided by its composition but these also depends on bead geometry, dimensions and physico-chemical properties of fluxes.
Brijpal Singh et al (2013)[14] the purpose of this literature review is to focus on an innovative approach which is needed while deciding weld chemistry. It would be worthwhile if one could develop a frame work to predict the Mn, Si, carbon, oxygen and other elements in the final weld metal, from a given combination of electrode, flux and base metal. The work done so far on Element transfer study is very limited. Much published information is not available about fluxes made by Industry professionals as they do not disclose the composition of the flux for which they claim higher strength and better mechanical properties. This literature review will provide the basis for researchers in the field of SAW.
Arun Rehal1 et al (2014) [15] studied of Submerged arc welding, because of its inherent

benefits such as higher metal deposition rate, good strength of the joint and good surface appearance, is extensively used in the fabrication of pressure vessels, pipe lines and off-shore structures. Welding flux constitutes nearly half of the cost in SAW process. Over the years, development of better welding flux compositions in terms of mechanical properties and productivity, which are economically cost effective too, has caught the eye of many researchers. In the present paper research work carried out by various researchers in the field of welding flux development has been reviewed.
Gyanendra Singh et al (2015) [16] carried out the Submerged Arc Welding process flux always plays a vital role. Cost of flux nearly amounts to 50% of the total cost of the overall welding work and after welding the slag hence formed is totally a waste. The ingredients present in flux effects the chemical as well as mechanical properties of the weld bead without the use of different metal or alloy of desired properties. The slag if can be recycled and some ingredients (metal powder) can be added to it then we on one hand can reduce the cost of the process by recycling the waste slag and on the other hand getting the desired property. In the present research, Surface Response Methodology (RSM) is employed for conducting the experiments and analyzing the effect of process parameters (open circuit voltage, travel speed) and weight percentage of Chromium Carbide into the developed flux on the surface hardness of the weld using submerged arc welding process.
Junaid Yawar et al (2015) [17] the submerged arc welding process is most widely used arc welding process for joining thick plates and pipes. The features that distinguishing submerged arc welding from other arc welding process is granually fusable material termed as flux. The flux used in submerged arc welding contributes a major part (above 50%) towards the total welding cost. The properties of weld metal have been found to be dependent upon flux-electrode-base metal-composition on welding parameters. Flux and filler metal play a central role in ascertaining property of weld metal. In the present work, the effect of operating arc voltage, welding current, welding speed and nozzle distance on flux consumption and chemical composition of carbon and silicon has been studied.
Arun Rehal et al (2015) [18] studied the present research work, an effort has been made to develop cost-effective welding flux composition, for joining mild steel by using advanced statistical techniques such as Extreme Vertices Design (XVERTD) and Response Surface Methodology (RSM). XVERTD technique has been used to design six sample flux compositions. Radiography, Tensile tests and Impact tests were carried out on the weld joints prepared using developed fluxes and then the RSM technique has been used to obtain the best and optimum welding flux composition.
A. Arul Marcel Moshi et al (2016) [19] discussed the stainless Steel have functional characteristics in wide variety of applications such as nuclear reactor vessels, heat exchangers, oil industry tubular and components of chemical processing units. Components have been used in such industries often required joining of materials with high thickness. There are many welding methods reliable for stainless steel welding. Among various welding methods, Submerged Arc Welding technique is familiar for high thickness welding .In this paper, Submerged Arc welding process and the effect of process parameter on quality of welding have been reviewed with various researches and discussed in detail because of its inherent benefits such as higher metal deposition rate, good strength of the joint and good surface appearance.

2.2. Method of submerged arc welding

There is a need to have more insight into the designing of flux such that indigenously manufactured flux results in high weld metal integrity and is cost effective. For analyzing and predicting the weld metal mechanical properties, it is essential to estimate the weld metal composition with from the wire, flux and parent metal combination. The welding parameters also affect the weld metal composition [11].

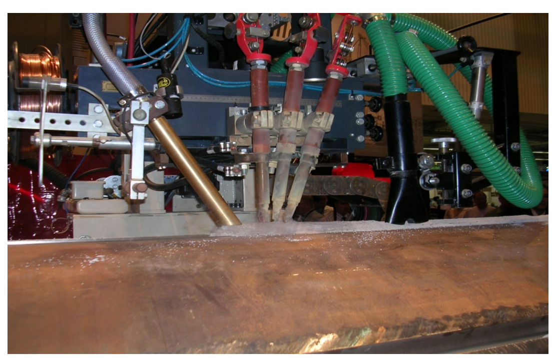

Figure 7: Method of submerge arc welding [11].

2.3. Applications

SAW is ideally "suited for longitudinal and circumferential butt and fillet welds. However, because of high fluidity of the weld pool, molten slag and loose flux layer, welding is generally carried out on butt joints in the flat position and fillet joints in both the flat and horizontal-vertical positions. For circumferential joints, the work piece is rotated under a fixed welding head with welding taking place in the flat position. Depending on material thickness, either single-pass, two-pass or multi pass weld procedures can be carried out. There is virtually no restriction on the material thickness, provided a suitable joint preparation is adopted. Most commonly welded materials are carbon-manganese steels, low alloy steels and stainless steels, although the process is capable of welding some non-ferrous materials with judicious choice of electrode filler wire and flux combinations" [18].

2.4. Conclusion

In this review study, "the oxygen, aluminum and manganese contents, as well as the inclusion compositions at the electrode tip, metal droplet and weld metal stages, have been determined. With fluxes, wire and base plate of known compositions, and from the relative changes from one stage to another, it was possible to assess and evaluate the different types of reactions occurring during the weld process and to identify the major factors which control the final oxygen level in the" weld metal.

REFERENCES

[1] **T. LAU, G. C. WEATHERLY AND A. MC LEAN (1986) "**Gas/Metal/Slag Reactions in Submerged Arc Welding Using CaO-AI203 Based Fluxes**"** SUPPLEMENT TO THE WELDING JOURNAL, Sponsored by the American Welding Society and the Welding Research Council

[2] **H Cary (1988)** Welding Technology, Prentice Hall, 2nd edition.

[3] **Richard Little (2001)** Welding and Welding Technology, McGraw Hill, , 1st edition.

[4] **R S Parmar (2004)** Welding process and technology, Khanna Publisher, New Delhi.

[5] **P. Kanjilal, T.K. Pal, S.K. Majumdar (2005)** "Combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal" Journal of Materials Processing Technology 171 (2006) 223–231.

[6] **Ana Ma. Paniagua- Mercado, Victor M. Lopez-Hirata , Maribel L. Saucedo Munoz (2005)** "Influence of the chemical composition of flux on the microstructure and tensile properties of submerged-arc welds" Journal of Materials Processing Technology 169 (2005) 346–351.

[7] **S.K. Majumdar, P. Kanjilal, T.K. Pal (2006)** "Combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal" Journal of Materials Processing Technology 171, 223–231

[8] **S V Nadkarni (2010)** Modern Arc Welding Technology, Ador Welding Limited, New Delhi.

[9] **Arun Rehal, J S Randhawa (2012)** "Submerged Arc Welding Fluxes" International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064, Impact Factor (2012): 3.358

[10] **Krishankant, Sandeep Jindal & Shashi Kant Shekhar (2012)** "Determination of Flux Consumption in Submerged arc Welding by the Effect of Welding Parameters by Using R.S.M Techniques" Global Journal of researches in engineering Mechanical and mechanics engineering, Volume 12 Issue 2 Version 1.0, Online ISSN: 2249-4596.

[11] **Jasvinder Singh, Kulwant Singh and Jatinder Garg (2012) []** "Reuse of Slag as Flux in Submerged arc Welding & its Effect on Chemical Composition, Bead Geometry & Microstructure of the Weld Metal" International Journal of Surface Engineering & Materials Technology, Vol. 1 No. 1 July-Dec. 2011, ISSN: 2249-7250

[12] **Rati Saluja, K M Moeed (2013)** "Reclamation of moisturized flux in submerged arc welding" International Journal of Technical Research and Applications e-ISSN: 2320-8163

[13] **Brijpal Singh, Zahid Akthar Khan and Arshad Noor Siddiquee (2013)** " effect of flux composition on its behavior and bead geometry in submerged arc welding" Vol. 5(7), pp.123 -127, October 2013 OI 10.5897/JMER2013.0284 ISSN 2141- 2383 © 2013 Academic Journals http://www.academicjournals.org/JMER.

[14] **Brijpal Singh, Khan, Z. A. and Siddiquee, A. N. (2013)** "Effect of flux composition on element transfer during submerged arc welding (saw)" International Journal of Current Research Vol. 5, Issue, 12, pp.4181-4186, December, 2013.

[15] **Arun Rehal1, J S Randhawa (2014) "**submerged arc welding fluxes" International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064, Impact Factor (2012): 3.358

[16] **Gyanendra Singh, Vivek Mishra, Vijay Shankar Yadav (2014)** "Effect of developed flux and process parameters on hardness of weld in saw" International Journal of Science, Technology & Management, Volume No 04, Special Issue No. 01, ISSN (online): 2394-1537.

[17] **Junaid Yawar and Harvinder Lal (2015)** "Effect of Various Parameters on Flux Consumption, Carbon and Silicon in Submerged Arc Welding (Saw)" International Journal on Emerging Technologies 6(2): 176-180(2015), ISSN No. (Online) : 2249-3255.

[18] **Arun Rehal (2015)** "Development of Cost-Effective Submerged Arc" Welding Fluxes for Mild Steel, SSRG International Journal of Mechanical Engineering (SSRG-IJME).

[19] **A. Arul Marcel Moshi, S. R. Sundara Bharathi , R. Rajeshkumar and R. Kumar (2016)** "Factors influencing submerged arc welding on stainless steel" ARPN Journal of Engineering and Applied Sciences, VOL. 11, NO. 2, JANUARY 2016, ISSN 1819-6608.