Chapter 1 Introduction

1. 1 Background and motivation

Welding of dissimilar materials has been always a challenge, due to enormous differences in mechanical, chemical, thermal and metallurgical properties. However, the dissimilar welding is an interesting area of research in terms of the industry as well as the academic point of views. The dissimilar joints are increasingly employed in different sectors of industries because of its technical and economic advantages (Okamura and Aota, 2004). Dissimilar materials such as copper (Cu) and aluminum (Al) materials are having special common properties of excellent electrical and thermal conductivities allow to apply for electrical and thermal engineering applications (Galvão et al., 2016, Marya and Marya, 2004, Mubiayi and Akinlabi, 2013, Xue et al., 2010). Electrical connectors, bus-bars, foil conductor in transformers, cell-cell and cell-bus bar battery inter connectors, capacitor and condenser foil windings, refrigeration tubes, heat-exchangers tubes and tube-sheets, nuclear canister are some common applications, wherein Cu-Al joints are applied, and these joints have strong potential on many other applications (Acarer, 2012, Akinlabi, 2011, Yang et al., 2017).

Conventional fusion welding processes are extremely unsuitable for dissimilar Cu-Al joints. Fusion welding of Cu-Al joints leads to the formation of large amount of intermetallic compounds (IMCs) and major macro defects. The solidification and liquefaction cracking are some common problems associated with the conventional fusion welding of dissimilar Cu-Al joints (Galvão et al., 2016). Therefore, the solid state welding processes such as friction welding, ultrasonic welding, cold rolling, explosive welding, magnetic pulse welding, diffusion welding and friction stir welding are found suitable for dissimilar Cu-Al joints (Bergmann et al., 2013, Acarer, 2012, Abbasi et al., 2001, Loureiro et al., 2016, Wu and Shang, 2014, Satpathy and Sahoo, 2016, Ni and Ye, 2016). Over the past few years, the researchers have focused on Friction Stir Welding (FSW) technology to obtain dissimilar joints (Mishra et al., 2014, Akinlabi and Akinlabi, 2014). FSW is type of sustainable manufacturing process, which provides extraordinary benefits such as environmental friendliness, minimum energy consumption, low material wastage and high process efficiency. FSW is a variant of friction welding, innovated by Wayne M. Thomas at The Welding Institute (TWI), London, United Kingdom (UK) in 1991, which works on remarkably simple concept of friction and stirring action that provided through non-consumable tool. This friction and stirring causes plastic deformation and material flow which subsequently leads to the joining of the materials (Mishra and Ma, 2005, Lohwasser and Chen, 2009). FSW is invented for aluminum and its alloys initially (Mishra and Ma, 2005), and has been continuously expanded for different materials and combinations through incredible process improvements. Varity of materials such as high temperature metals that includes steel, titanium, nickel, copper, etc., thermo plastics, composites and dissimilar combinations are possible to get successful joints (Mishra and Ma, 2005).

Considering importance of the research interest and promising process, the large numbers of research articles are arriving day by day. Initial research and feasibility of dissimilar Cu-Al FSW is performed by (Murr et al., 1998a, Murr et al., 1998b, Elrefaey et al., 2005, Ouyang et al., 2006). Afterwards, number of investigations are conducted on dissimilar Cu-Al FSW in order to acquire the knowledge of mechanical and metallurgical properties, microstructural variations, basic parametric effects, formation of IMCs and its influences, reported in review articles of (Akinlabi and Akinlabi, 2014, Galvão et al., 2016) and book chapter of (Mishra et al., 2014) Despite of these investigations and great interest of research, this topic is limitedly investigated at many important fields such as tool design, process parameters, hybrid approaches, dissimilar weld properties enhancement, parameters-properties co-relation and enlargement of process parameters window. Studies on these fields are sensible and worthwhile in order to enhance the impact of the topic.

1. 2 Aim and objectives

The aim of the present investigation is to analyse FSW for dissimilar Cu-Al system in terms of mechanisms and properties, process parameters, tool design and hybrid approaches. The assessment of weld quality is quantified by means of mechanical and metallurgical analyses. The precise objectives considered for the present study are as under:

To elucidate the mechanisms and properties of dissimilar Cu-Al FSW joints. These analyses include microstructure features, formation of IMCs, tensile properties, hardness profile and its co-relation.

Establish the effect of process parameters such as tool pin offset, welding speed and tilt angle on dissimilar Cu-Al FSW.

To analyse different features of tool design for dissimilar Cu-Al FSW system: studies on tool pin features and dimensions of tool pin as well as tool shoulder.

The FSW process window enlargement through hybrid approaches of assisted heating and cooling.

Investigate the effect of heating assisted FSW and cooling enhanced FSW on dissimilar Cu-Al joints.

To compare and analyse the properties of hybrid FSW with normal FSW.

1. 3 Scope and significance

The present work is proposed to develop comprehensive understanding on mechanisms of dissimilar Cu-Al joints. It is also envisaged that, the insights on process-properties co-relation will be suggested by the present investigation. It is expected to answer the influence of process parameters on properties of dissimilar Cu-Al FSW. The importance of tool features on behaviour of dissimilar joint properties will be identified by the present investigation. The present study will also be valuable to acquire the options that can make significant improvement in FS welded properties. The proposed study will provide detail information on implementation of hybrid approaches such as assisted heating and cooling FSW for dissimilar Cu-Al system. The study will also provide comparisons of properties, welded under normal FSW and hybrid FSW approaches.

1. 4 Limitations of thesis

- Present investigations are focused on dissimilar butt joint configuration. Different joint configurations and complex tool designs such as bobbin tool and stationary tool are not investigated.

- The presented investigation is focused on experimental work. Mathematical modelling and quantitative analysis is not co-related with experimental results.

- Hybrid approaches of heating assisted FSW and cooling enhanced FSW are investigated for its individual parametric effects. Combined effect of all the parameters of FSW and hybrid FSW are not studied.

- Optimization of process parameters is not performed analytically.

1. 5 Layout of thesis

The present structure of thesis is divided into five number of chapters. Description of each chapter is mentioned as under.

Chapter 1 briefly introduces the background, motivation, problem statement, aim, objectives and structure of the thesis.

Chapter 2 presents a comprehensive review on focused literature of dissimilar materials Cu-Al FSW. Introduction on FSW process, significance of process parameters, microstructural changes, weldability issues and defects, properties and variants of FSW for dissimilar Cu-Al system have been discussed in this chapter.

Chapter 3 describes the materials, methods and experimental set-up, which includes selection of tool design and process parameters, testing procedure and characterisation methods. Experimental methods followed for normal FSW and hybrid FSW for dissimilar Cu-Al joints are presented. Procedures for mechanical and metallurgical testing are mentioned as per respective standards.

Chapter 4 presents results and discussions for the considered objectives of the present work. Results obtained under different process parameters such as tool pin profiles, tilt angle, welding speed and tool pin offset are presented for normal FSW. Hybrid approaches are implemented based on the results of normal FSW. The results of hybrid FSW are compared with normal FSW.

Chapter 5 provides conclusions for the present work and future work possible under the topic of dissimilar Cu-Al FSW.