CHAPTER-1

INTRODUCTION

1.1 Introduction

One of the main welding processes used in the modern industries for the fabrication of huge structures, pipes, thick plates, boilers, pressure vessels, marine vessels, rail tanks, ships, heat exchangers and structures is Submerged Arc Welding (SAW) process. SAW is a versatile metal joining process in heavy industries. It is a multi-variable, multi-objective metal fabrication process, characterized by the use of granulated fusible flux which covers the molten weld pool during the operation. This arrangement facilitates slower cooling rates, prevents atmospheric contamination into weld pool and improves both mechanical properties and metallurgical characteristics of the weld bead as well as Heat Affected Zone (HAZ). Smoke and arc flash are absent in SAW. The key features of this process are high current, long weld runs, deep weld penetration, excellent surface appearance, invisible arc, lower welding skill requirement and high deposition rates, resulting in high savings in welding costs. It is one of the oldest automatic welding processes and was invented simultaneously in USA and USSR during 1930s [Howard Carry, Nadkarni, Houldcroft] [175,181,174]. The process contributes to approximately 10% of the total welding needs over the world and is commercially used for the welding of low carbon steels, high strength low alloy steels, nickel base alloys and stainless steels (Wilson [161]). 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 resistance (Khan [180]).

1.2 Submerged Arc Welding Overview

Submerged arc welding can be carried out with DC power source of constant voltage (for fully automatic welding system) or constant current (for semiautomatic system) and AC power sources of constant current. The main requirement of SAW power source is that it should be capable of supplying heavy current at high duty cycle. D.C. power can give easy and accurate arc start. AC is generally preferred for larger diameter (> 4 mm) feed wires. The power source should be rated at 100% duty cycle and not at 60% as required for manual welding. Power sources of current range between 600-2000A output, AC or DC using single or multiple (2 to 5mm) wires or strips of filler metal, although currents up to 5000 amperes have also been reported to be used with multiple arcs (Jeffus, Kalpakjian,) [176,179]. Automatic wire feed system and tracking systems on mechanized equipment permit high quality welds with minimum of manual skill requirements. High deposition rates up to 45kg/h on thick sections are major advantages of this process. Plate thicknesses up to 25mm could be welded in a single pass without edge preparation. Various filler metal flux combinations may be employed to obtain the desired weld deposit characteristics to suit the intended service requirements. Nearly one kg of flux is consumed per kg of filler wire used. The process is ideal for flat position welding of thick plates requiring consistent weld quality and high deposition rates. Constant voltage DC power supply is self regulating and could be used on constant speed wire feeder easily. It is a commonly used power source and is the best choice for high speed 80 mm/s welding of thin gauge steels. The important process variables
in submerged arc welding are: welding current, arc voltage, welding speed, nozzle to plate distance, flux depth, heat input and wire feed rate. The effects of these process variables can be determined through their effects on weld bead geometry and Shape relationships. SAW is being widely employed as one of the major fabrication processes in industries today due to its inherent advantages of deep penetration, smooth bead and superior joint quality, higher welding speed, excellent weld appearance (without spatter) and high deposition rates.

Around 1950s, the Engineers became conscious of the quality of the welded joints. It is now a well accepted fact that the weld bead geometric parameters have a large influence on the quality of the welded product. The studies on the effects of various welding process parameters on the formation of bead, depth of penetration, reinforcement height, and bead geometry have attracted the attention of many researchers to carry out further investigations in the direction. Recent developments in the artificial neural networks and multiple regression analysis have been found to be useful in solving many problems in different fields of engineering. Back propagation neural network has been proved to be one of the best algorithms for predictive type of work. Design of experiment (DOE) combined with factorial technique are being used as tools to determine and represent the cause and effect relationship between true mean responses and input control variables influencing the responses (as two or three dimensional hyper surface).

Quality of welded joint using SAW welding process depends on a number of factors, like the type and thickness of base metal, groove type, welding position etc. It is a well-known fact that optimal selection of welding parameters plays an important role in the quality of Submerged Arc Welds produced. Proper selection of welding parameters is therefore very important. Thus, the prediction of weld bead geometry for Submerged Arc Welds in
relation to the welding process parameters i.e. welding current, arc voltage, welding speed, wire feed rate, nozzle to plate distance and heat input.

In SAW of steel plates the engineers often face the problems of relating the welding process variables to the weld bead quality and optimization of the bead geometrical parameters. Welding is carried out with the aim of achieving a sound joint at a low cost. But without optimization, it is impossible to achieve high quality welding at low cost. Since any welding process has a multiple-objectives to achieve i.e. (Maximum penetration, minimum reinforcement, minimum heat input, minimum width, minimum dilution, low cost, maximum production rate). The optimum solution is a compromise in the selection of an appropriate weld bead parameter and its control is also equally important because if the selected parameter is the one determined and controlled by most of the other important bead parameters, then the optimization of that parameter will obviously include all the other parameters.

The geometry of the weld bead is the major factor influencing the structural adequacy of the weld, such as its strength. Some of the weld bead characteristics of significance are bead width, bead height, penetration depth, etc. The properties of the welded joints are affected by a large number of these weld bead parameters. The correlation between welding process parameters and bead geometrical characteristics can provide useful information about the quality of the welds. Many investigators have tried to identify the various welding process parameters with the consequent bead geometry. In the following paragraphs an attempt has been made to provide an insight into the above mentioned area through the review of literature.

Chandel et al.[25] presented theoretical predictions of the effect of current, electrode polarity, electrode diameter and electrode extension on the melting rate, bead height, bead width and weld penetration, in submerged-arc welding. They indicated that the melting rate of SAW can be increased by four
methods: (i) using higher current; (ii) using straight polarity; (iii) using a smaller diameter electrode; and (iv) using a longer electrode extension. The percentage difference in melting rate, bead height, bead width, and bead penetration has been found to be affected by the current level and polarity. It has been found that with the use of smaller diameter feed wire (electrode), the increase in the current level does not make a significant change in the percentage variation in weld bead geometrical parameters. Gupta and Parmar [53] developed mathematical models by using fractional factorial technique to predict the weld bead geometry and shape relationship for submerged arc welding of micro alloyed steel in the medium thickness range of 10-16 mm. The response factors namely, bead penetration, weld width, reinforcement height, dilution(percent weld metal), weld penetration shape factor (WPSF) and weld reinforcement form factor(WRSF) as affected by wire feed rate, open circuit voltage, nozzle to plate distance, welding speed and work material thickness have been investigated and analyzed. Ravindran and Parmar [85] developed mathematical models by using fractional factorial techniques to predict weld bead geometry and shape relations for CO₂, shielded flux cored arc welding, as a function of arc voltage, welding current, welding speed, nozzle to plate distance and gun angle. Kim et.al [78] studied the effect of welding process parameters on weld bead width in GMAW processes. Apps and Lelson [8] studied the effect of welding variables upon bead shape and size in SAW. Chandel, [26] presented the mathematical prediction of the effect of current, electrode polarity, diameter and electrode extension on the melting rate, bead height, bead width and weld penetration in SAW. Gunaraj and Murgun [56] developed analytical models to establish a relationship between process parameters and weld bead volume in SAW of pipes and also the optimization of weld bead volume was carried out using the optimization module available in the MATLAB (version 4.2b) software
package. Sukhomay, Surjya and Arun [141] predicted the effect of welding parameters on weld bead geometry in pulsed metal inert gas welding (PMIGW) process and developed a Back Propagation Neural Network (BPNN) model, a Radial Basis Function Network (RBFN) model and a regression model to predict the weld bead geometry of welded plates. Kumanan, Edwin Raja Dhas and Gowthaman [88] worked on the application of Taguchi Technique and Regression Analysis to determine the optimal process parameters for submerged arc welding. The experiments have been conducted on a semi automatic submerged arc welding machine and the signals to noise ratios have been computed to determine the optimum parameters. The percentage contribution of each factor is validated by ANOVA technique. Multiple Regression Analysis has also been conducted using Statistical Package for Social Science (SPSS) Software and the mathematical models have been developed to predict the bead geometry for the given welding conditions. Vairis and Petousis [151] have reported the procedure for the identification of significant process parameters using experiments that need to be carefully formulated as these could be a resource demanding process. They have used statistical techniques like the Taguchi method of factorial design of experiments and the numbers of necessary experiments have been found to be reduced and the statistical significance of parameters has also been safely identified. In the case of linear friction welding it has been found that the frequency of oscillation, power input and forging pressure have been found to be statistically insignificant for the range of friction pressures studied. Patnaik, Biswas and Mahapatra [112] worked on an evolutionary approach to parameter optimization of submerged arc welding in the Hard Facing Process. SAW has been reported to be characterized by a large number of process parameters influencing the performance outputs such as deposition rate, dilution and hardness, which
affect weld quality and this has been analyzed by using Taguchi method. The relationship between the controlling factors and performance outputs has been established by means of Nonlinear Regression Analysis. This has resulted in a valid mathematical model and Genetic Algorithm (GA) to optimize the welding parameters and performance output. Petr, Rostislav and Monika [114] have discussed the exponential technique to predict the geometry of the weld bead in the deposition of high chromium cast iron onto structural steel S235JR. Shigeo, Tadashi and Kouichi, [132] have discussed the high-speed one-side Submerged Arc Welding Process “NH-HISAW” using welding speeds up to 25mm/sec. It has been developed for ship welding of double-hull VLCC. Thao and Kim [145] focused on the development of a simple and accurate interaction model for the prediction of bead geometry for “Lap joints” using Robotic Gas Metal Arc (GMA) welding process. The subsequent experiments have been based on full factorial design with two levels of five process parameters to obtain bead geometry using a GMA welding process. The analysis of variance (ANOVA) has also been efficiently used for identifying the significance of main and interacting effects of process parameters. Samard and Kladari [127] have discussed the influence of welding parameters on weld characteristics in electric stud welding. Weld bead geometry during stud welding (Drawn Arc Welding process with ceramic ferrule) on steel plates and pipe has been analyzed as a variable for weld penetration. The changes in weld characteristics have also confirmed the finding through the measurements across the weld joint cross-section and the analysis of hardened zone. Mostafa and Khajavi [100] have described the prediction of weld penetration as influenced by FCAW process parameters of welding current, arc voltage, nozzle-to-plate distance, electrode-to-work angle and welding speed. Optimization of these parameters to maximize weld penetration has also been investigated. The discussion includes the statistical
technique of central composite rotatable design to develop a mathematical model for predicting weld penetration as a function of welding process parameters. Kolahan and Heidari [84] addressed modeling and optimization using a set of experimental data and regression analysis. The set of experimental data has been used to assess the influence of GMAW process parameters on weld bead geometry. The Taguchi method and Regression Modeling have also been used in order to establish the relationships between input and output parameters. Klaric, Samardzic and Ivica Kladaric [82] have reported that the quality of welded joint in MAG welding process depends upon a numbers of influencing factors; like the type and thickness of base metal plate, groove type, welding position etc. They have also found that the proper selection of welding parameters is also very important. The analysis of weld bead geometry using MAG welding process with regard to welding current, arc voltage and welding speed (heat input) and the type of shielding gas flow has also been discussed in this paper. The effect of proper selection of gas flow and heat input on geometrical characteristics of weld bead cross-section has also been included in this investigation. Karaoglu and Secgin [71] reported from their studies that the selection of process parameters have a great influence on the quality of a welded connection. Rather than the well-known effects of main process parameters, their study focuses on the sensitivity analysis of parameters and fine tuning requirements of the parameters for optimum weld bead geometry.

The present research initiative identifies the limitations and gaps through exhaustive review of published literature on SAW with the intent to explore the possibility for improving the efficiency and capabilities of the process/technique. The observations reported in the literature have been found to express conflicting opinions of researchers regarding the effect of certain process parameters on quality characteristics and therefore, a judicious,
precise and reliable opinion needs to be found about all of the performance measures of interest. The present work is aimed at achieving these objectives.

Although certain good research initiatives have been reported in the direction of controlling the process parameters and analytical modeling for suggesting the process mechanism but several key issues remain unexplored and the process can still be considered to be in its development stage.

1.3 Objective and Statement of the Problem

The main objective of the present work has been to study the effects of SAW process parameters such as arc voltage, welding current, welding speed, wire-feed-rate and nozzle-to-plate distance on weld bead geometry and to develop accurate, precise and reliable Mathematical Models using multiple regression analysis (MRA) for evaluating the effects of welding process parameters on the weld bead geometry. Further predictions of bead geometry using Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) have been made. A comparative study of these models has been carried out to compare the respective accuracies of predictions. The investigation begins with identifying the process parameters like arc voltage, welding current, welding speed, Wire-feed-rate and Nozzle-to-plate distance that significantly affect the quality of Bead Geometry viz., Penetration depth, Reinforcement height, Weld width.