Microstructural Characterizations of Dissimilar Friction Stir Welds

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Abstract—This paper reports the microstructural characteristics of dissimilar friction stir welds between 5754 aluminium alloy and C11000 copper. Dissimilar Friction Stir Welds of 5754 aluminium and C11000 copper were produced by varying the rotational speeds between 600 and 1200 rpm and the feed rate between 50 and 300 mm/min. The welds were characterized through Scanning Electron Microscopy (SEM). The SEM analysis revealed the levels of metallurgical bonding achieved at the joint interfaces of the welds produced and it can be established that better metallurgical bonding and good mixing of both materials joined were achieved in welds produced at lower feed rates of 50 mm/min and 150 mm/min while defect population was found to be common in the welds produced at high feed rate of 300 mm/min.

Keywords— friction stir welding, macrographs, metallography micrographs, Scanning Electron Microscopy,

I. INTRODUCTION

FRICTION Stir Welding (FSW) is considered to be the most significant development in joining over the past two decades. FSW was invented and validated by Dr Wayne Thomas and his team in 1991 at The Welding Institute (TWI), in the United Kingdom, as a solid-state joining technique [1]. The FSW process is remarkably simple but involves rather complex thermal and material dynamics. The process can most effectively be explained using Fig. 1.

Figure1 depicts two separate plates undergoing the Friction Stir Welding process, in a configuration of the conventional butt-weld. During the FSW process, a non-consumable tool is plunged into the abutting edges of the plates and then moved along the joint line. Due to the nature of Friction Stir Welding, the tool used significantly influences the joint integrity. The pin and the shoulder are familiar characteristics of the FSW tool and facilitate a few fundamental aspects of the FSW technique. The FSW tool facilitates heat generation, containment of heat, containment of the material and mixing of the two materials being joined to produce the joint. The main difference between the conventional welding techniques and the solid-state Friction Stir Welding (FSW) technique is that no heat is added to the 'system'; instead heat is generated internally by means of friction between the tool-material interface and plastic deformation [3]. The generation of heat internally revolutionized the welding industry because no pre-heating, post-heating or brazing fluxes are necessary for FSW. No pre or post preparation is also required because the FSW process is a comparatively stable joining technique in which materials are joined together without melting. Melting significantly alters the material mechanical properties. Materials with considerably different melting points such as aluminium and copper can now be successfully welded together which was not attainable with the conventional welding techniques. The heat acquired from friction and plastic deformation during the FSW process softens the material at the joint interface and enables a solid phase joint. Material flow during the welding process is a fundamental component of the Friction Stir Welding (FSW) process that makes this type of welding different from other conventional welding techniques. Material flow is the mechanism that

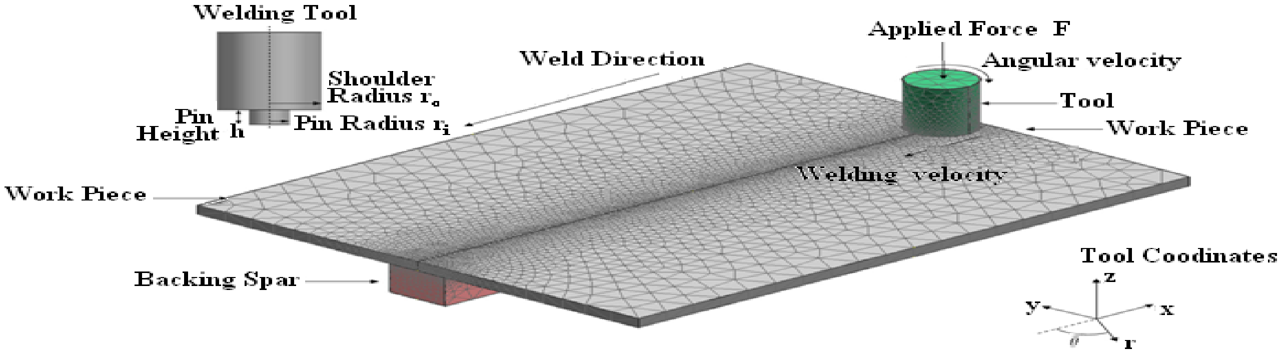

Fig.1: Schematic diagram of a Friction Stir Welding Process [2]

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enables the joining of Friction Stir Welded materials to occur. Material flow is dependent on several parameters. The dominant parameters are namely the downward force, the rotational speed and the feed rate [4]. Microstructural characterization in FSW was initiated by Threadgill [5]; he identified the different microstructural zones after FSW, viz: the weld nugget which is located in the center of the weld. This is where most of the materials mix and the region have undergone sufficient deformation at elevated temperatures to recrystallize the grains. The Thermo-Mechanically Affected Zone (TMAZ) is the immediate region surrounding the nugget zone, lying between the Heat Affected Zone (HAZ) and the nugget. The material in the TMAZ has both been heated and deformed but to a less extent to that experienced in the weld nugget. The Heat Affected Zone (HAZ) is similar to that obtained in conventional welds although the maximum peak temperature FSW process is significantly less than the solidus temperature and the heat–source is rather diffused. Many studies have been conducted to characterize the resulting microstructure in welds especially in aluminium [5-9] and it was reported that the weld nuggets were fully recrystallized with the presence of the onion ring structure indicating good material flow during the welding process. However, there is paucity in the literature on microstructural characterisation of dissimilar materials especially on aluminium and copper; this is significant towards achieving optimum results in this regard. The aim of this paper therefore, is to present results of microstructural characterizations of dissimilar welds of aluminium and copper produced at different welding parameters and the trends observed were also reported.

II. EXPERIMENTAL SET-UP

The Friction Stir welds between 5754 aluminium alloy and C11000 copper were produced at the Nelson Mandela Metropolitan University (NMMU), Port Elizabeth, South Africa using an Intelligent Stir Welding for Industry and Research Process Development System (I-STIR PDS) platform. The Friction Stir Welds of 5754 aluminium and C11000 copper were produced by varying the rotational speeds between 600 and 1200 rpm and the feed rate between 50 and 300 mm/min. The rotational speeds of 600, 950 and 1200 rpm were employed while 50, 150 and 300 mm/min were the feed rates considered representing the low, medium and high settings respectively. The tool employed is threaded pin and concave shoulder machined from H13 tool steel and hardened to 52 HRC. For consistency and comparism, all the welds produced were sectioned at 50 mm into the weld length. The aluminium alloy side was etched with Keller's reagent and the Cu was etched with the modified Poulton's reagent. The welds were characterized using VEGA 3 Scanning Electron Microscopy (SEM) in University Of Johannesburg, South Africa.

III RESULTS AND DISCUSSION

3.1 Macrograph characterization of the welds

The macrographs of the welds produced at a constant rotational speed of 600 rpm varying the feedrate at 50, 150 and 300 mm/min are presented in Fig. 2 (a) to (c).

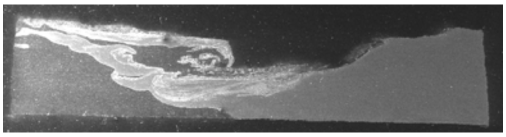

Fig. 2 (a): Macrograph of weld produced at 600 rpm and 50 mm/min.

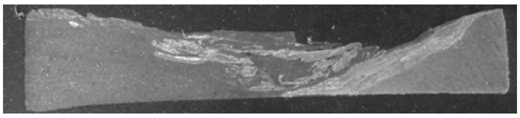

Fig. 2 (b): Macrograph of weld produced at 600 rpm and 150 mm/min.

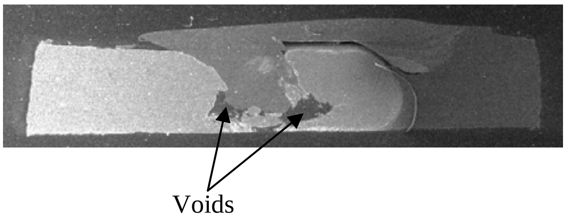

Fig. 2 (c): Macrograph of weld produced at 600 rpm and 300 mm/min.

Reduction in the thickness but good material mixing was observed in the weld produced at a constant rotational speed of 600 rpm and feed rates of 50 and 150 mm/min. The reduction in thickness at the joint interfacial regions can be attributed to heavy flash during the welding process due to high heat input because this welds were produced at a relatively low feed rates which results into high heat input while the weld produced at 600 rpm and 300 mm/min have large voids formed as indicated with arrows in Fig. 2 (c) and minimum material mixing. This can be attributed to fast rate of movement of the tool during the welding process thus resulting in poor weld consolidation as pronounced in the macrograph.

The macrographs of welds produced at a constant rotational speed of 950 rpm varying the feedrate at 50, 150 and 300 mm/min are presented in Fig. 3 (a) to (c).

Fig. 3 (a): Macrograph of weld produced at 950 rpm and 50 mm/min

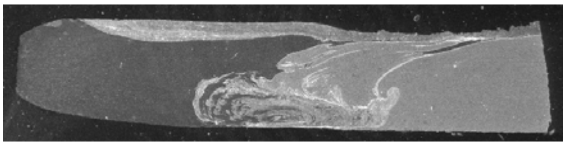

Fig. 3 (b): Macrograph of weld produced at 950 rpm and 150 mm/min

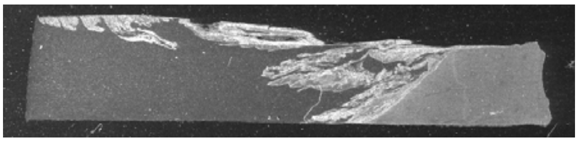

Fig. 3 (c): Macrograph of weld produced at 950 rpm and 300 mm/min

Reduction in the thickness of the interfacial region, a fairly good degree of material mixing, low length range of material mixing, and partly defined FSW regions were observed in the weld produced at 950 rpm and 50 mm/min. For the weld produced at 950 rpm and 150 mm/min, there was no thickness reduction but was characterized with high material mixing, medium length range of material mixing, fully formed vortex and distinct FSW regions and for the weld produced at 950 rpm and 300 mm/min, there was reduction in thickness at the joint interface, low material mixing, low length range of material mixing and no void was formed.

The macrographs of welds produced at a constant rotational speed of 1200 rpm varying the feedrate at 50, 150 and 300 mm/min are presented in Fig. 4 (a) to (c).

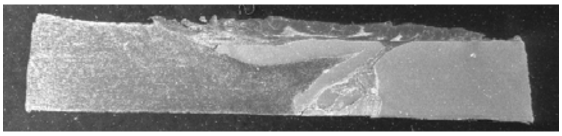

Fig. 4 (a): Macrograph of weld produced at 1200 rpm and 50 mm/min

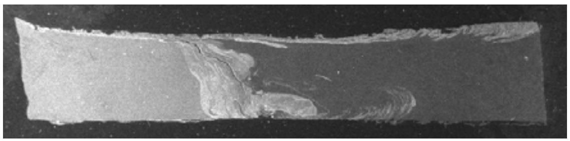

Fig. 4 (b): Macrograph of weld produced at 1200 rpm and 150 mm/min

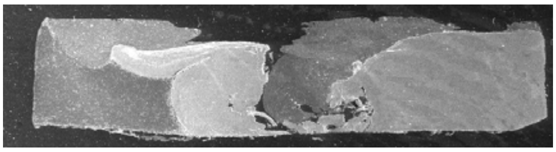

Fig. 4 (c): Macrograph of weld produced at 1200 rpm and 300 mm/min

It was observed that there was no reduction in thickness in the weld produced at 1200 rpm and 50 mm/min but there was a large volume of material mixing, small length range of material mixing and no void was formed at the interface; while, minimal reduction in thickness, medium material mixing, low length range for material mixing and no vortex was formed in weld produced at 1200 rpm and 150 mm/min; whereas the weld produced at 1200 rpm and 300 mm/min has reduction in thickness, minimal mixing, the joint was not fused and there was large number of concentrated voids formed at the joint interface. In general, considering the macrographs of the welds produced in this research work, an apparent trend was that the appearance of the cross sectional area of the welds changes significantly more with respect to the feed rate than the rotational speed. Majority of the welds produced at high feed rate of 300 mm/min have wormhole defect present in them resulting from lack of consolidation. The degree of material mixing and reduction in thicknesses at the joint interface can be related to heat generation during the process, high feed rates will result in less heat generation, which bestow difficulties for plastic deformation. For low heat generation, the displaced material attaches itself to the tool and is deposited on the outer edge of the weld region instead of mixing with the other material hence resulting into weld flash thereby reducing the thickness of the materials at the joint interface. The sliding motion of the tool on the surface can also contribute towards the formation of large voids in the welds. The range of the length of the processed interfacial regions is dependent on the transverse speed. Lower transverse speeds (feed rates) will provide more energy into the weld than higher transverse speeds; hence, the higher the level of energy generated during the FSW process will result into a larger range of plastically deformed material.

3.2 *Microstructural characterization of the welds*

Typical micrographs showing important features at the joint interfacial regions of the welds produced in this research are hereby presented.

Fig. 5 (a) presents the microstructure of the joint interface of the weld produced at 950 rpm and 150 mm/min.

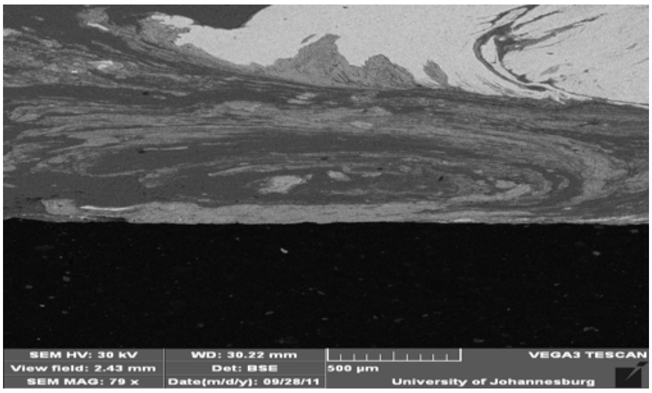

Fig. 5 (a): Microstructure of weld produced at 950 rpm and 150 mm/min

It was observed that the joint interface of the weld produced at 950 rpm and 150 mm/min (Fig. 5 (a)) is characterized with an onion ring structure indicating good material flow and mixing in this regard. This region can be referred to have undergone dynamic recrystallization during the FSW process.

Fig. 5 (b) presents the microstructure of the joint interface of the weld produced at 6000 rpm and 50 mm/min.

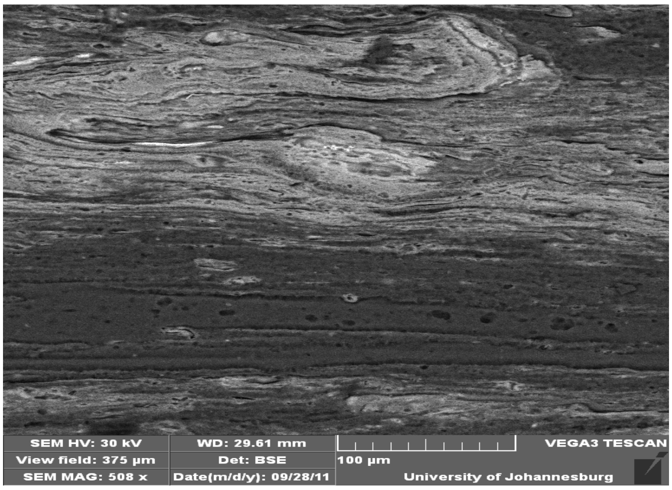

Fig. 5 (b): Microstructure of weld produced at 600 rpm and 50 mm/min

The joint interfacial region of the weld produced at 600 rpm and 50 mm/min was characterized with lamellar layers of aluminium and copper indicating good mixing of both materials joined.

Fig. 5 (c) presents the microstructure of the joint interface of the weld produced at 6000 rpm and 300 mm/min.

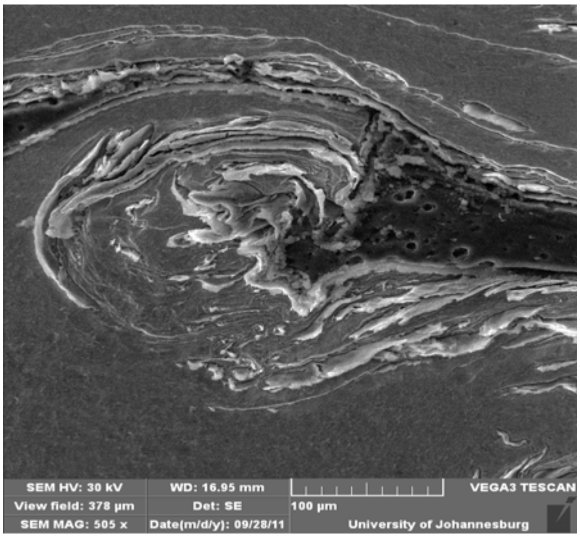

Fig. 5 (c): Microstructure of weld produced at 600 rpm and 300 mm/min

A wormhole defect also referred to as void was observed in the weld produced at 600 rpm and 300 mm/min. voids are known to be detrimental to weld properties [10] as such, they weaken the strength of the joint thereby adversely affecting the joint integrity.

IV CONCLUSION

The microstructural characterizations of dissimilar joint between aluminium and copper have been successfully conducted and reported in this paper. It can be concluded that the feed rate directly affects the quality of weld produced in this regard. Results showed that good material mixing was achieved in welds produced at lower feed rate due to high heat generated while the welds produced at high feed rates resulted in worm hole defect formation. The only weld characterized with the onion ring structure indicating a joint was produced at a setting of 950 rpm and 150 mm/min.

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