CHAPTER 1

INTRODUCTION

1.1 METAL MATRIX COMPOSITES

Composite materials are engineered from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. Although composite materials had been known in various forms throughout the history of mankind, the history of modern composites probably began in 1937 when salesmen from the Owens Corning Fibreglass Company began to sell fibreglass to interested parties around the United States. Fibreglass had been made, almost by accident in 1930, when an engineer became intrigued by a fibre that was formed during the process of applying lettering to a glass milk bottle. The Owens Corning Fibreglass Company was formed in 1935 by Owens-Illinois and Corning Glass Works to capitalize on this new fibrous material. A Japanese company (Nitto Boseki) had also made fibreglass and was attempting to market the fibres in Japan and the United States. The initial products that were produced from this finely drawn molten glass were insulation (glass wool) materials but structural products soon followed.

The two distinctive constituents of composite material are the matrix material and the reinforcement material. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means
that there is a path through the matrix to any point in the material. In structural applications, the matrix is usually a lighter metal such as aluminium, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common.

The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. A variety of material is used as reinforcing material in composites like aluminium oxide, titanium oxide, silicon carbide, titanium carbide, boron carbide, titanium boride, zirconium boride, aluminium nitride, silicon nitride, etc.,

Based on the matrix material and reinforcement, composites are classified into various types. Among those types of composites, the present research focuses on metal matrix composites (MMCs).

MMCs are composite materials with at least two constituent parts, one being a metal. The other material may be a different metal or material, such as a ceramic or organic compound as mentioned above. MMCs are made by dispersing a reinforcing material into a metal matrix. In the current industrial scenario, the need for light weight and high performance material has risen. Thus MMCs have emerged as the strongest contenders against their monolithic alloys. MMCs are used in aerospace, marine and automotive industries. Aluminum Metal Matrix Composites (AMMC) reinforced with ceramic and oxide particles are more sought after material than any other type of MMCs (Lubin & George 1982). This is because these types of AMMCs exhibit a high strength to weight ratio, high specific modulus, low thermal expansion and excellent tribological properties. These properties depend on the type, size, shape, weight percentage and distribution of the
reinforcement particles in the matrix (Strong 2008). The following list shows some of the applications of AMMCs.

- Airplane panels
- Aircraft structures
- Automotive disc brake
- Cylinder liners
- Drive shaft of automobiles
- Electrical contacts
- Electronic packaging
- Fuselage
- Helicopter transmission plated
- Landing gears
- Marine structures
- Missile panels
- Neutron shielding in nuclear reactor
- Pistons
- Space and satellite structures
- Storage battery plates
- Tanker armours

The application of the AMMCs is limited due to the problems faced in manufacturing those AMMCs as well as non-availability of standard procedures for the secondary operations like machining, forming or welding. Welding of AMMCs has always been a challenge to the researchers. The past few years are witnessing an extensive research in the field of producing AMMCs and processing those AMMCs. Out of various methods to produce the AMMCs, liquid route, especially stir casting method has proven to be a reliable technology for producing composites of sound quality (Yuyoung Chen & Chung 1996, Hashim et al 1999, Rajan et al 2007, Gopalakrishnan & Murugan 2009, Amirkhanlou & Niroumand 2010). Though there are literatures available on machining of AMMCs, very few researchers have tried welding the AMMCs. The utilization of AMMCs will be limited till the procedures for all the secondary processes are established.

- Chemical reaction between matrix and ceramic particles due to high temperature
- Coarse microstructure in the fusion zone
- Decomposition of ceramic particles to form brittle intermetallic phases
- Excessive formation of eutectic
- Incomplete mixing of the parent and filler materials
- Porosity in the fusion zone
- Segregation of ceramic particles

The properties of the joints are affected by the above said defects. Some modern developments in fusion welding process like composite filler rods are reducing the defects to a certain level (Garcia et al 2007, Xihe et al 2009, Guo 2010). But obtaining a sound weld having joint efficiency more than 60% is hardly possible by this method.

1.2 FRICTION STIR WELDING

The major problems in welding MMCs using fusion welding processes are overcome by employing solid state welding processes. Out of the various solid state welding processes, friction stir welding (FSW) is relatively a new welding process which can weld MMCs. FSW was first developed in 1991 by The Welding Institute (TWI) in the United Kingdom and ever since has gathered a great amount of interest in a variety of industrial applications such as automotive, marine, aerospace and construction industries. Many researchers have proved that FSW process can be used to weld materials that are previously extremely difficult to weld, obtain better weld properties and the process is highly versatile (Sanderson et al 2000, Mishra et al 2005, Nandan et al 2008). FSW was primarily meant for joining aluminium alloys. But presently it is being tried for the joining of metals
such as steel, titanium, copper, etc. Employing FSW to weld those materials has the following advantages:

- Aesthetic weld
- Absence of cracks
- Ease of automation
- Finer grains in the weld nugget
- Good dimensional stability and repeatability
- High weld quality
- Low distortion
- Low power consumption
- Less operator skill is required
- No edge preparation
- No filler metal
- No shielding gas
- No fumes during welding
- No loss of alloying elements
- Welding can be done in any position

Due to the ability of this process, it is also used to weld AMMCs. A few researchers have already tried this process to weld AMMCs.

13 FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) is a fairly recent discipline crossing the boundaries of mathematics, physics, engineering and computer science. The method has wide application and enjoys extensive utilization in the structural, thermal and fluid analysis areas. The finite element method is comprised of three major phases:
(1) Pre-processing, in which the analyst develops a finite element mesh to divide the subject geometry into sub domains for mathematical analysis, and applies material properties and boundary conditions.

(2) Solution, during which the program derives the governing matrix equations from the model and solves for the primary quantities.

(3) Post-processing, in which the analyst checks the validity of the solution, examines the values of primary quantities (such as displacements and stresses), derives and examines additional quantities (such as specialized stresses and error indicators). Due to the difficulty in manual execution of FEA problems, commercial software packages like ANSYS, NASTRAN, etc. are available to solve complex problems.

The problem in friction stir welding, as with many emerging technologies, is that the testing is expensive in terms of time, materials, and personnel. Much of the body of knowledge on the subject comes from running several experiments for each change in a parameter and then doing several metallurgical sections to study the results. This requires large amounts of time and money which will slow down the development of applications for this new process. What is needed is a faster, cheaper, more reliable way to test new theories regarding friction stir welding. This would eliminate unnecessary testing on parameters that do not show improvement or fail to create desirable properties. Finite element modelling is one option which would help to determine which parameters should undergo further real-world testing for validation and further analysis.

A few researchers have tried using FEA to analyze the FSW process. The major problem in solving problems related to FSW is deriving the governing differential equation. Despite the complex flow of material during FSW, researchers have found some success in modelling the heat transfer characteristics of FSW. Frigaard et al (2001) developed a finite difference thermal model for a moving heat source and correlated the predicted temperature profile with the measured
temperature profile for friction stir welded AA6082-T6 and AA7108-T79 extrusions. These models have been built with several assumptions as to how the material should be modelled, which meshing schemes are better to use, how the temperature evolves, how heat escapes from the welding area, and how this affects the material flow. The material response within the weld and the post-weld microstructure depends on how the material is heated, cooled and deformed. This makes it imperative that an improved model including the change in temperatures, strains, and strain rates experienced in the process as well as being able to do so in a reasonable amount of time. Hamilton et al (2008), has successfully derived a thermal model to simulate the FSW process. Using these expressions, a highly dependable FEA procedure can be derived for FSW process.

14 NEED FOR RESEARCH

Currently the automobile, marine and aerospace industries are focusing towards the design of materials for various reasons including high weight to strength ratio, better manufacturability, low cost, etc., MMCs with aluminium as the matrix material are proving to be the right candidate for these applications. The reinforcement particles that were used in the yesteryears were mostly SiC and Al₂O₃. In the recent years, the focus has been shifted towards producing MMCs with different reinforcements like Silicon oxide, titanium oxide, aluminium nitride, titanium carbide, boron carbide, titanium boride, zirconium boride, etc. The search for a better MMC using any one or a combination of two or more reinforcement particles is currently being studied. Moreover procedures for producing these composites and establishing procedures for the secondary operations for machining, joining and forming are in the infant stage. A lot of research and development should be carried out in this field to make these MMCs available for any common application.
Though a lot of research has been done and procedures are established to join aluminium and its alloys, research on joining of MMCs has not been developed completely. It is not possible to effectively employ the conventional welding techniques to join AMMCs because a number of difficulties have been identified, mainly in the case of fusion welding techniques. Some of those problems are listed below (Nakata et al 2003):

1. MMC melts above the melting point of the unreinforced alloy due to its high viscosity.
2. Segregation of the reinforcement during re-solidification.

However, to improve the potential applications of metal matrix composites in aerospace, automotive and marine system, FSW is being considered as the prospective joining process to overcome those problems mentioned above. As a solid-state joining process, FSW can eliminate the welding defects associated with fusion welding processes (Urena et al 2000, Huang et al 2001, Zhang et al 1999, and Askew et al 1998).

The quality of friction stir welded joints depends on the various FSW process parameters such as tool rotational speed, welding speed, axial load, etc. While developing the welding procedure for any specific application, the effect of the process parameters has to be studied thoroughly. This is possible by empirical, analytical or numerical methods. Present day computing facilities enable the easy modelling of any process or physical phenomenon. Therefore mathematical models for the prediction of mechanical properties of FS welded AMMC namely Al-TiB₂ need to be developed. A finite element simulation is also needed to be carried out for FSW process to predict the temperature distribution during the process. It is to be noted here that so far there has been only very few literatures on FSW of Al-TiB₂ MMC and its modelling. Hence, this attempt is believed to pave way for broader
research in the said area which has potentially significant applications in the industry.

1.5 OBJECTIVES OF THE RESEARCH

The main objectives of the present work are as follows:

1. To produce Al-TiB₂ MMC by in-situ stir casting method by varying the percentage of reinforcement from 10% to 14wt.%.  

2. To evaluate the mechanical properties like ultimate tensile strength, microstructural properties, wear resistant properties and corrosion properties of the cast composite.  

3. To design and develop FSW tool for joining the composite to have better mechanical properties.  

4. To determine the procedure for FSW of the cast composite, develop regression model to predict the tensile strength and dry sliding wear behavior of the weldment and optimize the FSW process parameters.  

5. To evaluate the microstructural properties of the weldment including microhardness survey, fracture morphology and wear morphology on the weldment.  

6. To carryout FEA on FSW of composite and validate the results.
1.6 PLAN OF RESEARCH

The present research work has been carried out following the plan as in Figure 1.1.

Figure 1.1 Plan of Research
1.7 ORGANIZATION OF DISSERTATION

The thesis is organized into eight chapters and the crux of each chapter is briefed below:

Chapter 2 presents the state of the art which includes production of metal matrix composites, friction stir welding of soft metals and metal matrix composites, design and development of friction stir welding tool, finite element analysis, metallurgical and mechanical characterization of composites and weldments.

Chapter 3 elaborates about the in situ fabrication of Al6061-TiB₂ MMC using stir casting process. It also describes about the evaluation of metallurgical, mechanical, tribological and corrosion properties of the produced MMCs.

Chapter 4 details about the design and development of FSW tools and selection of appropriate tool for FSW of Al6061-TiB₂ MMCs. It also describes about the optimization of FSW process parameters to obtain better mechanical and tribological properties. Here, regression models are derived from the response variables and optimization is carried out to improved these responses with the help of input variables.

Chapter 5 describes the metallurgical characterization of FS welded Al6061-TiB₂ MMCs. Microstructures from optical microscope, SEM, microhardness, fracture morphology and wear morphology are presented in detail.

Chapter 6 deals with finite element analysis of FSW process to predict the temperature distribution pattern during FSW.

Chapter 7 concludes the activities carried out in the research work and provides the jist of all the findings of the work.