# CHAPTER 1

# INTRODUCTION

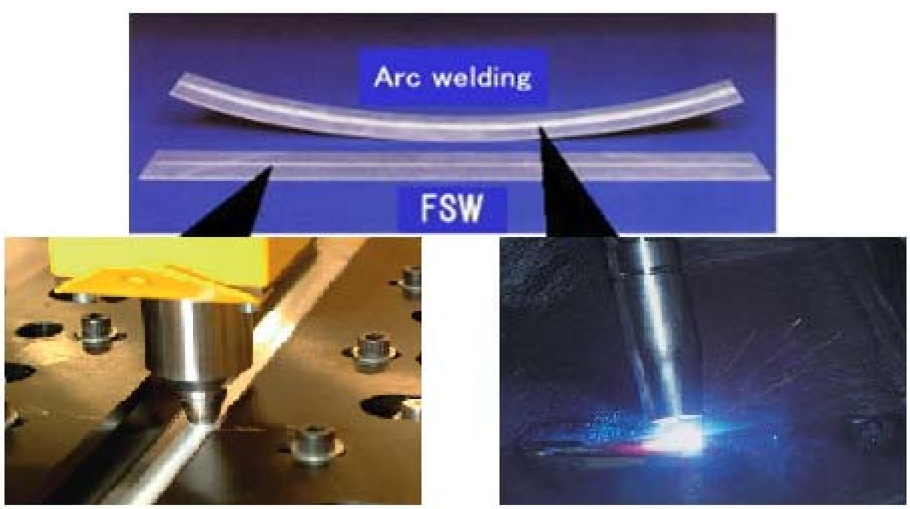
Today in the age of advancement and cut throat competition, there is a continuous demand for change in materials, manufacturing processes and fabrication techniques. To meet these challenges in many industrial applications steels are readily replaced by nonferrous alloys or metallic composites, specifically by aluminum alloys. Some of the aluminium alloys exhibit mechanical strength comparable with structural steels allowing for a significant reduction of weight. Additionally, aluminum is the most abundant material in the Earth's crust. It can be recycled easily and thus can be called as environmentally friendly metallic material. Owing to their corrosion resistant, lightweight, formability and toughness, aluminium and its alloys are the second most important structural metal alloys used in automotive, aircraft and watercraft industries after steel and its alloys [1]. Production of components of aluminum alloys is not very complex, but joining of these materials can sometimes cause serious problems.

Welding is the most versatile method of fabrication. This technique is widely used for joining different types of metals and alloys. There are many conventional methods (GMAW, GTAW) based on arc as heat source. There are non-conventional methods of welding which are also in industrial use (e.g. EBW, LBW, IBW and USW).

Traditionally, joining techniques for aluminium components have come as a result of adapting methods initially developed for joining of ferrous materials. In particular, joining of metals has largely been associated with fusion welding, where both the base metal and filler metal are melted by an electric arc, electron beam, or laser beam, thereby allowing metal-to-metal coalescence to be achieved in the trailing part of the weld pool during solidification.

There are new upcoming welding methods which have potential of replacing the conventional welding processes both in terms of technology and economy. These processes offer other advantages like its freedom from skill of the welder, its ease of application, cost effectiveness, reliability, safety and value addition. The most promising process in this category is friction stir welding (FSW) (Figure 1.1(a)).

Friction Stir Welding (FSW) is an innovative solid state welding technique which was invented and patented by The Welding Institute (TWI$^{TM}$, Cambridge, UK) in 1991[2]. It represents an alternative welding technology process over fusion welding, e.g. Gas Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW) Figure 1.1(b). These traditional joining techniques require close process monitoring, high energy consumption and labour involvement, and potentially provided poorer welded joints which require post processing work. Most of the energy supplied leads to local heating of the base metal and the formation of a wide heat affected zone (HAZ) around the weld joint. In addition, the excess energy (i.e., heat) being supplied leads to the development of high residual stresses in the weld region as well as to global deformations and distortions. This can be easily overcome by a FSW method. FSW also has the significant benefit of producing negligible fumes, no waste (slag), no requirement of shielding gases, fillers and additional weld joint preparation or cleaning processes [3][4], no electromagnetic radiation (arc), and has thus sometimes been termed 'green' welding or eco-friendly welding for its low environmental impact. Alloys that are difficult to fusion weld are weldable with FSW (Figure 1.2).




(a) (b)

Figure 1.1: Welding Technology (a) Friction stir welding (FSW) process [5] (b) Metal inert gas welding [6]

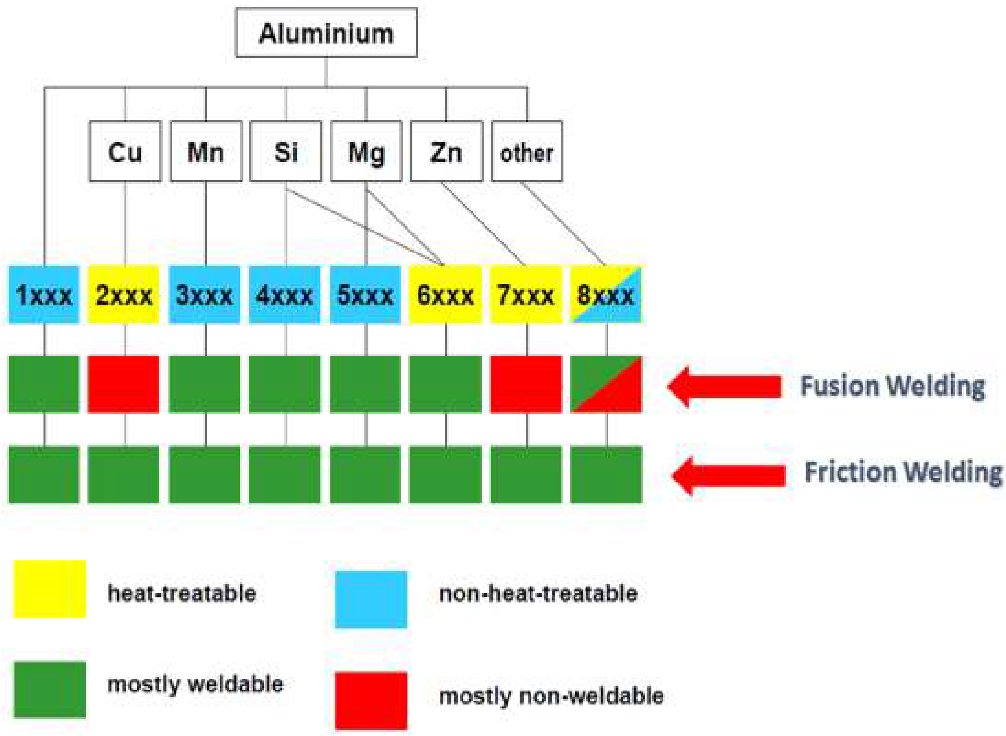



Figure 1.2: Capability of FSW, TWI ® [5]

The FSW process was initially developed for Aluminium and magnesium alloys; and later extended to different metals, composites and high melting alloys. The technology has been relatively well developed for welding thick Aluminium plates from one side. However, it is still a specialized form of welding. To adopt FSW, there are significant technological and process obstacles need to be overcome. Joining of thin sheet material is an issue commonly faced by fabrication industries. The reasons for the poor performance of FSW in these situations are yet to be understood properly.

## 1.1 FSW PROCESS PRINCIPLE

In the FSW process a frictional heat between the wear resistant non-consumable welding tool shoulder and pin (Figure 1.3) and the work pieces causes the work material to soften without reaching the melting point and allows traversing of the tool along the weld line. Under idealized conditions, there are three sources of heat generated: (a) heat from the mechanical mixing process, (b) swirling based material flow and (c) surrounding temperature and humidity (environmental conditions). The plasticized material is transferred to the trailing edge of the tool pin and is forged by the intimate contact of the tool shoulder and the pin profile. On cooling down, it leaves a solid phase bond between the two pieces [7][8]. This allows for producing defect-free welds characterized by good mechanical, thermal and electrical properties.

The main advantages of friction stir welding can be categorized in three ways (a) metallurgical, (b) environmental and (c) energy [8] as shown in Table 1.1. In addition to these, FSW has the capability of joining different weld thickness and dissimilar materials [9].

Table: 1.1 The benefits of Friction Stir Welding processes [8]

| Classifications | Advantages |
|---|---|
| Metallurgical benefits | 1. Sold phase process<br>2. Low distortion of work piece<br>3. Good dimensional stability and repeatability<br>4. No loss of alloying elements<br>5. Excellent metallurgical properties in the joint area<br>6. Fine microstructure<br>7. Absence of cracking<br>8. Replace multiple parts joined by fasteners |
| Environmental benefits | 1. No shielding gas required<br>2. No surface cleaning required<br>3. Eliminate grinding wastes<br>4. Eliminate solvents required for degreasing<br>5. Consumable materials saving such as filler wire, shielding gases |
| Energy benefits | 1. Improved materials use allows reduction in weight<br>2. Only 2.5% of the energy needed for a laser weld<br>3. Decreased fuel consumption in light weight aircraft, automotive and ship applications. |

Researchers have tended to categorize the development and advancement of the FSW technology based on tool design in the current research arena [10][11][12][13]. As shown in the Figure 1.3 there are two fundamental categories of tool, under which are numerous sub-categories that are influenced by a range tool design features. A FSW process that involves the usage of single sided shoulder (Figure 1.3(a)) is known as conventional friction stir welding (CFSW) and a process that uses double sided shoulder (Figure 1.3(b)) is known as bobbin friction stir welding (BFSW), bobbin tool friction stir welding (BTFSW) or self-reacting friction stir welding (SR-FSW) [14].

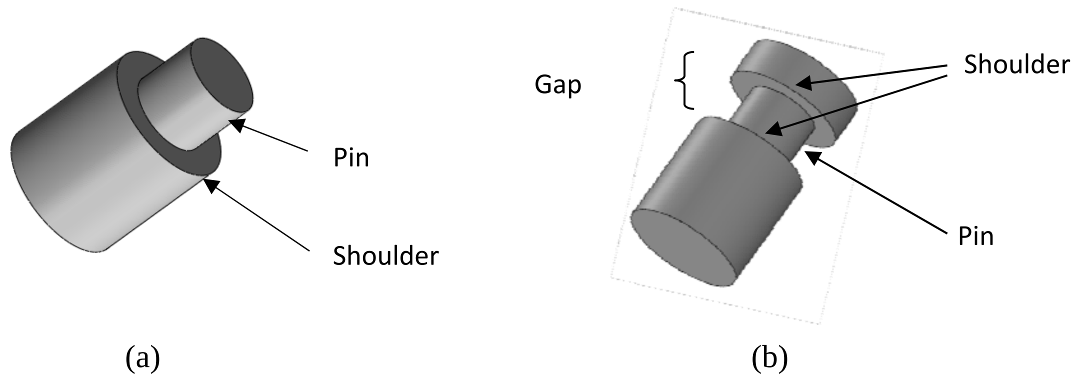



Figure 1.3: Illustration of tool types in FSW. (a) Single sided shoulder –CFSW.
(b) Double sided shoulder- BFSW.

## 1.2 PROBLEM STATEMENT

The present work was motivated specifically with an idea to develop in-house facility of FSW and to understand the fundamental technology know how as well as mechanics of welding. Secondly to understand design and process parameters influencing the quality of welds in standard or conventional friction stir welding (CFSW) process.

With continuous experimentation and literature review, it was observed that conventional friction stir welding was much more explored but friction stir welding using the fixed bobbin tool of thin plate substrate is known to be particularly difficult and hence from research perspective it was taken as a challenge to develop an understanding of the deeper mechanics of the welding process.

There are four knowledge gaps: (a) the work clamping requirement for both CFSW and BFSW to perform research experiment is given less importance during the experimental research, has lean published literature; and has a scope to develop it, (b) the mechanics of heat generation, material flow and metallurgical changes for CFSW are extensively studied, but in case of BFSW they are poorly understood; a combined study is required to be done, (c) linking of tool design features and process parameters, to weld quality need to be thought of, (d) welding of thin plate by BFSW has lean research literature. There is a large difference between CFSW and BFSW, the very first is additional shoulder, which in turn results in higher heat input ultimately affecting the microstructure and weld quality.

The welding industry should not have to "reinvent the wheel" [15]. There should be wide availability of established procedures. Through the use of information technology, new findings can be disseminated quickly and accurately to others in the industry. There will be no need for various segments of the industry to search extensively for information or repeat studies already carried out. Additionally, a history of past solutions should be made available in a database for easy access.

The aim of the research is to understand the parameters involved in the joining process of Al alloys using friction stir welding. The study also aimed at learning the effect of tool design and process variables on quality of friction stir welding of aluminum alloys. Also to investigate the effect of these variables on mechanical properties (like tensile strength, hardness, and bending), microstructure, corrosion resistance and conductivity of welded joint.

## 1.3 OBJECTIVE AND SCOPE OF RESEARCH

Based on available research information, it is observed that there is a wide scope to develop systematic understanding about various process parameters, its effect on weld quality along with tool design and fixture design in FSW. The present work will be an effort to investigate these aspects so as to widen the insight and understanding of welding of Al alloys by FSW.

Alloys in the 6xxx series contain silicon and magnesium approximately in the proportions required for formation of magnesium silicide ($Mg_2Si$), thus making them heat treatable. Although not as strong as most 2xxx and 7xxx alloys, 6xxx series alloys have good formability, weldability, machinability, and corrosion resistance, with medium strength.

Figure 1.4 shows the relationships between some of the more commonly used alloys in the 6xxx series.

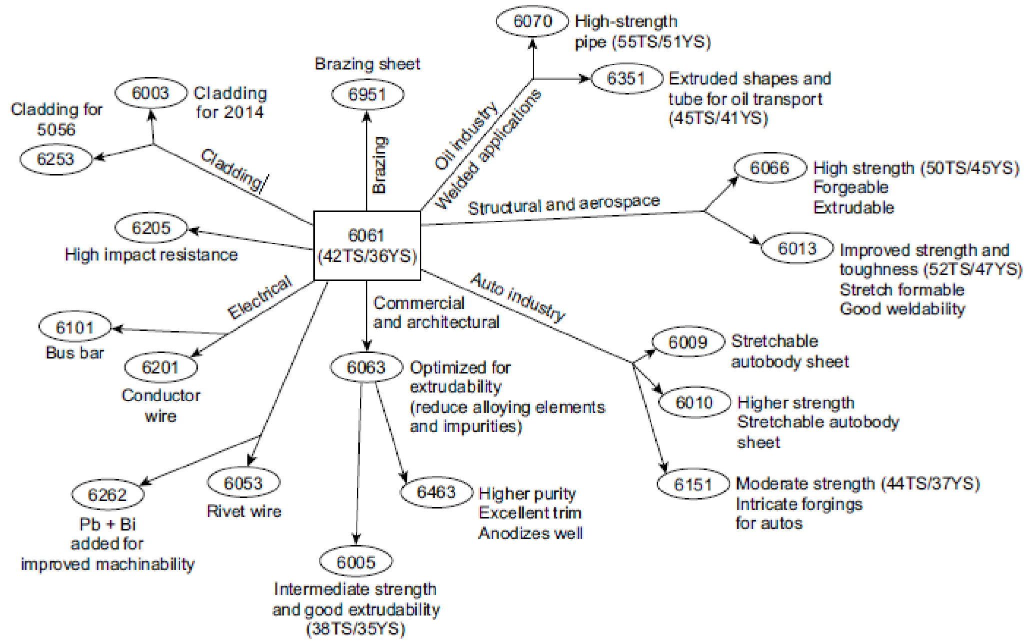



Figure 1.4: Relationships among commonly used alloys in the 6xxx series (Al-Mg-Si). Tensile strength (TS) and yield strength (YS) are in ksi units [16]

Out of the wide list, two alloys AA6101 and AA 6082 were selected for the experiment in the present work.

The objectives of this research project were:

- Design of tools and fixture for Friction Stir Welding.
- Fabrication as per design and specifications
- Experimental study of the process
- Welding Al alloys by FSW for different parameters and tool profiles
- Characterization and testing of weld
- Influence of FSW parameters on quality.