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# Optimization of elements transfer in low carbon steel welds during submerged arc welding

Dr.Brijpal Singh[1], Dr.Narender Singh[2]
[1,2]*Maharaja Surajmal Institute of Technology, Janakpuri, New Delhi*

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**ABSTRACT**: This study suggests that the optimal flux can be designed and selected for the Mn/S ratio in the weld and high penetration. Fuzzy logic optimization technique has been used for the selection of flux. The Mn/S ratio is important in the welds as the mechanical properties such as impact strength, toughness and tensile strength also depends upon the ratio of Mn/S in the welds. This ratio also affects the weld bead geometry like weld width, penetration and reinforcement. The fluxes were designed using RSM and were made by agglomeration technique. The optimized flux contains $CaF_2$, FeMn and NiO each as 8, 2 and 2%.

**KEYWORDS:** Submerged Arc welding, Bead Geometry, Penetration, Element transfer, Fuzzy Logic.

## I. INTRODUCTION

The Submerged arc welding is an important and old process and it was firstly used in 1920s in USA. In this welding a continuous wire in the form of a roll is used as the electrode and the arc is generated by the touch of the wire and workpiece. In this welding arc is not visible to the welder so it is also known as hidden arc welding.. The arc melts the metal and after cooling the joint is made. The circuit is completed by passing the current from the electrode to the workpiece. The arc is generated between the base metal and electrode. The heat produced by the arc melts the electrode, base plate and the adjacent flux. In this welding the arc is submerged in the molten flux so it is known as submerged arc welding.

The weld made by this welding is of very high quality as there is double protection from thee atmospheric gases.Ultravoilet and other rays are not visible to the welder as arc remains hidden in the molten flux. The current used is of the range of 2000 amp which is very high. This is used for welding thick plates like pressure vessels and ship building. The metal deposition rate is very high In this welding dueto high current used the melting rate of electrode and work piece is very high. The electrodes used for SAW are either bare and usually they are coated with copper in order to avoid corrosion. The coating of electrodes helps in increasing the electrical conductivity of the electrode wire. There are variety of combinations of electrode wire and fluxes which are used in this welding.

Submerged arc welding make very high quality joints as it gives the double protection from atmospheric contamination (Houldcroft,1989) [1]. In this welding process the arc is buried in the molten flux and it is not visible to the operator. The flux is supplied with the help of a hopper fixed on the machine.. This hopper moves ahead with the torch No shielding gas is required for the protection of the weld and the unused flux gives additional shield from the atmospheric gases parmar [2]. Both AC and DC current can be used.. The welds made by the SAW process have high strength and ductility with low hydrogen and nitrogen content. The elements transfer and welding parameters also have a significant effect on weld bead geometry Little [3].

## II. SAW FLUXES

The purpose of the flux is too reduced the oxidation of the weld metal and clean the weld from the impurities. The SAW fluxes contain calcium fluoride, ferromanganese, manganese oxide, titanium oxide, lime and other compounds. In SAW, the weld pool is submerged under the layer of molten flux and this gives the protection from the atmospheric gases.. The flux which is melted becomes a conductive medium and serves as a path for carrying the current from electrode to the work piece. Fluxes can be classified as bonded fluxes, fused fluxes and agglomerated fluxes. They can also be classified based on the value of basicity index value. The weld metal properties and the

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composition of the weld is decided by the flux and wire composition.

## III. WELD PENETRATION

The weld penetration may be measured as the distance between the base plate top surface and depth of the weld up to which the fusion has taken place. The weld penetration is important parameter in bead geometry as it increases the strength of the weld. If the penetration is high, then the strength of the weld will be large. The no of passes in the thick plates are reduced if the penetration is large. The penetration is also increased with increasing of the weld current. The production rate is also high if the penetration is large. There are various factors which influence the depth of penetration in the weld. Some of the factors are flux composition, the welding speed, type of polarity, travel speed, electrode stick out, basicity index and physical properties of the flux. The penetration mainly is decided by the heat input by the arc. The depth of penetration, also depends upon the diameter of the electrode. The thickness of the electrode also affects the weld bead geometry and shape (Caddell, 1967) [4].

## IV. BEAD GEOMETRY AND DESIGN OF EXPERIMENTS

The bead geometry is defined by its weld width (W), reinforcement (R) and weld penetration for weld bead geometry and shape relationship the weld width (W), depth of penetration (P), height of reinforcement (R), dilution (D), weld penetration shape factor (WPSF) and weld reinforcement factorare measured. Figure 1 depicts the bead width, reinforcement and penetration.. The weld joint properties are decided by these parameters and affect the mechanical properties of the welding joints. The important process parameters voltage, current, travel speed, nozzle to platedistance, the flux composition also decides the joint strength and other properties.

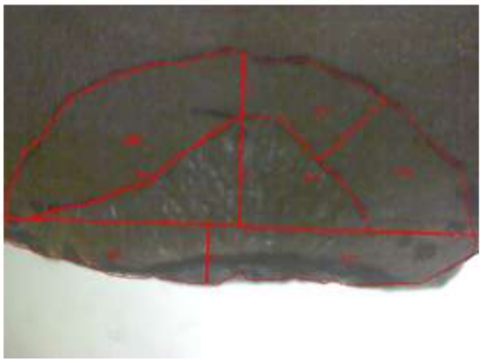

Fig.1

Fig.2

Various researchers have used various techniques for the optimization of the bead geometry and shape relationship. As the load carrying capacity of a weld joint also depends on the shape and size of the weld, so the study of bead geometry and shape relationship was carried out. The polished weld beads and a photo of weld bead parameters are given in the Fig2

## V. EXPERIMENTAL PROCEDURE

For correlating the input factors with the output, following procedure for experimentation was followed.

1) The fluxes were designed by using RSM methodology. CCD design has been used as it is compact and effective. The designed matrix has been shown in Table No1.

2) Three fluxes CaO, $SiO_2$ and $Al_2O_3$ were selected as base and were mixed in the ratio of 7:10:2. This was decided with the help of binary and ternary phase diagrams. The range of additives was decided as (2-8)% .

3) In this experiment as per the design twenty fluxes were made d by agglomeration technique. The base flux constituents has been given in Table no- 2

4) The out factors such as e width, reinforcement, penetration and weld dilution has been shown in Table No2.

Full factorial design has been used for design of fluxes. The fluxes were usually designed by using hit and trial method.. However, in this study a scientific methodology has been used for developing the fluxes. The optimization techniques decide that which flux is best suited for the desirable outputs. So multi objective optimization should be used for getting desirable output. The multi objective optimization for low Mn/s ratio and high penetration. The three input factors are as CaF2, FeMn and NiO. With this technique a single MRPI factor was calculated.

| Table 1: Design matrix for input factors | | | |
|---|---|---|---|
| No. of Experiment | $CaF_2$ wt % A | FeMnwt% B | NiOwt % C |
| 1 | +1 | -1 | -1 |
| 2 | 0 | +1 | 0 |
| 3 | +1 | -1 | +1 |
| 4 | -1 | -1 | -1 |
| 5 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 |
| 7 | +1 | +1 | +1 |
| 8 | 0 | 0 | 0 |
| 9 | 0 | -1 | 0 |
| 10 | +1 | 0 | 0 |
| 11 | 0 | 0 | +1 |
| 12 | -1 | -1 | +1 |
| 13 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 |
| 15 | +1 | +1 | -1 |
| 16 | -1 | 0 | 0 |
| 17 | 0 | 0 | 0 |
| 18 | 0 | 0 | -1 |
| 19 | -1 | +1 | +1 |
| 20 | -1 | +1 | -1 |

## VI. LITERATURE REVIEW

For $SiO_2$ base fluxes by Kumar and mahrshwari. 2013 [5]. Jindal etal.2013 [6] used the composite desirability approach for optimization of UTS, Impact strength and hardness for HSLA steel. They suggested the flux mixture for maximum UTS, maximum Impact strength and a targeted value of micro hardness. (P. Kanjilal et.al 2006)7,8 studied the combined effect of flux mixture and welding parameters on submerged arc weld metal composition and mechanical properties. Bead on plate welds were made forlow carbon steel welds. Two factors interaction effect was found higher on mixture related variables. Polarity was important for welding parameters only. Tanaka et al.1980) [9] studied the effect of flux composition on transfer of the elements silicon, manganese, titanium, boron and oxygen during submerged arc welding by adding simple substances titanium, boron and alloys of ferro boron, ferro titanium etc. In this study it was found that Si, Mn transfer to the weld depends not only its concentration in the flux but it was affected by the presence of Ti, Mg, Al and Ca. (A. Bhattacharya et.al. 2012) [10] optimized the multi-response submerged arc welding process for weld bead by grey relation analysis. By the use of grey relation analysis three responses were combined together to get the single grey relation grade and analyzed by the ANOVA. The regression analysis was used to predict the optimal value of parameter level.

## VII. FUZZYLOGIC OPTIMIZATION

In grey relational analysis the concept of higher the better or lower the better is considered but in this analysis the chances of error are however minimized with the application of fuzzy logic optimization along with the application of GRA,

Fuzzy methodology can be applied for multi objective optimization of parameter In a fuzzy logic system. A membership function based on certain rules is applied to an engine. The membership functions based on fuzzy logic and rules generates a fuzzy value and that value is converted in to multi characterization performance index (MCPI) by a defuzzifier. This structure of the two-input-one-output fuzzy logic unit is depicted in Fig. 3.The input are, CaF2,FeMn and Nio contents and output are Mn/S ratio and penetration.

## VIII. RESULT

The used fuzzy model consists of two inputs and one output which fuzziest the input data using three triangular membership functions. These triangular membership have been used for the two inputs and one output.. Using fuzzy logic rules in the Mumdani inference, multi characteristic performance index for each experiment value has been calculated using centroid method of defuzzification. The observed results of output characteristicsfound in the form of MPCI shows that the value of this characteristic is maximum for experiment no3. The results are shown in Table 3.So we can infer from this that the input parameters for flux no3 can give the optimized results. The results were also verified by doing the Experiments and the results were found in the reasonable range. So the experiment no 3 can be suggested for high penetration and low Mn/S ratio. The membership functions for Mn/S ratio and the fuzzy rules are given in figure 4,5 and 6.

**Table 2 Measured Responses**

| Flux | $CaF_2$ % | FeMn % | NiO % | CaOgm | $SiO_2$ gm | $Al_2O_3$ gm | Mn% | S% | Mn/S | Penetration |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8 | 2 | 2 | 486 | 695 | 139 | 0.17 | 0.014 | 12.14 | 7.19 |
| 2 | 5 | 8 | 5 | 453 | 647 | 130 | 0.37 | 0.015 | 24.66 | 9.31 |
| 3 | 8 | 2 | 8 | 453 | 647 | 130 | 0.23 | 0.015 | 15.33 | 9.18 |
| 4 | 2 | 2 | 2 | 519 | 742 | 148 | 0.17 | 0.014 | 12.14 | 8.01 |
| 5 | 5 | 5 | 5 | 470 | 671 | 134 | 0.35 | 0.014 | 25 | 8.83 |
| 6 | 5 | 5 | 5 | 470 | 671 | 134 | 0.31 | 0.013 | 23.84 | 9.42 |
| 7 | 8 | 8 | 8 | 420 | 600 | 120 | 0.38 | 0.014 | 27.14 | 6.5 |
| 8 | 5 | 5 | 5 | 470 | 671 | 134 | 0.34 | 0.016 | 21.25 | 9.53 |
| 9 | 5 | 2 | 5 | 486 | 695 | 139 | 0.34 | 0.015 | 22.66 | 10 |
| 10 | 8 | 5 | 5 | 453 | 647 | 130 | 0.42 | 0.015 | 28 | 6.25 |
| 11 | 5 | 5 | 8 | 453 | 647 | 130 | 0.15 | 0.011 | 13.63 | 9.25 |
| 12 | 2 | 2 | 8 | 486 | 695 | 139 | 0.25 | 0.014 | 18.00 | 9.76 |
| 13 | 5 | 5 | 5 | 470 | 671 | 134 | 0.38 | 0.015 | 25.33 | 8.83 |
| 14 | 5 | 5 | 5 | 470 | 671 | 134 | 0.34 | 0.014 | 24.28 | 9.0 |
| 15 | 8 | 8 | 2 | 453 | 647 | 130 | 0.24 | 0.011 | 21.81 | 6.04 |
| 16 | 2 | 5 | 5 | 486 | 695 | 139 | 0.25 | 0.014 | 17.86 | 7.33 |
| 17 | 5 | 5 | 5 | 470 | 671 | 134 | 0.5 | 0.013 | 38.46 | 9.57 |
| 18 | 5 | 5 | 2 | 486 | 695 | 139 | 0.29 | 0.013 | 22.30 | 8.69 |
| 19 | 2 | 8 | 8 | 453 | 647 | 130 | 0.33 | 0.013 | 25.38 | 9.24 |
| 20 | 2 | 8 | 2 | 486 | 695 | 139 | 0.33 | 0.013 | 25.38 | 9.0 |
| | | | | | | | | | | |

**Table 3 Results obtained**

| Run Order | Normalized | | Grey Reltion Coefficient (GRC) | | MPCI | Rank |
|---|---|---|---|---|---|---|
| | Mn/S | Pn | Mn/S | Pn | | |
| 1 | 1.000 | 0.2904 | 1.0000 | 0.4134 | 0.6500 | 4 |
| 2 | 0.524 | 0.8258 | 0.5125 | 0.7416 | 0.5452 | 9 |
| 3 | 0.879 | 0.7929 | 0.8049 | 0.7071 | 0.6663 | 3 |
| 4 | 1.000 | 0.4975 | 1.0000 | 0.4987 | 0.6500 | 6 |
| 5 | 0.511 | 0.7045 | 0.5058 | 0.6286 | 0.4735 | 16 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 0.555 | 0.8535 | 0.5294 | 0.7734 | 0.5633 | 8 |
| 7 | 0.430 | 0.1162 | 0.4673 | 0.3613 | 0.4190 | 18 |
| 8 | 0.654 | 0.8813 | 0.5909 | 0.8082 | 0.5839 | 7 |
| 9 | 0.600 | 1.0000 | 0.5557 | 1.0000 | 0.6500 | 5 |
| 10 | 0.397 | 0.0530 | 0.4535 | 0.3455 | 0.4078 | 19 |
| 11 | 0.943 | 0.8106 | 0.8983 | 0.7253 | 0.7470 | 1 |
| 12 | 0.777 | 0.9394 | 0.6919 | 0.8919 | 0.7172 | 2 |
| 13 | 0.499 | 0.7045 | 0.4994 | 0.6286 | 0.4735 | 15 |
| 14 | 0.539 | 0.7475 | 0.5202 | 0.6644 | 0.4988 | 13 |
| 15 | 0.633 | 0.0000 | 0.5764 | 0.3333 | 0.3997 | 20 |
| 16 | 0.783 | 0.3258 | 0.6970 | 0.4258 | 0.5193 | 12 |
| 17 | 0.000 | 0.8914 | 0.3333 | 0.8216 | 0.5264 | 11 |
| 18 | 0.614 | 0.6692 | 0.5643 | 0.6018 | 0.4516 | 17 |
| 19 | 0.497 | 0.8081 | 0.4985 | 0.7226 | 0.5344 | 10 |
| 20 | 0.497 | 0.7475 | 0.4985 | 0.6644 | 0.4988 | 14 |

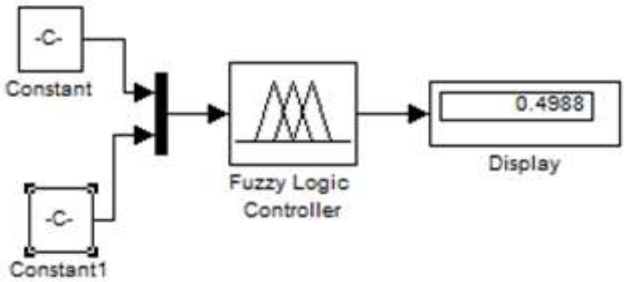


Figure 3 Fuzzy Inference system

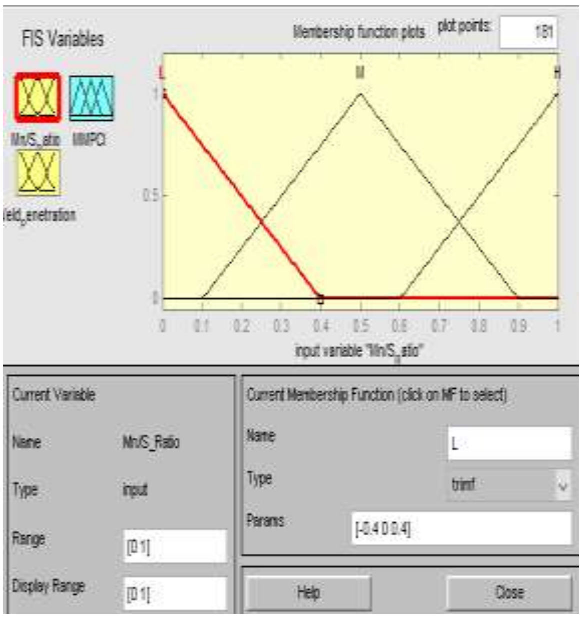


Figure 4Membership functions for Mn/S ratio

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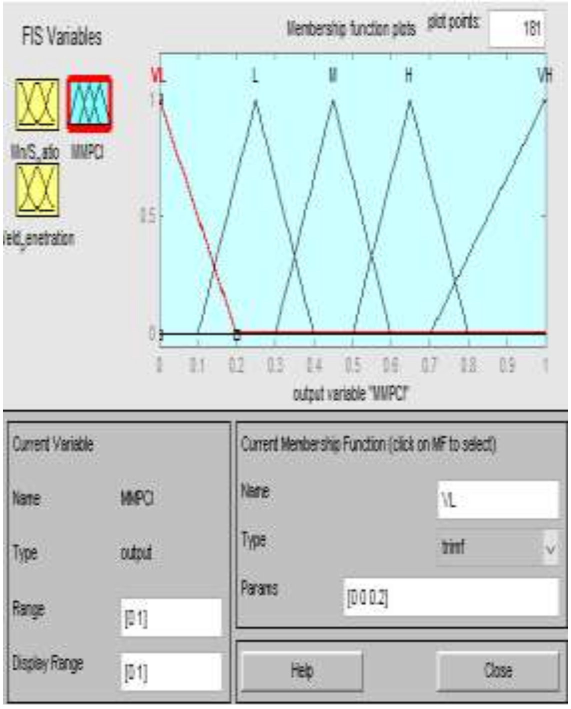


Figure 5Membership functions for Output

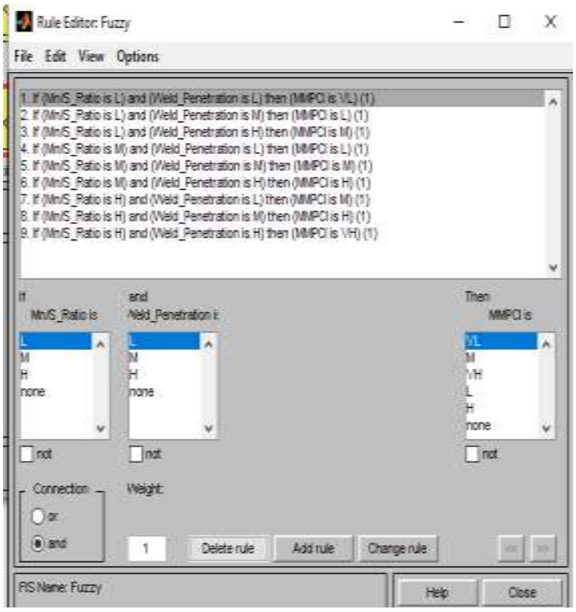


Figure 6Rules for MPCI

## IX. CONCLUSION

1) Response surface methodology has been adopted for design of welding fluxes and the manufacturing of fluxes was done by agglomeration method.
2) As we have to optimize the two output parameters and we desire high penetration and low Mn/S ratio in the weld joints so, multi objective optimization has to be adopted.
3) This experimental analysis shows that the optimized flux constituents for low Mn/S ratio and high weld penetration. The optimized values are 8% calcium fluoride, 2% ferro manganese, and 8% nickel oxide.

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