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Effects of processing parameters on corrosion properties of dissimilar friction stir welds of aluminium and copper

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Abstract: The influence of friction stir welding processing parameters on dissimilar joints conducted between aluminium alloy (AA5754) and commercially pure copper (C11000) was studied. The welds were produced by varying the rotational speed from 600 to 1200 r/min and the feed rate from 50 to 300 mm/min. The resulting microstructure and the corrosion properties of the welds produced were studied. It was found that the joint interfacial regions of the welds were characterized by interlayers of aluminium and copper. The corrosion tests revealed that the corrosion resistance of the welds was improved as the rotational speed was increased. The corrosion rates of the welds compared to the base metals were improved compared with Cu and decreased slightly compared with the aluminium alloy. The lowest corrosion rate was obtained at welds produced at rotational speed of 950 r/min and feed rate of 300 mm/min which corresponds to a weld produced at a low heat input.

Key words: aluminium alloy; copper; corrosion; friction stir weld; processing parameters

1 Introduction

It is estimated that corrosion destroys one quarter of the world's annual steel production, which corresponds to about 150 million tons per year, or 5 tons per second [1]. Corrosion is not limited to steel but affects other materials used in various applications especially in welded joints. Corrosion is known to destroy a material or degrade its functional properties, rendering it unsuitable for the intended use [1]. Generally, the durability and the life time of welds, installations, machines and devices are critically dependent on their corrosion rate and wear resistance. Welded joints are specifically susceptible to corrosion when exposed to the environment and most especially dissimilar welds.

Friction stir welding (FSW) process is a solid state welding technique invented by Dr W. THOMAS of The Welding Institute (TWI), United Kingdom in 1991 [2]. FSW is a continuous process that involves plunging a portion of a specially shaped rotating tool between the butting faces of the joint. A schematic of the process is presented in Fig. 1. The relative motion between the tool and the substrate generates frictional heat that creates a plasticized region around the immersed portion of the tool. The tool is moved relatively along the joint line, forcing the plasticized material to coalesce behind the tool to form a solid-phase joint [3].

The resulting microstructures of friction stir welds are described by the different zones as follows: 1) the base metal (BM), which is the material remote from the weld that has not been deformed, and is not affected by the heat in terms of microstructure or the mechanical properties; 2) the heat affected zone (HAZ) which is a region that lies closer to the weld centre and has experienced a thermal cycle that has modified the microstructure and/or the mechanical properties, however, no plastic deformation has occurred in this area; 3) the thermo mechanically affected zone (TMAZ) which is a region where the FSW tool has plastically deformed the material at the weld interface; and 4) the weld nugget (WN) which is the fully recrystallized area,

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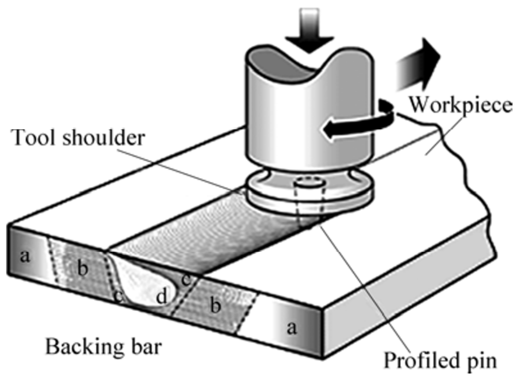

Fig. 1 Schematic diagram of FSW process [3]

sometimes called the stir zone (SZ) or the stir nugget (SN), and refers to the zone previously occupied by the tool pin during FSW [4].

The benefits of this technology include: low distortion, greater weld strength compared with the fusion welding process, little or no porosity, no filler metals, little or no post-weld repair, no solidification cracking, no welding fumes or gases, improved corrosion resistance, and lower cost in production applications [5,6]. Because of the many demonstrated advantages of FSW over the fusion welding techniques, the commercialization of FSW is proceeding at a rapid pace. The FSW of aluminium and its alloys has been commercialized [7,8]; and recent research interest is focused on joining dissimilar materials such as aluminium and copper. Components consisting of aluminium and copper possess the beneficial properties of both. Aluminium is mainly required for its low cost, high corrosion resistance and high specific strength, while copper is mainly used for its superior electrical conductivity and its high thermal expansion. Such applications include bus-bars, switchgears and heat sinks, and many other applications are currently being developed. By successfully joining these metals with superior corrosion resistance, the superior properties of both materials can be utilized in many applications requiring a combination of these properties. Friction stir weld of aluminium and copper being a dissimilar joint is susceptible to galvanic or bimetallic corrosion. Corrosion in these joints can result from the formation of an electrochemical cell between the two metals joined and the corrosion of the less noble metal is thus accelerated. Published literatures in this regard include research by SUREKHA et al [9] on the effect of processing parameters on the corrosion behavior of friction stir processed AA 2219 aluminium alloy. It was found that the resistance to corrosion increases as the rotational speed increases in the processed aluminium samples. This is due to the dissolution of the $CuAl_2$ particles during the friction stir processing which reduces the number of sites available for galvanic coupling and hence increases the corrosion resistance. Further study was conducted by RAO et al [10] on the effect of friction stir processing on the corrosion resistance of aluminium–copper alloy gas tungsten arc welds. It was found that the friction stir processing improved the corrosion resistance of the welds. Fusion welds of this grade of aluminium alloy are known to suffer from poor corrosion resistance due to the uneven distribution of copper in the welds, which produces large differences in the electrochemical potentials [11]. $AlCu_2$ was the major intermetallic compound found, which imparts greater strength in this alloy but decreases the corrosion resistance. This is due to the formation of galvanic cells between the noble $AlCu_2$ and the aluminium matrix [10]. To improve the corrosion resistance, it is necessary to create a uniform level of copper in the weld. Other studies on corrosion properties of friction stir welds include a report by PAGLIA and BUCHHEIT [12] on the corrosion properties of friction stir welds of 7075-O aluminium alloy. They found that the welds are susceptible to intergranular corrosion. However, they suggested that short-term post-weld heat treatments with temperatures similar to the welding temperatures can be used to modify the microstructure and improve the corrosion resistance of the welds. The effect of welding parameters on the corrosion behavior of friction stir welded AA2024–T351 was also conducted by JARIYABOON et al [8]. They found that the rotational speed has the greatest influence on the corrosion sensitivity on the weld cross sections. It was concluded that for low rotational speeds, the corrosion attack is in the nugget region due to the significant increase in the anodic reactivity in this region. For higher rotational speeds, the corrosion attack was in the HAZ region owing to the presence of sensitized grain boundaries in this region. BOUSQUET et al [13] conducted a research on the relationship among the microstructure, microhardness and corrosion sensitivity of friction stir welded joints of AA 2024-T3. They found that the HAZ close to the TMAZ is the region most sensitive to intergranular corrosion because of the presence of the continuous lines of intergranular precipitates at the grain boundaries and the pitting corrosion observed was due to the presence of intermetallic particles at such regions. However, the majority of these studies are limited to joining similar materials especially aluminium and its alloys.

In view of the foregoing, concerted efforts are geared towards optimizing the processing parameters to produce metallurgically sound joints of aluminium and copper using FSW [14−17] which will ultimately lead to its commercialization. It is very important to have an