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A Review on 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. Therefore, welds made by FCAW are shown to have much improved mechanical properties than the corresponding fusion welds. Hence, this study plan the effects of process parameters of FCAW used for boiler quality steel through experiment and statistical analysis.
Keywords : Flux cored arc welding, boiler quality steel, mechanical properties, fusion welds, Statistical analysis

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. Welding is a joining process that produces coalescence of materials with or without the application of heat, pressure and filler material. Welding has become one of the fabricating and repairing metal products. This type of welding is more popular in industries. 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. At elevated temperature and high pressure, high hardness is offered by boiler quality of steel. For this purpose this steel is quenched or even tempered. 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

Joining Process: In arc welding an electric arc is created between the pieces being joined the work pieces and an electrode. The electrode may be consumable or non-consumable type. The consumable electrode melts and supplies filler metal to the joint. The basic arc welding process is shown in Figure-1. It uses an alternating current (AC) or direct current (DC) power source connected by a "work cable" to the work piece and by a "hot cable" to an electrode. When the electrode is positioned close to the work piece, an arc is created across the gap between the metal and the electrode. In arc welding process, the welding consumable serves as the electrode to generate an arc and simultaneously as the filler metal to supply the deposited metal for the weld. This process is called the consumable-electrode welding process include Flux Cored Arc Welding (FCAW)

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. Sometimes this FCAW is performed with no shielding gas and is referred as FCAW-S. The shielding effect of the weld pool is obtained by melting of the flux and this electrode is termed as inner-shield. In the other type a shielding gas is provided for protection of weld pool and is known as FCAW-G. These electrodes are referred as outer-shield. FCAW-G is the most widely used FCAW process which has been developed primarily for welding of thick steel plates. The slag created by this flux can also be removed easily. However, it cannot be used in a windy environment as the loss of the shielding gas from air flow will produce visible porosity on the surface of the weld.

Fig.1: FCAW

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. MIG process with CO_2 shielding gas is almost exclusively used for welding low carbon and alloy steels; and often referred to as CO_2 welding. It is a reactive gas, dissociates into carbon monoxide and free oxygen in the heat of the arc. Carbon dioxide is an active gas and produces an oxidizing effect, sound welds can be consistently achieved with pure CO_2. 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.

II. LITERATURE REVIEW

The flux cored arc welding process was introduced in early 1950. Flux cored arc welding with gas shielding (FCAW-G) has been introduced to the market around 1957. The flux -cored arc welding self-shielded

(FCAW-S) was introduced to the market later, around 1960. 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.

In [2] a fundamental study was conducted on the effect of various factors of arc and gas absorbing phenomena. 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. In general, for a given welding wire, the higher is the oxidation potential of a shielding gas, the lower is the strength and toughness of the weld. This occurs because the oxygen and carbon dioxide in the shielding gas increase the number of oxide inclusions and reduce the level of alloying elements such as manganese and silicon in the weld metal. The influence of variation in the shielding gas composition on the weld properties was investigated in several works. The influence of shielding gas compositions on the apparent weld bead geometry had been previously studied by researches [3]. The significance of the shielding gas compositions on the arc stability and efficiency, deposition rate, microstructure, chemical and mechanical properties of mild carbon steel welds was established [4]. Weld metal ferrite content was decreased by increasing the amount of CO_2 in the Ar + CO_2 mixtures. 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]. They observed that, variation in the CO_2 content of the shielding gas from 8% to 100% increased the oxygen content of the weld metals but decreased the recovery of manganese, silicon and other major alloying elements. Higher heat input further decreased the recovery of manganese and silicon for a given wire and gas combination. Increasing the CO_2 content in the shielding gas made the arc harsher and increased the spatter levels, the bead convexity and the weld penetration. The changes in shielding gas and heat input produced inconsistent trends in the Charpy impact transition temperature. In [7] the influence of variation in the shielding gas composition on the weld properties of steel ST 37-3 was investigated. Six different shielding gas compositions in addition to pure argon (Ar) and pure CO_2 were studied in this work using flux cored arc welding (FCAW) process. This study was aimed to examine how different shielding gas compositions influenced the metallurgical, mechanical and chemical properties of mild carbon steel welds using semi-automatic FCAW process. 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. The major sources of hydrogen in the weld metal deposited with a tubular wire are moisture in the flux, hydrogenated flux ingredients, residual lubricant on the wire surface, moisture in the shielding gas and in the atmosphere. It is well established that hydrogen is the most harmful gas in steel weld metals because it is the agent for cold cracking [10]. Bracarense et al. [11] conducted an exhaustive study on factors affecting diffusible hydrogen content of FCAW weld metal. This work was developed to evaluate the effect of welding current on hydrogen content in flux cored arc weld metal. The study was based on measurement of diffusible hydrogen using gas chromatography, recording of the electrical parameters - welding voltage and current, collection of metal droplets during welding and high speed cinematography recording. A polynomial regression analysis was done from this work and they concluded that increases in hydrogen content with current was better described by a linear function with proportional constant of approximately 0.7 or 70%. It was observed from the GMA welding metal transfer behaviour, and statistical analysis that only in metal droplet size occurred with increase in current. Also increase in droplet size was relatively insignificant with increase in current in FCAW. While current increases approximately 50% (from 105 to 150 A), droplet size increased. In [12] an attempt was made to establish input–output relationship in MIG welding process through regression analyses carried out both globally as well as cluster-wise. The investigation was based on the data collected through full-factorial design of experiments. 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]. Model prediction was compared with experimental data in order to validate the model. The effects of welding process parameters on these welding fields were analysed and reported. The effort to correlate the residual stress and solidification was initiated, yielding some valuable results. In most engineering metallic structures, welded joints are often the locations for the crack initiation due to inherent metallurgical, geometrical defects as well as heterogeneity in mechanical properties and presence of residual stresses. Kocak [15] addressed to stainless steels such as Type 304 and Type 316L became chief material for the cargo tanks of chemical tankers in place of ordinary carbon steels with paint coating. Chemical tankers carry a wide variety of chemicals, petroleum products and food materials, and the corrosion of tanks by the cargo has always been a major problem. 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. A mathematical model for prediction of melting rate in welding with solid and cored wires was presented too. In [19] microstructure and microhardness variations had been investigated and correlated in an HSLA-100 steel weldment fabricated with an exploratory ultra-low-carbon (ULC) welding consumable designated as CTC-03. These results were compared to the Microhardness maps of four other weldments, made with different ULC candidate filler metals (designated CTC-08 and ARC-100), base plates and heat inputs. 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. It was observed that when transverse cracks were propagated in a quarter or half-circle shape, the specimen broke at low cycle in the presence of a surface crack. However, when the crack was inside the specimen, it propagated in a circular or elliptical shape and the specimen showed high fatigue strength, enough to reach the fatigue limit within tolerance of design stresses. Many structures are welded, which, from a fatigue life point of view is far from optimal. Linking the analysis of the effects of weld discontinuities and failure analysis of weldments, it is indicated that fatigue alone was considered to account for most of the disruptive failures and often precedes the onset of brittle failure, even though the weld metal was good enough in fatigue life [21]. 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). A mathematical model was also developed to predict the fatigue life of flux-cored arc-welded (FCAW) cruciform joints containing lack of penetration (LOP) defects. The influence of cruciform joint dimensions on fatigue life was analysed in detail. Larger weld and lower LOP-sizes and a straight-fillet profile produced better fatigue properties for cruciform joints. Aloraier et al. [23] reported research work carried out to investigate whether a fully automated flux cored arc welding process with bead tempering could be used in repair welding instead of manual metal arc welding in order to eliminate the use of post weld heat treatment (PWHT). Temper bead welding (TBW) had been accepted and employed as an alternative technique for PWHT. TBW was affected enormously by welding parameters such as wire diameter, heat input and bead overlap. Bead overlap was considered to be one of the most important factors that needed to be controlled in order to achieve a high percentage of refinement. The paper also examined different percentages of bead overlaps and studies their effects on the mechanical properties as well as the microstructures. The results show that desirable microstructures and hardness values were obtained using flux cored arc welding when 70% bead overlap was used. 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. In equipment manufacturing, there are occasions that the base metal (BM) needs to be hot or cold worked prior to welding. After welding, the components have to be submitted to a normalizing heat treatment in order to recover its original mechanical properties. 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. They concluded that corrosion rate was decreased by increasing the heat input. Another important aspect with welding process is fume generation. Radiation from the arc can cause eye and skin damage. Gases and respirable particles in the welding environment contain chemicals that can create adverse side effects after inhalation, if delivered in the appropriate dose and chemical state. The emission characteristics of the FCAW and GMAW process were modelled in [27]. In [28] various chemical analysis techniques and their applicability to welding fume particles were presented. Particle agglomerates smaller than one micrometre was respirable. Coarse welding fume particles larger than one micrometre were termed as micro-spatter. Flux cored arc welding fume contained approximately 30% micro-spatter by mass. A more detailed division of the modes of toxic metal emission can be found in [29]. An experimental effort was undertaken to expand and update Cr (VI) emission factors for stainless steel welding and included four welding processes: gas-metal arc welding (GMAW), shielded metal arc welding (SMAW), flux core arc welding (FCAW) and pulsed gas metal arc welding (P-GMAW). The emission factors for Cr (VI) from stainless steel electrodes were determined and compared to existing data. More over non-metallic inclusions play an important role in the evolution of microstructures in steel weld metals. They influence the partitioning of alloying elements 18 between solid solution and second phases depending upon the temperature of the formation. Also, they may act as nucleation sites for solidification and solid-state transformations on cooling. Inclusions are also known to have a direct effect on mechanical properties. The only earlier investigation on non-metallic inclusions [4] showed a log normal size distribution. The inclusions in the lower oxygen basic weld metals were significantly finer than those in the acid weld metals. Higher heat inputs result in coarser inclusions. The non-metallic inclusions in the basic weld metal were complex oxides of silicon, manganese, titanium and aluminium. Those in the acid weld metals were complex oxides of silicon, manganese and titanium. The inclusions are heterogeneous in their composition. Complex sulphides of manganese and copper were also observed in all weld metals. It also stated the role of the inclusions in nucleating acicular ferrite. Quintana et al. [30] concluded that the inclusions in the weld with high-aluminium concentration were predominantly aluminium nitride. In contrast, the inclusions in welds with low aluminium and high-titanium concentrations were mostly aluminium oxide and titanium carbonitrides. Most of the documented work on inclusions in weld metal has focused on welding processes that shield the arc and molten metal from atmospheric contamination. In [31] weld metal microstructures were investigated in commercial FCAW-S steel welds with two different aluminium concentrations. The causes and influence factors of the pore formation in the weld of self-shielded flux-cored wire (SSFCW) were extensively analysed in [32]. The results of this study revealed that not only nitrogen content was the main influencing factor, as well known for formation of porosity in the weld of SSFCW, but also oxygen could rapidly increase the quantity of pore in the weld of SSFCW. A flux cored arc welding electrode contains multiple powdered ingredients within a metal sheath. Moreover, the variety of the ingredients that can be used in FCAW is enormous. A study [35] was undertaken to determine the intermixing effects on two electrodes weld metals as a result of intermixing with various FCAW-S deposits. In [36] and [37] and in several other works the influence of heat input on the weld quality had been discussed. 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. The welding heat input had a great influence on the weldments properties. Popovich et al. [37] described the influence of welding heat input on the weld metal toughness of high-carbon steel surface welded joint. In [38] creep tests of the dissimilar welds between high B-9Cr steels and Ni base alloys for Alloy 617 and Alloy 263 were conducted at 650 °C. Tabuci et al. [39] compared creep damage distribution between experimental and computed versions using the finite element method and damage mechanics. In [40] study was undertaken with the objective of determining the effects of weld speed on the weld profile and dilution analysis of the MIG butt welds of IS 2062 E250 A mild steel plates at constant wire speed rate and constant arc voltage and welding current. In [41] the authors optimized the wire feed speed against the welding speed during the pulse-MIG lap joint fillet weld of 1.6 mm aluminium alloy typically used for the light-weight car body. Generally, the quality of a weld joint is directly influenced by the welding input parameters during the welding process; therefore, welding can be considered as a multi-input multi-output process. 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. A plan of experiment based on Taguchi technique had been used to acquire the data. 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). The objective functions had been selected in relation to parameters of FSW parameters; rotating speed, welding speed and tool shoulder diameter. 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. In this approach, the grey relational analysis was adopted to solve the SAW process with multiple weld qualities.

III. DISCUSSION AND FUTURE TRENDS

Within the scope of literature survey, it is seen that significant information is available so far as welding of different materials with FCAW is concerned. But information regarding welding of boiler quality steel with FCAW. 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.

IV. CONCLUSION

In this study, the conclusions of the research work are presented in this chapter. 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. Therefore, welds made by FCAW are shown to have much improved mechanical properties than the corresponding fusion welds. Hence, the present investigation was planned the effects of process parameters of FCAW used for boiler quality steel through experiment and statistical analysis.

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