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Friction stir welding of aluminum to copper—An overview

Nidhi SHARMA, Zahid A. KHAN, Arshad Noor SIDDIQUEE

Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India

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Abstract: Components made by joining different materials are required in various engineering applications. Fabrication of such components is a challenging task due to the vast difference in mechanical, thermal and electrical properties of the materials being used. Friction stir welding (FSW) is capable of joining dissimilar materials such as aluminum (Al) and copper (Cu) and therefore researchers have used this novel process for dissimilar joining. Consequently, several works pertaining to dissimilar joining, specifically Al−Cu, are available in the literature but they are scattered in different sources, which makes the task of gathering information about dissimilar FSW of Al−Cu cumbersome. This work has been written with an aim to provide all pertinent information related to dissimilar FSW of Al−Cu at one place to ease the problems of researchers. It comprehensively covers and summarizes the topics such as the effect of tool design and geometry, FSW process parameters, FSW strategies on mechanical properties, microstructure and formation of defects during dissimilar FSW of Al−Cu. In addition, it also presents and discusses several variants of dissimilar FSW of Al−Cu. Finally, this work not only puts forth major findings of the previous researchers but also suggests future recommendations for dissimilar FSW of Al−Cu.

Key words: aluminium; copper; friction stir welding; intermetallic compounds; mechanical properties; weld nugget zone

1 Introduction

Obtaining an efficient weld of dissimilar materials is a challenging research task and a matter of concern for the engineers and scientists. The necessity to develop the machines/parts/systems that culminate in weight reduction, high strength, high corrosion resistance, improved thermal and electrical properties at the joint interface is continuously increasing. Nowadays, most of the components require multiple properties that need the use of different materials in a single component/ structure [1]. Al and Cu possess good electrical and thermal conductivities and they are widely used for thermal and electrical applications. Al to Cu joints are commonly found in various applications, such as busbars, electrical connectors, transformer's foil conductor, condenser and capacitor foil windings, tubes of heat exchangers, refrigeration tubes and tube sheets. Al and Cu are incompatible materials with regards of joining because of very high affinity of these materials at temperature higher than 120 °C [2]. Joining of Al−Cu produces a large number of IMCs in different weld zones which are hard, brittle and possess lower strength and higher electrical resistance [3]. Fusion welding processes used to join Al−Cu are not recommended because of the solidification and liquefaction cracking and also the tendency to form large hard and brittle IMCs consequently the weld defects [4]. Solid state welding of Al to Cu could avoid such problems and different welding techniques such as ultrasonic welding, friction welding, explosive welding, cold rolling, diffusion welding, and friction stir welding techniques are benefited in such joins [5,6].

FSW is an innovative solid-state welding technology originated and patented by the Welding Institute (TWI), London, UK, in 1991 [7−13], which possesses great prospective for joining materials of high chemical affinity such as Al and Cu and having completely different physical, chemical and mechanical properties [14]. It has been widely reported that the microstructure and mechanical properties obtained using FSW of dissimilar material are very similar to those of the base materials unlike fusion welding [15]. Specially designed non-consumable rotating tool is the main element of FSW and it usually consists two parts: shoulder and pin, as shown in Fig. 1 [16].

The bottom part of the tool known as tool pin is

Corresponding author: Nidhi SHARMA; E-mail: nid.sharma83@gmail.com
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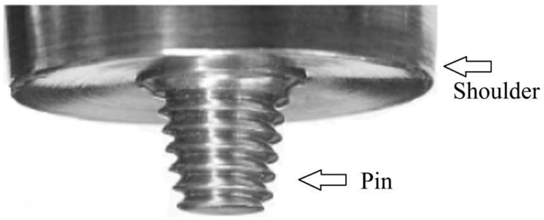

Fig. 1 Parts of FSW tool [16]

completely inserted between adjoining surfaces until the upper part of the tool known as the shoulder comes in contact to the base plate or sometimes a plunge depth is also given during FSW while other process parameters are carefully selected. The strong rubbing action of the tool and workpiece generates a large amount of frictional heat which softens the workpiece materials. This softened material flows in horizontal and vertical directions inside the stir zone [7−13]. Three distinct zones forming the final nugget zone in FSW are: forged zone affected by the shoulder or axial force, shear zone influenced by the pin, and swirl zone affected by the bottom of the pin [17,18]. The basic schematic diagram of dissimilar FSW of Al−Cu is shown in Fig. 2.

The sound joining of Al−Cu is difficult to achieve even with FSW and joints usually failed at the interface or nugget zone during mechanical testing [19−21]. Formation of different IMCs of a brittle nature in the nugget zone is a possible reason for such failures and poor weld quality [19]. Dissimilar FSW joint characteristics are affected by various parameters, i.e., tool offset, tool rotation rate, tool traverse speed, and weld strategy [14,22].

Complete understanding of this important subject of Al−Cu welding using FSW is of vital importance. An understanding on the effect of FSW parameters, their interaction, various welding strategies and their implications on joint properties is still evolving. Considerable work still needs to be done to fully compile and integrate the domains and islands of information/ knowledge of the state of the art. This review work was compiled by studying a large number of published articles in the area of dissimilar FSW of Al−Cu. The review has been performed with the objective to map various aspects during FSW of Al−Cu, correlating these aspects, highlighting contiguity and gaps in this area. This work also gives the latest developments and provides directions for the interested researchers the further domain of FSW process used to join Al−Cu. The following section presents the effect of several FSW parameters of dissimilar welding of Al and Cu as reported by the researchers.

2 Process parameters

The main process parameters during FSW are tool material, tool design and geometry, tool shoulder and pin, welding speed and rotational speed. These process parameters have been studied by various researchers to find out the effect on dissimilar FSW of Al−Cu in order to achieve a defect free joining. The main contribution of these process parameters on FSW are given in Table 1 [23,24].

It is advisable to carefully select the operating range of process parameters, so as to lead to an acceptable quality weld using FSW. Here, the FSW process parameters have been summarised with respective to the weld quality.

2.1 FSW tool

FSW tool is a principal process parameter and its main function is to provide appropriate heating and softening of workpiece materials by the friction occurring between the tool and workpiece. It also

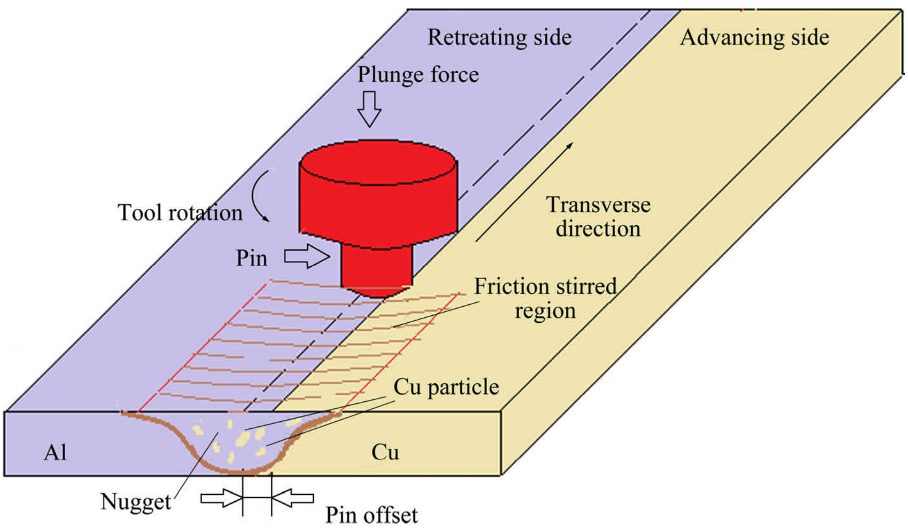

Fig. 2 Schematic diagram of dissimilar FSW of Al the Cu