Journal of Manufacturing Processes 34 (2018) 96–105

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

The study of material flow behaviour in dissimilar material FSW of AA6061 and Cu-B370 alloys plates

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ARTICLE INFO

Keywords:
Dissimilar material
Material flow model
FSW

ABSTRACT

Friction stir welding is a solid-state joining process which proved to be very effective for similar low strength materials. However, the joining of dissimilar materials is far complex than the similar materials because of divergent material properties. The need to study friction stir welding of dissimilar materials is inevitable due to increasing demand of modern industries. In the current study, the joining of aluminium alloy (AA-6061) and copper alloy (Cu-B370) plates is accomplished for studying the material flow movement throughout welding zone. A novel material flow model for dissimilar material friction stir welding is proposed based on the temperature and strain rate dependent material properties. The model used the volume of fluid (VOF) approach in the commercial FVM package ANSYS fluent 14.5. Experiments are also conducted to validate the model with thermal profiles and optical micrographs. Furthermore, the effect of tool rotational and the welding speed are studied on the material movement. It is found that process parameter had a huge impact on the nugget zone formation during the welding. The tool rotaion and welding speed directly affect the amount of platisized material mixing.

1. Introduction

Friction stir welding (FSW) [1] is a solid phase pressure welding process in which the material gets plasticized and joined together. Friction stir welds are prepared by plunging a hard, non-consumable, expeditiously rotating tool with no filler material into the two mating material pieces. Friction heat is generated by the interaction between high speed rotating tool and the workpiece. This plasticized the material, which then forced to mix with each other by the stirring action of the tool. The technique proved to be very effective for welding low strength alloys. Moreover, it is able to join alloys which are considered to be unweldable by conventional welding technique [2]. The FSW tool consists of two parts, the shoulder and the pin. The majority of the heat generation in FSW process is achieved by the shoulder surface and the mixing is dominated by the pin.

In last decade, the substantial amounts of research were conducted on dissimilar metal FSW. Prior to this, the researchers were primarily confined to similar metal joining. The Dissimilar metal FSW process lacks the knowledge of weld quality obtained in terms of microstructure, intermetallic compounds, defects and mechanical properties of the joints. In the advanced world, many applications require dissimilar metal joining such as mild steel-Cu, Al-Cu, Al-Ti etc. Joining dissimilar metals having different mechanical properties is a tedious job. Many authors reported that FSW is capable of joining the dissimilar materials. The tool and machine requires for Al-Cu are much cheaper in comparison to the equipment required to join harder materials. Therefore, huge experiments are reported on Al-Cu to gain sufficient knowledge on dissimilar metal FSW. The problems associated with Al-Cu FSW process are common with other dissimilar material FSW.

The Al and Cu have excellent electrical and mechanical properties thus the joining of these two metals found many applications in sectors like power generation, electronic and transportation [3], [4]. Though the research started on the dissimilar metal joining in the late 90's [5], the extensive experimentations begin after 2006 [6]. The effect of process parameter like rotational, welding speed, material position, tool geometry, tool offset etc. on the microstructure formation in the weld zone are reported in many articles. Two types of approaches are used by the authors for studying the influence of rotational and traverse speed. One in which a single parameter is varied with the remaining parameters constant, whereas in other approach both the parameters are varied simultaneously. Xue et al. [7] used the first approach to study the effect of rotational and traverse speed on microstructure. Liu et al. [8] followed the same approach to study welding parameter on the microstructure. Both of them concluded that the material interaction increases with increase in rotational speed keeping the transverse speed constant and decrease in welding speed provided the same conclusion

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https://doi.org/10.1016/j.jmapro.2018.05.035
Received 26 January 2018; Received in revised form 30 May 2018; Accepted 30 May 2018

at a constant rotational speed. Abdollah-Zadeh et al. [9] and Barekatain et al. [10] agreed to same conclusions by performing the experiments in a similar approach. However, discords are found in case of the effect of process parameter on the surface finish of the weld joint among all authors. Higher formation of the brittle intermetallic compound at lower values whereas insufficient material mixing on higher values of welding speeds are observed by Muthu and Jayabalan [11]. The authors like Galvão et al. [12] and Bisadi et al. [13] used the second approach to study the influence of rotational and welding speed on the microstructure. The Galvão used rotational to welding speed (ω/v) ratio to determine the weld quality and found that the material interaction increases with increase in ratio while the Bisadi used ω^2/v ratio to decide that the higher values provide the better surface finish and the best material interaction. The higher heat input values provide better material mixing which occurs at higher rotational and lower welding speed.

Some research articles placed Cu on advancing side and some placed Al on the advancing side. Though the material welding side significantly affects the welding [6], there is no consensus among the authors regarding the material placement. Galvão et al. [14] noticed that healthier welds are obtained by placing Cu on the advancing side. A similar trend is observed by Xue et al. [7] and Liu et al. [8] and found inconsistent weld is obtained by placing Al on the advancing side. In contrary to that, Tan et al. [15], Kahl and Osikowicz [16], and Ouyang et al. [17] obtained sound weld on placing Al on the advancing side.

Tool offset plays a significant role in achieving a proper weld. Many authors obtained a defect-free weld by offsetting the tool on the Al side. However, the amount of offsetting is not fixed; different authors provided different values of offset. Okamura and Aota [18] obtained better surface finish and less defective weld by completely shifting the tool toward the Al side. In good agreement with that, Genevois et al. [19] achieved better surface finishing in joining AA1050 with pure Cu by doing the same. In the above cases, the welding obtained are not considered good as the joining occur by friction stirs diffusion bonding and many discontinuities are found in the microstructure. Avettand-Fenoël et al. [20] concluded that the welding conditions became worse on shifting the tool towards the interface. Similarly, Xue et al. [7] found improvement in surface finish and reduction in brittle intermetallic compounds formation by offsetting the tool on the aluminium side.

For understanding the physics of welding, a huge amount of work is conducted on the numerical models of the process. The effect of tool profile on temperature distribution is studied by Mandal et al. on aluminium alloys [21,22]. However, Mohanty et al. [23] made use of neural network to study the effect of tool geometries on FSW. Further, material flow analysis is also performed using thermally coupled models for aluminium [24]. The study is extended to find the effect of pin profile on material flow [24,25] and found that pin had a significant role in moving the material along the thickness of the plates. All the mentioned articles worked for the similar material simulation, the dissimilar material FSW simulations need more exploration.

The researchers reported many defects in the articles for dissimilar material FSW in identical welding conditions. The insufficient knowledge in this regard led to disagreement among the researchers on right process parameters, tool selection, tool eccentricity and material side selection. Majority of work performed by the researchers is experimental, very small amount of work is done in the numerical simulation fields. Among the numerical simulations articles, the proposed material flow models considered the welding of similar material only. No material flow study is conducted on dissimilar material FSW, thus the study in this area is firmly vital. Therefore, the current study deals with the real-time material flow of Al-Cu FSW. The proposed model used the volume of fluid (VOF) approach for the mixing of two fluids in the commercial finite volume methods (FVM) package ANSYS Fluent 14.5. All the temperature dependent material properties are used in the model. Experiments are conducted to justify the results obtained from the numerical simulations. The material used for conducting the FSW analysis is AA6061 and B370 copper plates. A cylindrical flat shoulder threaded tool is used to conduct the experiments. Furthermore, the effect of tool rotation and welding speed on the material movement are studied.

Fig. 1. Tool used for performing the experiments.

2. Experimental procedure

The commercial aluminium alloy (AA6061) and copper (Cu) B370 plates of 200 mm × 100 mm × 6 mm sizes are used to perform by friction stir butt welding. The copper plates are kept on the retreating side (RS) whereas on advancing side (AS) aluminium alloy plates are placed. The tools are fabricated for the experiments using D3 Tool steel i.e. right helix threaded tool (RHT) with flat cylindrical shoulder with 28 mm shoulder diameter, and cylindrical pin with 6 mm pin diameter, 5.7 mm pin height and 1.1 mm pitch of threads, shown in Fig. 1.

A vertical milling machine of 7.5 HP motor capacities is modified and used as an FSW machine. The edges of the workpieces are grind and cleaned with the methanol thereafter wiped with the clean cloth to remove oxide films, oil and grease before performing the experiments. Tool pins are placed such that it is 2 mm in copper plates and 4 mm in aluminium alloy plates. To prevent the abutting of joint faces, the workpieces are clamped rigidly on a cast iron backing plate as shown in Fig. 2.

3. Finite volume model

The FSW of Aluminum Alloy 6061 and Copper B370 (Cu) plates are performed in a numerical Finite Volume Model. The Aluminum and Cu plates dimensions used in the model is same as the experiments i.e. the length of 200 mm, 100 mm width and a thickness of 6 mm. The dimensions of the tool used in the model remained same as experiment with RHT as shown in Fig. 3. Likewise, the copper plates are kept on the retreating side (RS) whereas on advancing side (AS) aluminium alloy plates are placed with 1 mm eccentricity of the tool towards aluminium side. The tool geometry is introduced as a wall in the plates which are meshed with tetrahedral and brick elements. A finer mesh is provided near the pin region to capture all features of the pin as shown in Fig. 4. The tool is rotated on Z-axis whereas the welding is performed along X-axis in the model. The model used for the analysis is the volume of fluid model (VOF) to determine the material mixing in the weld region.