Effect of tool offset and tilt angle on weld strength of butt joint friction stir welded specimens of AA2024 aluminum alloy welded to commercial pure cupper

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Abstract

The aim of the present work is to investigate the mechanical properties and microstructure of butt joints friction stir welded (FSW) of dissimilar material specimens welded with single pass .The material used is AA2024 aluminum alloy 5 mm thick and pure commercial copper .20 mm Flat shoulder tool 6 mm Pin diameter with a rotational speed of 900 rpm and 25 mm/min feed is used in this work ,the tool is tilted 2^o to the Z axes of the machine. The welded specimens have been tensile tested at room temperature in order to analyze the mechanical properties with respect to the parent metals. The microstructure of the welded specimens has been studied by employing optical microscopy. Micro-hardness examination is also performed on the welded specimens. FSW specimens welded with flat shoulder tool and 2^o tilt angle showed higher ultimate stress than the specimens welded with flat shoulder tool and zero tilt angle . Specimens welded with 1 mm pin offset showed higher strength than the specimens welded with 0.5 and 1.5 mm pin offset.

Keywords: Friction stir welding, subsequent passes , mechanical properties

1.Introduction

Friction stir welding (FSW) is a solid state welding process invented by the Welding Institute in 1991 . It has widely used for welding soft materials such as Al and Mg alloys since then. In FSW the rotating pin is plunged into a rigidly held work piece and traversed along the joint to be welded .Welding is achieved by plastic flow of frictionally heated material from a head of the pin to behind it. Such joining process is demonstrated to avoid severe distortions and the generated residual stresses are proved particularly low, compared to the traditional welding processes (Bussu & Irving 2003, Jata et al. 2000).

welding of copper is usually difficult by conventional fusion welding techniques because of its high thermal diffusivity, which is 10–100 times higher than that of steels and nickel alloys. Hence, the heat input required for welding is much higher, resulting in quite low welding speeds (Andersson et al. 2000).

The FS Welded material produces three different areas: the weld nugget, the thermo-mechanically affected zone and the external heat affected zone. The micro-structural grain structure in the weld nugget is usually very fine and equi-axed, ensuring elevated mechanical strength and ductility (Jata et al. 2000, Charit et al. 2002).The micro-structure in the weld nugget zone to undergo a continuous dynamic recrystallization process leading to elevated mechanical properties (Jata & Semiatin 2000).

Even that the FS Welded specimens show lower proof stress at 0.2% and limited total elongations with respect to the base metals, the mechanical results are extremely good considering the drastic conditions to which the materials are subjected during the Friction Stirring process (Cavaliere et al. 2006). The tensile properties of the welded joints are lower than those of the base materials (Parcellona et Al. 2006, Liu et al. 2003, Liu & Maeda et al. 2003, Liu &Fujii & Maeda 2003).

This advanced technology is capable to weld aluminum alloys difficult to be welded with traditional fusion techniques (the 2xxx series alloys show limited weldability).Dendrite structure occurs in the fusion zone due to conventional TIG and laser welding ,leading to a drastic decrease of the mechanical behavior (Su et al. 2003).The

FSW process is a sold- state process, therefore the solidification micro-structure is absent in the welded metal and the presence of brittle inter- dendritic and eutectic phases is avoided (Rhodes et al. 1997).

In this work the mechanical properties and microstructure of AA2024-Cu butt joints friction stir welded (FSW) specimens welded with 2^o tilt angle 20 mm diameter flat shoulder and 6 mm pin diameter tool ,were investigated.

2.Experimental work

The base metal used in the present work were AA2024 aluminum alloy plate of 5 mm thick in T3 conditions and commercial pure Copper plate 5 mm thick.

The plate was cut and machined into rectangular samples of 100X 150 mm and they were butt welded using HMT milling machine. The longitudinal direction of FSW line was perpendicular to the rolling direction of the plates. HSS tool with pin and flat shoulder diameters of 6 mm and 20 mm respectively was used to achieve the weldment .The tool rotational speed was 900 rpm and 25 mm/min travel speed , according to optimized welding parameters determined so far. The tool axis was tilted by 2^o with respect to Z-axis of milling machine ,see fig. 1 . Pin length was 4.8 mm with multi grooves of 0.5 mm depth .

The experiment was achieved by plunging the pin in the Aluminum plate and then the pin moved toward the copper side until the pin inter the copper, pin offset represents the distance which the pin inter into the copper ,see fig.2.

The parameters which we aimed to study in the present work were ,the tilt angle of the tool and pin offset. The advance and retreat sides were kept at the Aluminum and copper plate respectively.

Two sets of experiments with 0^o and 2^o tilt angles and 1 mm offset were achieved to evaluate the optimum tool setup which gives higher weld strength

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Three other sets of experiments using 2^o tilt angle (the optimum tool setup) and three pin offsets of 0.5 , 1.0 and 1.5 mm were achieved to evaluate the strength of the weldment depending on the pin offset in the copper side.

Tensile test have been executed at room temperature using (Zwick/Roell Z100) testing machine having a load capacity of 100 KN, the axial applied load was perpendicular to the weld line, the specimens having calibrated standard dimensions .

The Vickers hardness profile of the welded zone have been measured 1 mm below the top surface of the tool shoulder in a direction perpendicular to the weld line , using a Vickers indenter with 500gf load for 10 sec.

3.Results and discussion

Friction stir welded specimens welded with 900 rpm pin rotational speed 2^o tilt angle and 25 mm/min feed were tensile tested to evaluate the joint strength. Three specimens were tested for each condition ,the average value for these three tests were recorded. Tensile test results of the base metals used in the present work are listed in table 1.

The tensile test results of the welded specimens are shown in Tables.2,3.

Fig. 3 .Shows the stress strain curves of the welded specimens. It is clear from the tensile test results and that welding with 2^0 tilted tool gives higher strength than welding with 0^o tilt angle . This is due to the additional compression of the tool shoulder which resulting in more heat .This additional compression of tilting the tool can remove any voids or tunnels resulting from the gap existing initially between the welded plates .

The percentage elongation of the welded specimens was too low compared with the elongation of the base metals, this is due to the brittle interface between the welded plates which is resulted from welding dissimilar material with different physical properties.

Welding with 0.5 and 1.5 mm tool offset in the copper side of the welded specimens showed less ultimate tensile strength compared to 1 mm tool offset which recorded an ultimate tensile stress of 248 MPa (88.57% of the copper ultimate tensile strength) . The heat generated when welding with 0.5 mm tool offset was not enough to lowering the yield strength of the cupper to match the yield strength of the aluminum so that the mechanical pond resulting was week, while welding with 1.5 mm tool offset resulting in high temperature which in turn resulting in melting the aluminum plate at the weld interface resulting also in low tensile strength.

The fracture of the welded specimens was brittle and always occur at the weld interface.

Fig.4 . shows the micro-hardness test results for the specimens welded with 1 mm tool offset and 2^{o} tilt angle of the tool. This figure showed that the hardness at the weld interface and 1 mm depth in both copper and aluminum was constant and raised compared to the copper side , while lowered in comparison to the aluminum side.

Fig.5. is a magnified overview of weld interface. It can be seen that many relatively coarse pieces are spread through the aluminum side of the nugget. The copper pieces are well distributed within the nugget .

In fig. 6 . the onion rings were clear it is known that FSW nugget of dissimilar alloys such as Al alloy welded to copper are characterized by complex vortex-like and swirl-like intercalation (Murr et al. 1998, Murr & Li et al. 1998, Ouyang & Kovacevic 2002).

Fig.7.Shows the copper hook in the weld nugget which gives the weld its strength, this hook distributed along the weld line and across the depth of the weld which is resulted from the rotation of the pin.

Conclusions

From the results of the welded specimens of AA2024 aluminum alloy to pure copper the following conclusions were recorded.

1. Welding of AA2024 aluminum alloy to pure copper with 2^{o} tool tilt angle gives higher strength than welding with 0^{o} tool tilt angle.
2. Fracture of the welded specimens is brittle and always occur at the weld interface.
3. The nugget contains large pieces of copper distributed uniformly in addition to the copper hooks.

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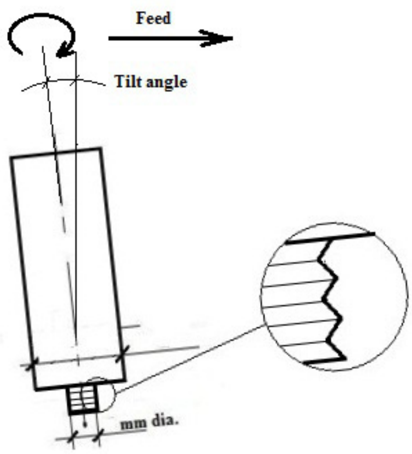

Fig.1. Friction stir welding tool
The tool axis was tilted by 2^o with respect to Z-axis of milling machine

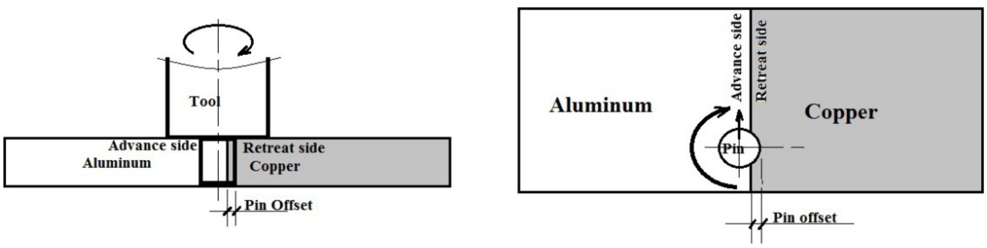

Fig. 2. Pin offset in the copper side
pin offset represents the distance which the pin inter into the copper

Table 1. Mechanical properties of base metals

Mech. Properties / Materials	Ultimate tensile stress (MPa)	Elongation %
Al Base Metal	**482**	**17.2**
Cupper base metal	**280**	**12.2**

Tensile test results of the base metals used in the present work

Table 2..Mechanical properties of the welded specimens welded with 2^o Tool tilt angle

Mech. Properties / Tool offset	Average Ultimate tensile strength MPa	Average % elongation	Tilt angle Deg.
0.5 mm offfset	98.5	0.08	2
1.0 mm offset	248	0.8	2
1.5 mm offset	150	0.17	2

The tensile test results of the welded specimens for different tool offsets.

Table.3.Mechanical properties of the welded specimens welded with 0^o tool tilt angle

Mech. Properties / Tilt angle	Average ultimate tensile strength MPa	Average % elongation	Tool offset (mm)
0^o tilt angle	98.5	0.08	1
2^o tilt angle	248	0.8	1

The tensile test results of the welded specimens for different tilt angles.

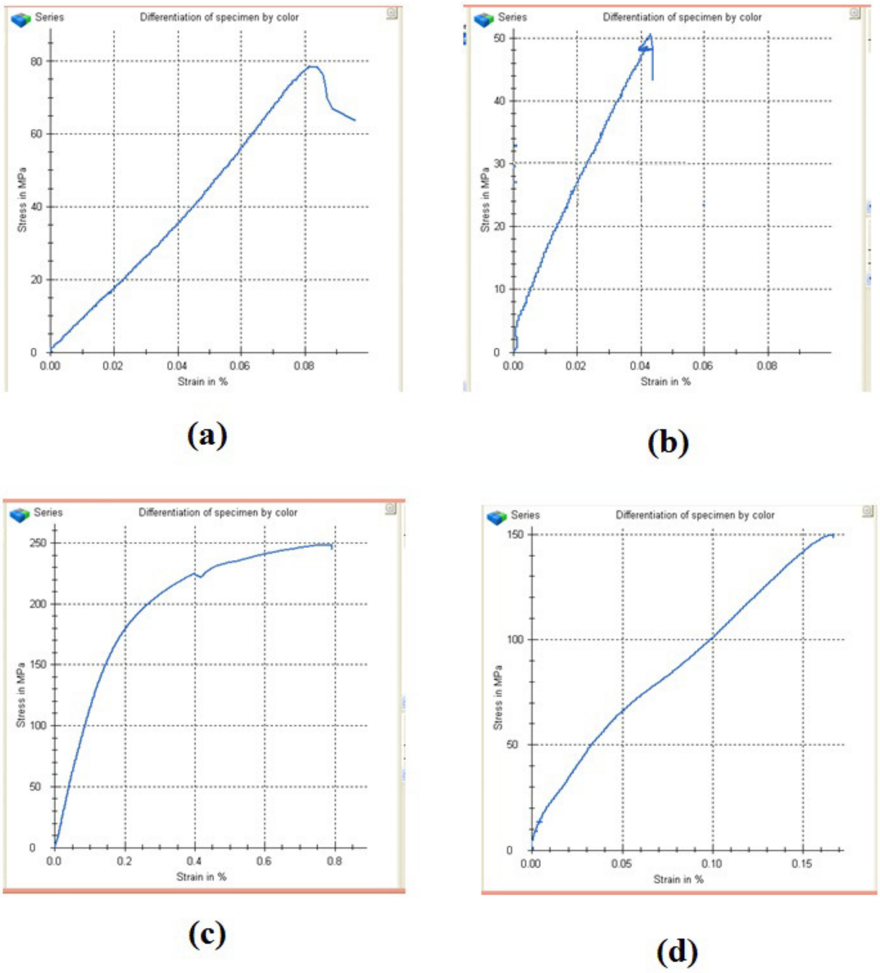

Fig. 3 . Stress strain curves of welded specimens welded with ,(a) 0^{o} tool tilt angle and 1 mm tool offset,(b) 2^{o} tool tilt angle and 0.5 mm tool offset,(c) 2^{o} tool tilt angle and 1 mm tool offset,(d) 2^{o} tool tilt angle and 1.5 mm tool offset.

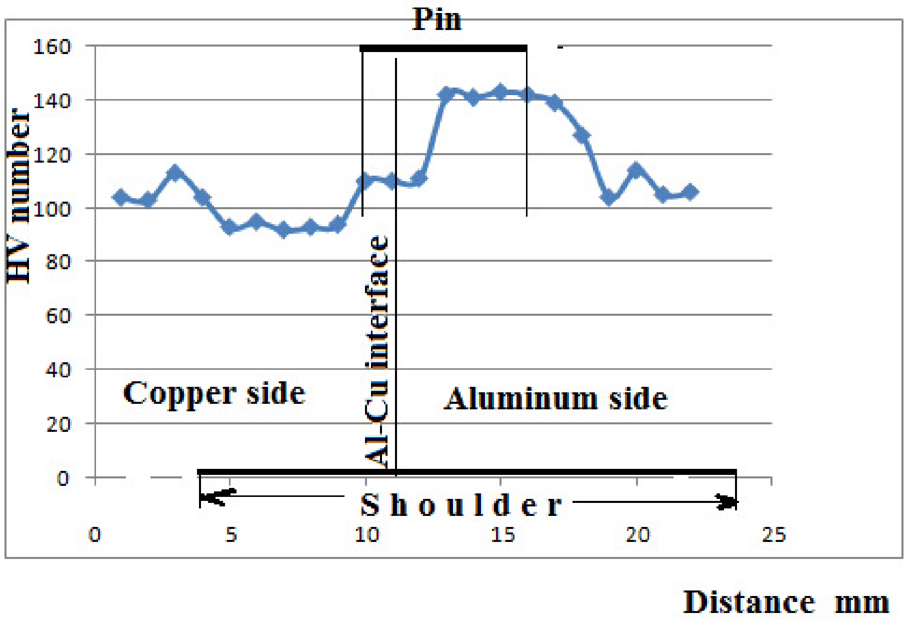

Fig. 4 . Vickers hardness distribution 1 mm from the weld interface

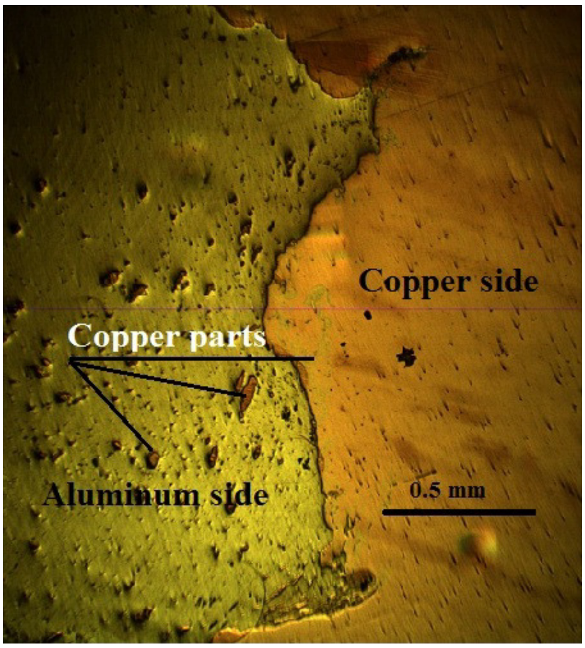

Fig.5.AA2024 aluminum - copper weld interface.

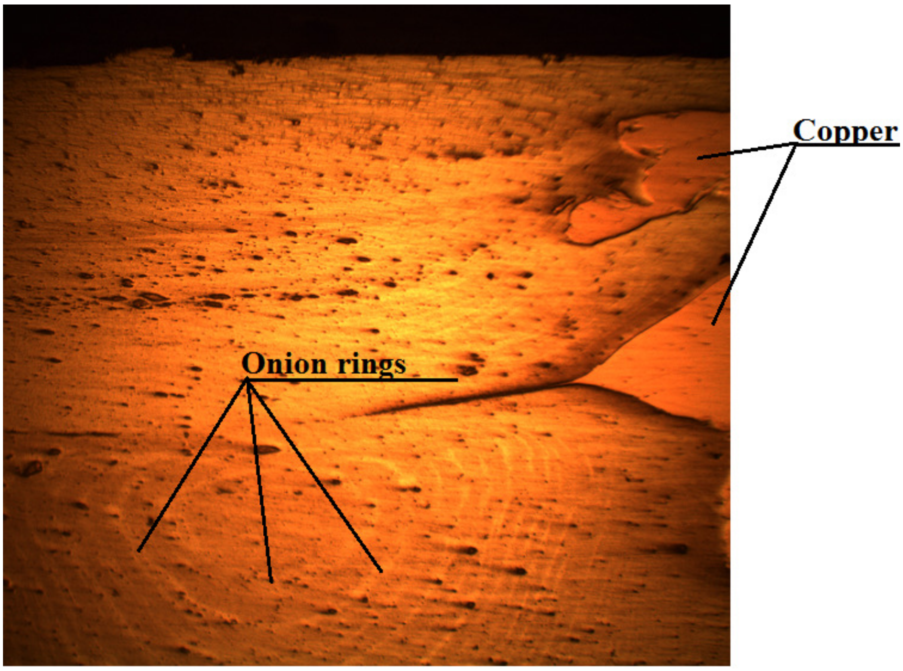

Fig.6. The onion rings in the nugget of the weld

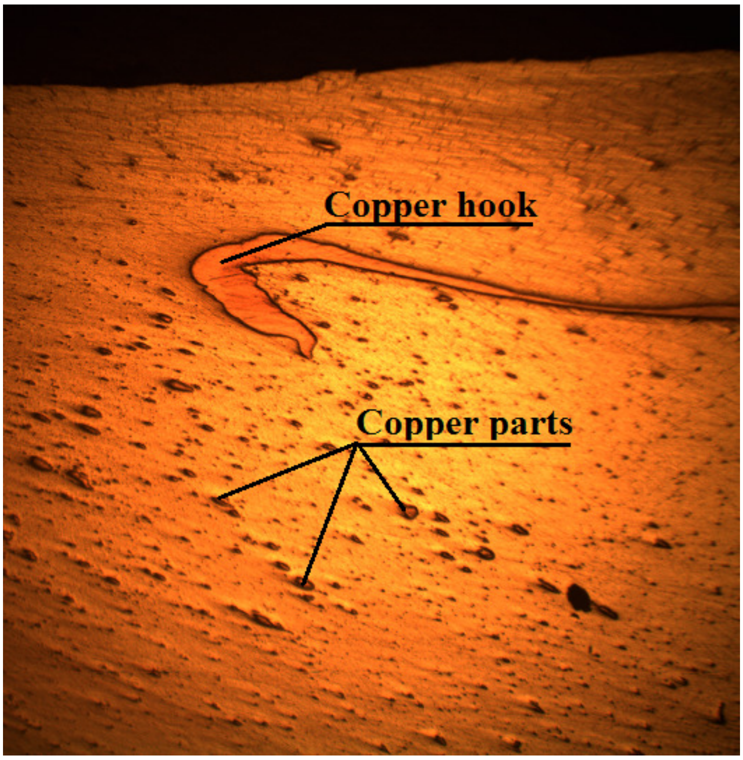

Fig.7. Cooper hook in the weld nugget