CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The gas tungsten arc (GTA) welding process is a common joining technology used in almost all industries, especially in the manufacturing industry. The GTA welds are stronger, more ductile and more corrosion resistant than welds made with any other welding process. The welds used in the parts of aircrafts, ships, nuclear power plants etc. are made by GTA welding. The selection of process parameters is vital for obtaining a quality weld; otherwise, welding defects such as poor penetration, hot cracking, hardness variation in the weldment etc. are commonly encountered in GTA welding. Experimental, analytical and numerical studies are being carried out at all levels to avoid the welding defects. Numerical modeling and simulation have very specific advantages of virtual experimentation which requires less time, less cost and no materials. Hence, intense research is continuing on the modeling of GTA welding.

Since 1941, many numerical models for arc welding processes have been developed and in particular, numerical simulation of GTA welding has been carried out for about six decades. Despite this fact, the simulation of GTA welding process has not been used for many practical process design needs. This is partly due to the fact that the physical processes associated with the electric arc and its interactions with the work material are very complex phenomena. In general, material interactions during welding are associated with electric, magnetic, kinetic, thermal, chemical, atomic and fluidic
processes and the complete simulation of all of these coupled processes is computationally intensive. The computational time and facility requirement are the vital problems in the case of numerical simulation of any welding process. Numerical simulation is attractive due to its flexibility for studying the phenomena under varying conditions, which are very difficult to acquire experimentally.

1.2 WELD POOL CONVECTION

During welding, a small volume of metal is molten by a heat source which is moved along the line of joining two metal parts (Raj et al 2006). The motion of molten metal in the weld pool formed during the fusion welding process enhances the heat transfer from the weld pool to the surroundings. The flow of heat is enhanced in convection mode, when the molten metal gains momentum due to the forces such as buoyancy, electromagnetic field, surface tension, are pressure and drag. Variations in weld characteristics which are likely to occur from the changes in weld pool convection are: weld penetration, weld shape, macrosegregation, gas porosity and microstructure after solidification. Weld pool convection is an essential part of the mechanism that controls the development of the weld. To understand the convective behaviour in the weld pool, the effects of various driving forces, individually and collectively, on the weld bead geometry have to be primarily studied.

The heat flux from the welding arc generates spatial and temporal density gradients in the molten metal to cause thermally driven flows in the weld pool. Change of density with temperature, induces buoyancy forces that stir the weld pool. The other important force due to the electric arc is the Lorentz force that is induced by interaction between the current flow in the weld pool and its magnetic field. The welding current and the self induced magnetic field can influence the flow in the weld pool by way of
electromagnetic interactions. At a high welding current, the Lorentz force is dominant and largely determines the weld pool fluid flow. The surface tension induced flow (Marangoni flow) occurring in the weld pool at the free surface due to the temperature gradient, has major effects on weld pool shape. Other forces that induce flow in the weld pool are surface tension, arc pressure, drag etc. Arc pressure and drag forces are generally important at very high currents. The final weld shape is significantly affected by the content of the surface active elements in the base metal (e.g. sulphur) that alter the direction of surface tension induced flow. High sulphur steel tends to generate an inward fluid flow pattern, producing deeper penetration. But, low sulphur steel experiences shallow penetration due to an outward fluid flow pattern in the weld pool. Thus, the prediction of weld pool convection is essential and it relies on accurate modeling of the overall welding process.

1.3 MODELING OF WELD POOL

There is considerable published literature dealing with the mathematical modeling of weld pool and the effects of weld pool convection on the welded material. Experimental investigation of flow conditions in a weld pool is limited to the measurement of surface velocities. Furthermore, accurate observation of the surface velocities is not easy during the actual welding process, due to the presence of arc over the weld surface. Measurement of temperature also requires skill for fixing thermocouples at the right places, the facility to automatically acquire the data and a large time for setting up the experiments. Moreover, provision must be made to drill in a hole for fixing thermocouples in the workpiece. At this juncture, mathematical (computational) modeling approaches, which can simulate convection in the weld pool as an integral part of the overall heat transfer conditions, have become an essential and practical tool for investigating the processes that occur during welding.
A variety of numerical models have been developed for a long period. Heat conduction models were first developed before the advent of modern computers in the 1980s. The use of high speed computers has spurred a faster development of heat and fluid flow models. Mathematical models describing convection in the weld pool are essential, not only because of the quantitative understanding they provide, but also because of the difficulties associated with the experimental measurements of weld pool convection. The detailed literature on weld pool modeling has been discussed in Chapter 2.

1.4 OBJECTIVES OF THE PRESENT STUDY

Even though, several axisymmetric models and few 3-D models for certain applications have been developed in the last few decades, no models have been in use for simulating welding process for all welding conditions. Modeling and simulation for a three dimensional heat and fluid flow problem requires large computing power, memory and computational time. An equivalent two dimensional model for linear welding process will require much less computational resources than the three dimensional approach. From an accuracy point of view, there is experimental evidence to suggest that the weld pool geometry does not vary significantly in the direction of welding, if the welding speed and the other process parameters are maintained at uniform values. Hence, it is definitely advantageous if the three dimensional heat and fluid flow problem is approximated to an equivalent 2-D form with suitable assumptions. The present study has been carried out with the following objectives:

A 2-D heat and fluid flow model, which is equivalent to 3-D model for linear GTA welding, is to be developed to reduce the computational time and cost.
Simulation of GTA welding of AISI 304L stainless steel plate has to be carried out.

Validation of simulated results with experimentally measured weld bead dimensions and temperature has to be performed.

Validation of results obtained from the present model with the results of FLUENT simulation has to be performed.

Post arcing heat and fluid flow in the weld pool is to be investigated, to understand the effect of weld pool convection, during the solidification phase of welding, on the weld bead dimensions.

The microstructure and microhardness variation in the weld metal are to be analyzed, to study the effect of weld pool convection on hardness in the weld metal zone.

The effect of including an insulation layer of asbestos over the bottom surface of the stainless steel plate on the weld bead dimensions is to be studied.

Simulation and validation of GTA welding of IS 1079:1992 (AISI 1010) low carbon steel are to be carried out.

1.5 **ORGANIZATION OF THE THESIS**

In this research work, the subsequent chapters describe in detail, the newly developed equivalent 2-D heat and fluid flow model for linear welding process, simulation of GTA weld pool and the effect of weld pool convection on weld pool formation, solidification, microstructure and hardness of the weld metal. Further, the applications of the equivalent model and validation with the results of Fluent simulation have been discussed. Chapter 2 provides
the literature available and earlier works in the area of numerical modeling and simulation of GTA welding. In Chapter 3, the equivalent 2-D heat and fluid flow model has been developed for linear GTA welding process, resulting in a C++ code based on the Finite Volume Method (FVM). The code has been validated by many bench mark problems such as, the lid-driven cavity flow, 2-D channel flow, natural convection in a square cavity etc. Based on the weld simulation parameters, a parametric study has been performed to demonstrate and understand the effectiveness of individual simulation parameters on heat and fluid flow in the molten weld pool and the final configuration of welds. In Chapter 4, the equivalent 2-D numerical model has been used to simulate the linear gas tungsten arc welding process for a wide range of welding conditions. The simulated results for bead-on-plate type welding on a 4.35 mm thick plate of stainless steel of type AISI 304 L, have been validated by comparison with measured weld bead geometry. The results of the equivalent 2-D heat and fluid flow model are also validated with the simulated results obtained using the Fluent software. Moreover, the existence of turbulence in the weld pool is studied at high heat input conditions.

In Chapter 5, the post arcing heat and fluid flow in the weld pool have been investigated. The effect of heat transfer during solidification on weld penetration has been analyzed. Chapter 6 deals with the effects of heat inputs on microstructure and hardness of the weld metal as a preliminary work. The effects of predicted velocity fields on the microstructure and hardness variation have been explained. Chapter 7 deals with the simulation of GTA welding of stainless steel plate with bottom surface insulated using an asbestos fibre board. The effects of including an additional insulation layer on weld bead dimensions have been studied using the newly developed equivalent 2-D heat and fluid flow model. The results have been compared with the experimental results for the weld bead geometry and found to agree
well. This chapter also deals with the application of the equivalent model for GTA welding of low carbon steel of type AISI 1010 (Equivalent to IS-1079:1992).

Chapter 8 presents a summary of results and conclusions derived from the present study. This chapter concludes with suggestions for future work on the modeling of welding process.