Abstract

In many industrial applications steel is readily replaced by non ferrous alloys, in most cases aluminium alloys. Some of these materials combine good mechanical strength which is comparable with structural steel and low weight that allows a significant reduction in weight. But the joining of aluminium alloys by conventional welding processes can sometimes cause serious problems. The difficulties are often attributed to the solidification process and structure – including loss of alloying elements and presence of segregation and porosities in the weld joint. Friction stir welding (FSW) offers an alternative through solid-state bonding, which eliminates all these problems of solidification associated with the conventional fusion welding processes.

In this research work an attempt has been made to develop an empirical relationship between FSW variables and the mechanical properties (tensile strength, yield strength, percentage elongation, micro hardness and impact toughness) of friction stir welded aluminium alloy 6082-T651 joints. Response surface methodology was adopted for analyzing the problem in which several independent variables influence the response. Central composite rotatable design matrix was used to prescribe the required number of experimental conditions. A four-factors-five-level central composite design was used to determine the optimal factors of friction stir welding process for aluminium alloy. The central composite design (CCD) with a quadratic model was employed. Four independent variables namely - tool rotational speed (N), welding speed (S), axial force (F) and pin diameter (P) were selected. Each independent parameter was varied at five levels which were -2,-1, 0, +1 and +2. First 16 experimental conditions were derived from full factorial experimental design matrix ($2^4 = 16$). All the variables at the intermediate (0) level constitute the centre
points while the combinations of each process variable at either their lowest (-2) or highest (+2) with the other three variables of the intermediate levels constitute the star points. A total of 31 different combinations (including seven replicates of centre point each assigned the coded value 0) were chosen in random order according to a CCD configuration for four factors. The mathematical relationships were developed from the data generated. The developed mathematical relationships were useful for prediction of tensile strength, yield strength, percentage elongation, micro hardness and impact toughness in friction stir welded AA6082 aluminium alloy joints at 95% confidence level. It will also be helpful for selection of process variable to obtain the desired strength of the joint. The direct and indirect effect of the process parameters on the desired response are represented in graphical form for better understanding. The micrographs showing the microstructure of base material and all the welded joints are presented. SEM fractographs of the fractured surface of the tensile test specimens of the welded joints and base material are presented to know the behavior of fractured surface.

Some weld joints were selected for post weld heat treatment. Post weld treatment was carried out at 175 °C for a soaking period of 18 h. The mechanical properties after post weld heat treatment were evaluated and compared with the mechanical properties as-welded joints.

Four TIG weld joints of the aluminium alloy used in this research work were prepared to make the comparative study between TIG welded joints and FS welded joints. The mechanical and metallurgical properties of the TIG welded joints were evaluated and compared with the mechanical and metallurgical properties of friction stir welded joints.
The thesis is divided into chapters and the detail of the chapters is as follows:

Chapter-1: Introduction

A brief overview of aluminium and its alloys, four digit classification systems, and the temper designation system of aluminium alloys is presented in this chapter. Also the difficulties that arise during conventional welding of aluminium alloys, introductions of friction stir welding, including an overview of the process, process parameters, the advantages, disadvantages and applications of the friction stir welding process are discussed in this chapter.

Chapter-2: Literature Review

This chapter presents the review of the literature published on friction stir welding of aluminium alloys. After a comprehensive study of the existing literature, a number of research gaps have been observed in friction stir welding of aluminium alloys which are given below:

- Most of the researchers have investigated the influence of a limited number of process parameters on the friction stir welding of aluminium alloys.
- Literature review reveals that the researchers have carried out most of the work by varying one parameter at a time and no consideration has been given to interaction effect of two or more parameters.
- No literature is available to study the effect of post weld heat treatment on the mechanical and metallurgical properties of FS welded 6082-T651 aluminium alloy joints.
- The comparison of friction stir welded joints and TIG welded joints of 6082-T651 aluminium alloys is not available in the published literature.

Thus, keeping in view the above mentioned research gaps, it has been planned to investigate the effect of process parameters on mechanical and metallurgical
properties of friction stir weld joints of aluminium alloy using design of experiment technique. The objectives of the present research work are presented below:

a) Development of parametric window for friction stir welding of aluminium alloy AA6082-T651.

b) To study the effect of process parameters on the mechanical and metallurgical properties of friction stir welded aluminium alloy joints using design of experimental technique.

c) To conduct the welding of aluminium alloy 6082-T651 using TIG welding process and then compare the mechanical and metallurgical properties of TIG welded joints with those of FS welded joints.

**Chapter-3: Design of experiments**

This chapter gives the short information of the various designs of experiment approaches and their working range, development of design matrix for conducting the experiments.

**Chapter-4: Methodology and experimentations**

The detailed information about the methodology adopted for achieving the desired objectives is discussed in this chapter. All the experimental details like machine used, procedure of preparation of the weld plates, equipment used for testing of the weld joints are also discussed in this chapter.

**Chapter-5: Results and Discussions**

The mechanical and metallurgical tests were conducted on the weld joints and the data thus generated is presented and discussed in this chapter. The mathematical models were developed from the generated data and their direct and interaction effects are presented graphically and also through response surface plots for better understanding. The effect of process parameters on the mechanical and metallurgical
properties of friction stir welded aluminium alloy joints is discussed. The optical micrographs showing the microstructure of the welded joints and SEM fractographs showing the fracture behavior of tensile specimens are also given in this chapter.

**Chapter-6: Effect of the post weld heat treatment on FS weld joints**

This chapter gives an introduction about the effect of post weld heat treatment on the mechanical properties of friction stir welded aluminium alloy joints. The comparative study between the mechanical properties of as-welded joints and post weld heat treated joints is discussed in this chapter.

**Chapter-7: Comparison of FSW weld and TIG welds**

The comparative study of the mechanical and metallurgical properties of the weld joint of aluminium alloy 6082-T651, prepared using Friction stir welding and TIG welding, is discussed in this chapter.

**Chapter 8: Conclusions and Scope for future work**

This chapter contains the summary of the present research work. After the analysis of the experimental results conclusions have been taken out and recorded to summarize the outcome. At the end of the chapter some suggestions for future work on friction stir welding are given.