Chapter 1

Introduction

1.1 Background and motivation

The present trend in manufacturing demands joining or welding of materials that are capable of withstanding increased stresses and temperatures. Unfortunately, weld quality deteriorates due to poor joint strength, limiting the versatility of welding – a matter of prime concern to the manufacturers. Significant efforts have already been made to improve the weld quality using gas metal arc welding (GMAW) processes through auxiliary preheating of solid filler wire [Shahi *et al.*, 2007], multi-pass welding [Murti *et al.*, 1993], preheating of welding plate [Lin and Lee, 1997] and weld post heating [Mohandas, 1999], ultra-narrow gap GMAW [Nakamura, and K. Hiraoka, 2001], pulsed GMAW [Ghosh *et al.*, 2000] etc.

The weld joint quality is strongly influenced by bead shape and weld microstructure. It can be improved significantly using pulsing mode of current. The weld productivity is also highly improved using pulsed current in thin sheet metal fabrication industries [Ghosh *et al.*, 2000]. Arc stability and thermal behavior of the weld pool are highly affected by pulse shape or pulse parameters. The arc voltage, welding torch position and

its movement during welding is also an important factor [Nouri *et al.*, 2007]. Hence, it is required to develop the relationship between process parameters with weld quality features. However, GMAW processes are highly non-linear with some uncertainties. Therefore, various adaptive intelligent systems like soft computing tools have been developed rather than mathematical models for proper learning and control of the weld quality.

Online process monitoring is also a challenging task in automated manufacturing industries. Arc sensors are often used to monitor the process in real time. In recent years, various auxiliary sensing systems such as infrared, artificial vision, radiography, etc have also been used to completely characterize the process. Since very high arc temperature, spatter formation, fumes, etc are observed near the arc during welding, it becomes very difficult to grasp the dynamic characteristics of welding. The arc acoustics may be an alternative solution to overcome these problems.

In the present work, the influence of pulse parameters for various torch angles on low carbon steel weld bead geometry characteristics, its microstructure and joint mechanical properties have been investigated in pulsed GMAW (P-GMAW). The primary objective was to investigate the effect of each pulse parameter at various torch angles on weld quality. The correlation between weld bead geometry features, grain morphology and ferrite percentage with mechanical properties of the weld have been studied in detail. The current, voltage, sound and temperature sensors' signals have been used to monitor the joint quality. Various features of sensors' signals have been extracted to correlate with process outputs. These important features have been used in artificial neural network (ANN) models to improve the monitoring capability. Finally, multi-objective optimization has been done using non-dominated sorting genetic algorithm (NSGA-II) to achieve desired joint quality features.

1.2 Objectives of the research

In the last twenty years, various works have been investigated the influence of process parameters on low carbon steel weld quality in GMAW. Theses works mainly focused on improving weld quality by adjusting various pulse parameters at various torch angles in P-GMAW. The weld quality monitoring is highly required in today's automated manufacturing environment. Though several works are available on weld quality monitoring in GMAW using infrared pyrometers and arc sensors, there is hardly any work in P-GMAW. Hence, this work emphasizes the use of these sensors for weld quality monitoring in P-GMAW. The present work also attempts to exploit the use of arc acoustics as one of the new techniques in the area of weld quality monitoring. Finally, mathematical and soft computing models correlating process parameters and various weld quality features have been developed for further process monitoring and optimization. Various sensor-based ANN models have also been developed and their weld quality prediction performance has been compared. Though NSGA-II is a powerful tool in multi-objective optimization. So, this technique was considered in the present work. To summarize, the primary objectives of the research are as follows:

- Investigation of the influence of pulse parameters on the weld quality features at various torch angles.
- Improvement of weld mechanical properties with the reduction of welded plate distortion and defects.
- Time domain, frequency domain and time-frequency wavelet analysis of the various sensors' signals at different process parameters to properly characterize the process.
- Development of correlation between welding emitted sound and various process parameters to monitor the metal transfer modes and weld quality features.
- Monitoring of the weld quality using arc acoustics and weld temperature signatures along with arc sensors' signals.
- Development of regression and ANN models using process parameters and acquired sensors' signals for various weld characteristics.
- Comparative evaluation of weld quality monitoring capability of different combination of extracted sensors' features used to the developed ANN models.

• Multi-objective optimization of P-GMAW process parameters to achieve high joint tensile strength with reduced distortion.

1.3 Contribution of the thesis

The primary contributions of the thesis are summarized as follows:

- Study of the influence of pulse parameters at various torch angles on the weld bead geometry and microstructure to joint mechanical properties.
- Investigation on arc sound generations in P-GMAW for different process parameters and its correlation with various weld quality characteristics, along with the arc sensors.
- Feature extraction of various sensors' signals in time domain (mean, RMS, kurtosis etc.), frequency domain (FFT), as well as time-frequency domain (wavelet) to completely characterize the process.
- Monitoring of metal deposition, bead geometry, weld microstructure, joint mechanical properties, welded plate distortion and defects using an infrared pyrometer and sound sensor together with arc sensors.
- Modeling of weld quality features with process parameters and various sensors' outputs using BPNN technique.
- Multi-objective optimization of P-GMAW process parameters using neuro-NSGA-II algorithm to achieve desired weld quality.

1.4 Organization of the thesis

This thesis contains seven more chapters in addition to this brief introduction of the research. The summary of each chapter has also been provided at the end of corresponding chapters. A brief overview of the proceeding chapters is given below.

A detailed literature review on the experimental investigation, sensor based monitoring, and applications of soft computing techniques on the modeling and optimization of GMAW processes have been presented in *chapter 2*.

An overview on the arc welding processes starting from the physics of arc generation, metal transfer behavior during welding and applications are mentioned in *chapter3*. The arc sound generation mechanisms in P-GMAW has also been briefly discussed in this section.

The experimental procedures and measurement of various weld quality characteristics, such as bead geometry, its microstructure and deposition efficiency have been explained in *chapter 4*. The influence of pulse parameters, torch angle and other process parameters on weld quality have been discussed for both bead-on-plate as well as butt welding in this section.

Various time domain statistical feature extraction of four sensors namely current, voltage, sound and temperature have been mentioned in *chapter 5*. The correlation between these sensor output features and weld quality parameters has been developed. Finally, frequency domain and time-frequency domain (wavelet) analysis have also done for further monitoring of weld quality.

The relationship between process parameters and weld joint quality features have been modeled using mathematical regression and back propagation neural network (BPNN) and compared in *chapter 6*. Various sensor based BPNN strategies have also been developed and compared to improve the weld quality monitoring capability in this chapter.

The multi-objective optimization using neuro based NSGA-II technique has been applied to achieve high joint tensile strength with less distortion, which is discussed in *chapter 7*.

The conclusion has been made as well as direction of future work has been suggested in *chapter 8*. Finally a list of references cited in the text is presented in *References*.