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Experimental Study of the Flux Cored Arc Welding through Process Parameter

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ABSTRACT

Flux cored arc welding (FCAW) is a semi-automatic or fully-automatic welding method that is widely used for welding large sections and with materials of great thicknesses and lengths, especially in the flat position. In the present work a MIG welding setup has been used to join boiler quality steel. For the experimentation, three process parameters namely, shielding gas flow rate (G), wire feed rate (F) and voltage (V) with five different levels are selected after trial run within the scope and limitation of the MIG welding setup. All the welded samples have been studied through visual inspection, tensile test, and micro-hardness test. Grey relational grades obtained from the grey relational analysis have been used to optimize the process parameters of FCAW process of boiler quality steel with multiple performance characteristics (deposition rate, percentage of elongation, ultimate tensile strength and average hardness of fusion zone) using Taguchi S/N ratio concept on the results of grey relational analysis. The optimization of the complicated multiple performance characteristics is greatly simplified through this approach. The relative importance among the welding process parameters on the multiple performance characteristics has been analysed through Analysis of Variance (ANOVA) method.

Keywords : Flux cored arc welding, boiler quality steel, tensile test, micro-hardness test, Analysis of Variance

I. INTRODUCTION

Pressure vessel is fabricated with superior quality of carbon steel which is designed to withstand the high internal pressure in pressure vessels and boilers. Boiler quality steel is very popular due to its diversity of use and a lower cost than that cost of traditional stainless steel grades. For welding of this material flux cored arc welding process is required. Flux Cored Arc Welding (FCAW) works on the principle of MIG welding with an electrode wire having the flux in its core. With FCAW, high deposition rate is possible maintaining a good quality of work as compared to other types of arc welding processes. Boiler quality steel is used for these applications since it provides the required properties. The key quality for boiler quality steel is its hardness at elevated temperature and pressure. It is harder than mild steel but less hard than stainless steel. The benefit of using boiler quality steel is that the working life of the plant and machinery can be increased which improve the reliability, durability and safety of structures and equipment's which helps to reduce the maintenance costs associated with plant. This steel contains 0.19 % Carbon, 0.94 % Manganese, 0.23 % Silicon, 0.026 % Sulphur and 0.035% Phosphorous. Mechanical properties of the boiler quality (BQ) steel used in the present experiment are given in Table-1

Table - 1: Mechanical properties of BQ steel

Yield strength MPa	UTS MPa	Elongation %	Hardness HV
350 – 370	470 – 480	23	175-190

Flux Cored Arc Welding Process: FCAW is a process in which a tubular electrode with flux in the core of the electrode is used. The electrode is supplied in coiled form. The machine used for the purpose is same as the MIG welding setup. FCAW with CO_2 gas shielding gives deeper weld penetration and can weld metal ranging from 1.6 mm to 13 mm thickness with no edge preparation. When CO_2 is not used, the maximum thickness that can be welded is only about 6 mm. The working principle of CO_2 welding is given here. The advantages of carbon dioxide are good width of fusion and the achievement of good mechanical properties. However, oxidation of iron and carbon in CO_2 welding is suppressed by the addition of deoxidizer and reduce the oxides.

Fig.1: Flux cored arc welding

II. LITERATURE REVIEW

During the last two decades, research on FCAW process involves a large number of areas and these are improvement of commercial electrodes, effect of shielding gas on weld quality, prediction of the level of diffusible hydrogen on weld and its control, development of welding consumables, study of different welding sequences and study of fatigue strength. At the beginning, this process, mainly for economic reasons, was limited to an AC welding system made up of a combination of a comparatively large size electrode and an AC power supply. After years of research, however, the users recently preferred a DC welding system using a fine electrode which is more advantageous both in quality and usability than the AC system.

The main objective of this paper was to the improvement of commercial electrodes and applications of typical electrodes recently developed for the DC system. The shielding gas is used to protect the finished weld from the effects of oxygen and nitrogen in the atmosphere. Although the weld metal properties are primarily controlled by the composition of the consumable, the shielding gas can influence the welds strength, ductility, and toughness and corrosion resistance. **Arivazhagan et al.** [5] used four types of shielding gases in the experiment: pure argon (Ar), pure CO_2, premixed shielding gases 80% Argon + 20% CO_2 and 95% Argon + 5% CO_2 and it was found that 95% argon + 5% CO_2 was the ideal shielding gas medium for FCAW process to meet the toughness requirements with better process characteristics. The effects of the shielding gas composition and heat input on the microstructure and properties of welds with four commercially available flux cored wires were studied by **Lathabai et al.** [6]. The nature of the applied shielding gas had a strong influence on arc stability and transfer metal mode of the welding process. **Zielin et al.** [8] showed that effects of shielding gas are linked to the chemical and microstructural modifications of the anode tip during the gas metal arc welding process. Chemical reactions at high temperature such as oxidation–reduction reactions between shielding gas and melted metal govern the transition of the spray-arc to globular transfer mode. **Prakash et al.** [9] dealt with the detailed study of shielding gas used for aluminium welding. FCAW exhibits many important favourable characteristics such as high productivity, good quality weld and low cost, reports have shown that the diffusible hydrogen found in the weld deposits is usually higher than the ones found in the weld made by SMAW and GMAW. **Pang et. al.** [13] concentrated on the hardness in the heat affected zones produced by submerged arc welding of two low-carbon quenched and tempered steels. Weld thermal cycle simulation had been used to confirm the results obtained from actual welds and to clarify the causes of this unexpected phenomenon. Finite element thermo-mechanical model of GMAW process for temperature and stress with solidification model was analysed by **Choi et al.**[14]. **Hiroshige et al.** [16] started the development of a stainless steel and welding consumables for the steel having significantly improved corrosion resistance for application to chemical cargo tankers and in 2003, launched a new stainless steel along with proper welding consumables. This paper reported the development of the welding consumables specially designed for the new stainless steel. **Qinglei et al.** [17] investigated the influence of welding wire on the microstructure, tensile strength and impact toughness of Q550 steel weld joints. Results showed that the microstructure of the weld metal of joints produced using ER50-6 wire was a mixture of acicular ferrite and grain boundary ferrite including pro-eutectoid ferrite and ferrite side plate. **Suban et al.** [18] described a study on welding productivity, i.e. melting efficiency of the filler material (solid and cored wires) in various shielding media. **Aloraier et al.** [20] investigated the role of the deposition sequence and the spatial deposition of the weld beads in micro-structural variation in the critical zones of the resulting weldments such as HAZ and characterizing the metallurgical properties (viz., hardness) of such zones. **Balasubramanian et al.** [22] carried out similar fatigue tests on welded joint of quenched and tempered steel of weldable quality in the form of rolled plates of 8 mm thickness using a flux-cored arc welding (FCAW) process with matching weld metal consumable (AWS E100 T5-K5). **Vuherer et al.** [24] concluded that welding thermal cycle had negative influence on HAZ mechanical properties. In order to avoid cold cracking in HAZ, it is important to perform preheating before starting the welding operation. **T. Filho et al.** [25] studied microstructure and mechanical properties of four different low alloy steel weld metals (WM) both in the as welded condition and after normalizing heat treatment. **K. Babu et al.** [26] conducted an experimental work to evaluate and compare corrosion and its inhibition in steel weldments made by FCAW process with two different heat inputs exposed to hydrochloric acid medium. **Jaiswal et al.** [36] calculated and analysed the effect of controllable process variables on the heat input and the Microhardness of weld metal and heat affected zone (HAZ) for bead on joint welding using design of experiment and fractional factorial technique developed for the multipass welding of boiler and pressure vessel plates. **Popovich et al.** [37] described the influence of welding heat input on the weld metal toughness of high-carbon steel surface welded joint. **Tabuci et al.** [39] compared creep damage distribution between experimental and computed versions using the finite element method and damage mechanics. **Kim et. al.** [49] followed the dual responses approach to determine the welding process parameters, which produce the target value with minimal variance. The dual response approach optimizes the penetration in gas metal arc (GMA) welding. **Sapakal et al.** [50] presented the influence of welding parameters like welding current, welding voltage, welding speed on penetration depth of C20 material during welding. **Aydin et al.** [51] focused on the multi-response optimization of friction stir welding (FSW) process for an optimal parametric combination to yield favourable tensile strength and elongation using the Taguchi based Grey relational analysis (GRA). **Tarng et al.** [52] reported the use of grey-based Taguchi methods for the optimization of the submerged arc welding (SAW) process parameters in hard facing with considerations of multiple weld qualities.

From the literature review, it is understood that Information regarding optimization of welding parameters of FCAW in welding of boiler quality steel is not much available in literature Issues like monitoring and control of welding parameters are of great importance in all arc welding for the purpose of making products with a consistent and defined quality for high productivity. It is well established that hardness, microstructure and a number of weld joint properties are largely influenced by heat input which is a function of arc voltage and welding current. The wire feed rate is usually controlled by the welding power source. Keeping all these under consideration, for the present study the input parameters selected are arc voltage, electrode wire feed rate and shielding gas flow rate. The output parameters which have been selected are tensile strength and percentage of elongation of the welded joint, weld metal deposition rate, micro-hardness of heat affected zone and micro-hardness of fusion zone of weldment. The present investigation focused on the influence of the process parameter on microstructure, micro-hardness and mechanical properties due to the welding process.

III. Methodology

In this work, MIG welding setup has been used. Boiler quality steel of thickness 12 mm have been cut into pieces of size 100 × 50 × 12 mm. For butt welding of these plates, edge preparation is required and same has been done by using shaping machine. The work-piece after edge preparation is shown in Fig.2.

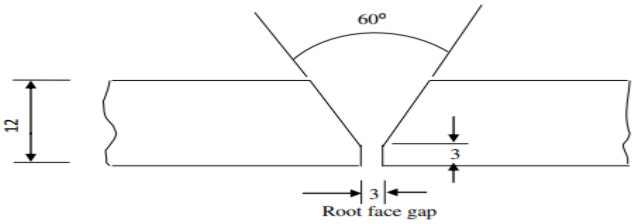

Fig.2: Groove geometry of test plates

In this work, E71T-1 flux cored wire has been selected as the electrode. Its composition is given below Table-2.:

Table-2: Composition of Electrode E71T-1

Element%	Percentage
% C	0.05 %
% Mn	1.00 %
% Si	0.74 %
% S	0.05 %
% P	0.008 %
% Fe	Rest

Carbon dioxide has been selected as shielding gas for the present work. This is an oxidising gas. As a shielding gas it ensures arc stability and accurate welding profiles. Carbon dioxide (CO_2) is the most common of the reactive gases used in MIG welding and the only one that can be used in its pure form without the addition of an inert gas. Pure CO_2 provides very deep weld penetration, which is useful for welding thick material; however, it also produces a less stable arc and more spatter than when it is mixed with other gases. It is also limited to only the short circuit process. In the present work CO_2 flow rate is considered one of the controlling parameter on weld quality. For the experimentation, three process parameters namely, shielding gas flow rate (G), wire feed rate (F) and voltage (V) with five different levels are judicially selected after trial run within the scope and limitation of the MIG welding setup. They are listed in Table-3. L_{25} Taguchi Orthogonal array for the above three factors and five levels have been adopted for the experimentation.

Table - 3: Welding parameters and their level

Level	**Factors**		
	Gas flow rate (G) l/min	**Wire feed rate (F) m/min**	**Voltage (V)**
1	5	6.05	28
2	10	6.74	30
3	15	7.43	32
4	20	8.21	34
5	25	8.94	36

Fabrication of Joints:


Specimen 1


Specimen 2


Specimen 3


Specimen 4


Specimen 5


Specimen 6


Specimen 7


Specimen 8


Specimen 9


Specimen 10


Specimen 11


Specimen 12


Specimen 13


Specimen 14


Specimen 15


Specimen 16

Specimen 17 Specimen 18 Specimen 19 Specimen 20

Specimen 21 Specimen 22 Specimen 23 Specimen 24

Specimen 25

Fig.3: Photographic view of specimens for experimental runs 1- 25 at different process parameters

IV. RESULTS AND DISCUSSION

1. Welding Characterization by Visual Inspection

It is observed that after third pass lack of penetration are there in some of the samples. To obtain better weld quality fourth pass weld has been carried in the root side of the weld. Visual appearance of all welded joints at different process parameters are shown in Fig. 3

Specimen 16 Specimen 22 Specimen 11

Fig. 4: Lack of penetration for experimental runs 16 and 22; sufficient penetration for specimen 11

- Small amount of spatter is observed in specimen 10, otherwise FCAW-G process is free from spatter defects. Very poor penetration is observed in specimen 6, 16 and 22, all these joints have been carried out at very low wire feed rate and hence low welding current.
- On the other hand specimen 11 shows high penetration as shown in Figure 5.2, though this welding is also at low wire feed rate. Poor penetration may be caused due to low wire feed rate where specimen 11 over penetration is due to lower traverse speed which is manually operated. A second run for experiment 11 is done that provides low depth of penetration.
- Undercut and root undercut is visualized in specimen 5, 9, 14 and 25. Welding is done in these samples, except 14, at high level of voltage, high level of current and at various shielding gas flow rate, whereas the specimen 14 has been welded at gas flow rate at level 3, wire feed rate level 4 and voltage level 1. High voltage and high wire feed rate indicates high heat input.
- Hence it may be concluded that high heat input may cause undercut in FCAW welding and shielding gas has no effect on undercut but high heat input may not be the only reason. It may be noted that this undercut is not very significant.

2. Tensile Test: The loads at ultimate point of the specimen are noted. The ultimate tensile strength is calculated and is given in the Table-4. The specimen 21 after breaking in of in UTM is shown in Fig.5.

Fig.5: Specimen 21 after breaking in UTM

Table-5: Ultimate tensile strength and percentage of elongation

Sl. No	Gas flow rate (l/min)	Wire feed rate (m/min)	Voltage (V)	Ultimate Tensile Strength (σ_u) (MPa)	Percentage of elongation (%)
1	5	6.05	28	456.0	20.8
2	5	6.74	30	464.3	23.6
3	5	7.42	32	469.3	26.7
4	5	8.21	34	468.0	20.8
5	5	8.94	36	466.0	22.8
6	10	6.05	30	473.1	29.2
7	10	6.74	32	460.1	19.6
8	10	7.42	34	465.0	20.8
9	10	8.21	36	460.0	27.3
10	10	8.94	28	466.5	26.8
11	15	6.05	32	477.0	26.0
12	15	6.74	34	474.2	34.9
13	15	7.42	36	478.0	21.0
14	15	8.21	28	472.0	24.5
15	15	8.94	30	467.0	15.4
16	20	6.05	34	468.0	21.8
17	20	6.74	36	486.1	22.5
18	20	7.42	28	469.0	20.9
19	20	8.21	30	474.0	22.6
20	20	8.94	32	464.8	25.0
21	25	6.05	36	474.5	23.7
22	25	6.74	28	454.9	20.8
23	25	7.42	30	457.3	24.1
24	25	8.21	32	462.4	20.4
25	25	8.94	34	478.4	25.0

3. Microhardness Test: In the present work 100 gf load has been applied. By trial run with the Vickers Microhardness Testing Machine, it has been observed that with low load, the indentation is quite small; with very high load (≈ 1000 gf), the indentation is very high but at the time with this very high indentation surface is damaged. To avoid this, load of 100 gf has been selected and the error has been found to be minimum. The hardness in unaffected base material, HAZ and weld material deposited regions with respect to distance from the centre of fusion zone up to few millimetres beyond HAZ in the base material, for three different specimens fewer than three different heats.

Table-6: Hardness measurement for Specimen 1

Specimen 1			
	Sr. No.	**Distance from centre line of FZ (mm)**	**Hardness Value (HV)**
Base	1	11.3	199.9
	2	10.3	181.9
	3	9.3	200.1
HAZ	4	8.3	237.7
	5	7.3	222.0
	6	6.3	254.8
Fusion Zone	7	5.0	270.4
	8	4.0	269.9
	9	3.0	282.0
	10	2.0	272.1
	11	1.0	280.8
	12	0.0	294.6
	13	-1.0	288.5
	14	-2.0	281.5
	15	-3.0	265.4
	16	-3.5	232.9
	17	-4.1	235.5
HAZ	18	-5.2	222.8
	19	-6.5	220.3
	20	-7.8	196.2
Base	21	-9.8	180.2
	22	-10.8	196.0
	23	-11.8	237.7

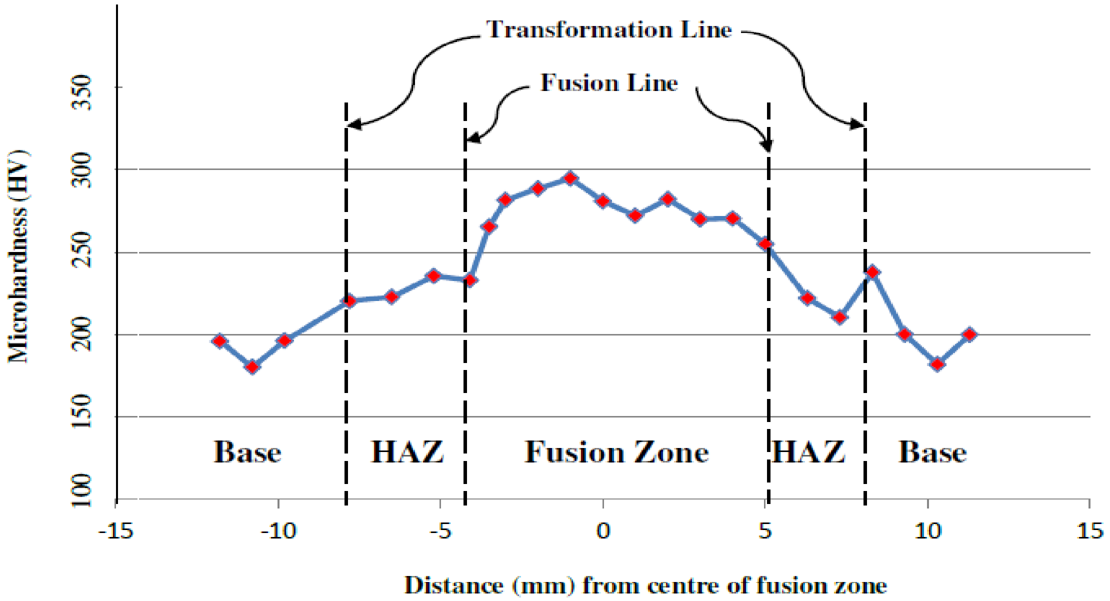

Fig.6: Hardness at different zones of butt-welded specimen 1

Parametric Optimization through Grey Relational Analysis of Data

1. Deposition Rate

Weight (W_P) of the work piece has been measured before welding. Using a stop watch the total time (t) for welding has been recorded. Weight of the specimen after joining (W_f) has been measured by electronic weighing machine. Higher deposition rate is highly desirable as it gives the high productivity. The grey relational analysis for deposition rate, the “larger-the-better” criterion has been considered.

2. Ultimate Tensile Strength and Percentage of Elongation: For the grey relational analysis, the “larger-the-better” criterion has been considered for these outputs.

3. Average Microhardness of HAZ and Fusion Zone: Lower hardness is the indications of better performance as it gives better toughness of the joint. In the similar manner considering the “Smaller-the-better” criterion normalised values for HAZ and fusion zone hardness are computed.

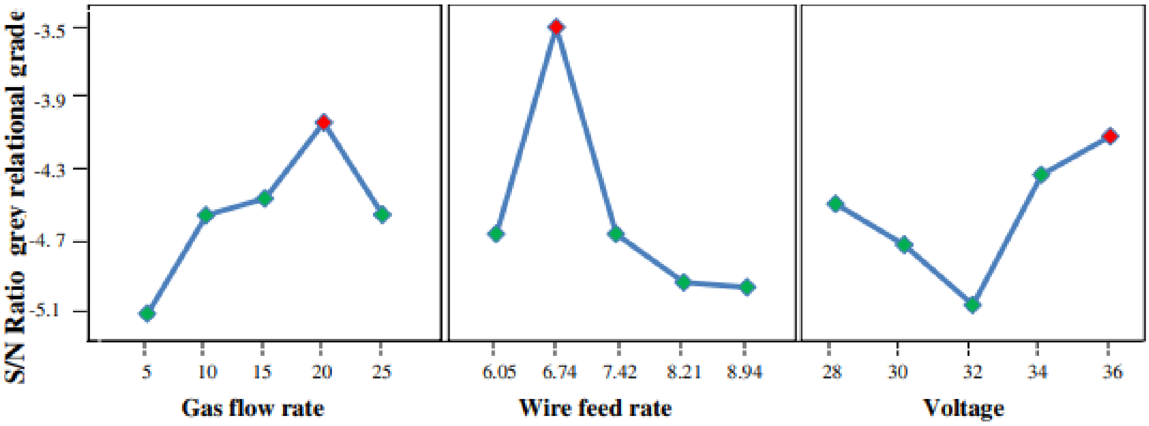

Fig.7: Process parameter level vs. S/N ratio of grey relational grade

Effect of wire feed rate on overall response characteristics grey relational grade shows low presumption against the null hypothesis. The P-value and F-values are 0.097 and 2.21 respectively for this controlling parameter. Voltage and shielding gas flow rate has no significant effect on grey relational grade. Optimization of process parameter through grey relational analysis gives the optimum parameters that maximize grey relational grade as gas flow rate 20 l/min, wire feed rate 6.74 m/min and voltage 36 through Fig.7.

V. CONCLUSION

The conclusions derived from this experimental investigation are presented below.

- From the above three inspection it is observed that welding should not be carried out at very high wire feed rate and low voltage. Better welding in FCAW process with shielding by carbon-dioxide gas may be carried out at medium to high gas flow rate, low wire feed rate and at high voltage.
- Measurement of hardness at various regions of the weldment in FCAW of boiler quality steel has been done. Hardness of the base material i.e. boiler quality steel is found to be between 175 HV and 200 HV. With high heat input, weld metal hardness is found to be more uniform within the entire regions of weld metal. Width of heat affected zone decreases with increase in heat input. Hardness gradually increases from base material to the centre of fusion zone.
- The optimal welding process parameters predicted using this analysis are shielding gas flow rate at level 4 (20 l/min), electrode wire feed rate at level 2 (6.74 m/min), and voltage at level 5 (36 V). It was found that the optimum conditions obtained from grey relational analysis correlates with the conformity test result. The difference was found to be less than 7%. This indicates that the optimization methodology proposed in this study is effective.
- The highly effective parameter on the multiple responses is the electrode wire feed rate (31.7%) whereas shielding gas flow rate (13.4%) and welding voltage (11.8%) are less effective factors.

VI. FUTURE SCOPE

In future, the effect of the process parameters will be investigated on the residual stress field for several materials. Thus, fatigue crack growth tests will be carried out to find out their influence on the fatigue life. A comparative study between FCAW and other widely used welding method may be investigated.

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