Synopsis

Out of the known aerospace metal and alloys, Aluminium (Al) and Titanium (Ti) are important due to their unique combination of properties, such as strength, ductility and corrosion resistance etc. For these reasons, welding of these two materials, especially in the butt and lap configuration, has a significant impact for structural applications. However, welding of Al to Ti is a challenge due to wide differences in their physical properties and properties of the brittle intermetallics that are formed. Such problems in Ti-Al weld can be minimized if the temperature of welding is reduced. Therefore, many solid-state welding processes have been introduced for this system in the past few decades. Amongst these processes, Friction Stir Welding (FSW) is among the most appropriate for dissimilar materials in the butt and lap configuration, as this process involves lower temperature of processing. The present thesis is an attempt to address the issues pertaining to the friction stir welding of commercially pure Al and Ti. Though these commercially pure materials are seldom used in actual applications, where alloys such as Ti-6Al-4V and Al 2219 (and their variants) are used, this work is done to get a fundamental understanding of the underlying mechanisms during Friction Stir Welding (FSW).

The study has been extended to the effect of using a thin strip of other metallic materials between Al and Ti. These inserts are likely to play a role in the formation of intermetallics and control the after effects of the formation of these intermetallics. Two metals have been chosen for this purpose, namely Zinc (Zn) and Niobium (Nb).

The thesis has 8 chapters that attempts to systematically understand the process of FSW of cp-Al to cp-Ti.

In Chapter 1 of the thesis, the FSW process is introduced with an emphasis on important parameters that control the welding process. In addition, a brief introduction of Al-Ti binary system is also given.

Literature related to conventional solid state welding processes and friction stir welding process is presented in Chapter 2. In this chapter, previous works on the FSW of various materials is reviewed, with more emphasis on welding of aluminium to titanium. At the end of the chapter the scope and motivation of the present investigation has been outlined.

Chapter 3 includes the experimental details involved in the present study. In addition to the details of the processes and various characterization techniques used in the present investigation, the basic principles involved in various techniques, names as X-ray tomography, Scanning Electron Microscopy (SEM) with Electron Back-Scattered Diffraction (EBSD), X-Ray Diffraction (XRD) and Electron Probe Micro-Analysis (EPMA) have also been given. Micro-hardness and tensile tests results are also reported in this chapter.

A detailed study on FSW of Al and Ti_is presented in chapter 4 of the thesis. The effect of process parameters on the evolution of microstructure and mechanical properties has been reported. A bottom-up approach on experimentally determining the "process window" is presented. The results emphasises on the distribution of titanium fragments and intermetallic particles in the nugget zone and their influence on mechanical properties of the weld. The microstructural evolution in the matrix is also detailed. The most noteworthy observation is substantial grain refinement in the nugget zone due to the presence of fine fragments of titanium and intermetallics. Cross-tensile tests of the samples welded under the optimised conditions fail in the retreating side of the aluminium material and has strength more than the parent material. The last section in this chapter deals with thermal stability of the microstructures.

Chapter 5 deals with the use of Zn as interlayer between Al and Ti. The microstructural evolution and its effect on the mechanical properties have been examined. The investigations clearly show that FSW of Al and Ti with Zn interlayer has superior mechanical properties compared to Al-Ti welds without interlayer. The resulting microstructure has a better thermal stability.

The use of Nb as interlayer has been studied in chapter 6. The microstructural investigation of the nugget zone reveals that Nb interlayer does not readily form solid solution with any of the base materials and Nb gets distributed more heterogeneously compared to Ti itself. This has led to a reduction in the strength of the weld, however, the ductility increases. The thermal stability of the microstructure is poor compared to FSW of Al to Ti with Zn interlayer.

In chapter 7, salient features of the different micro-mechanism operating during FSW of the investigated combinations has been discussed in detail.

Finally, the outcome of the thesis has been summarized and scope for future investigation is outlined in chapter 8.