Effect of Tool Pin Offset on Mechanical and Metallurgical Properties of Dissimilar FSW Joints of 6061t6 AL Alloy to Copper Material.

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ABSTRACT

In the present investigation effect of tool pin offset on mechanical and metallurgical properties of dissimilar FSW joints of 6061T6 Al alloy and Copper material was studied. Keeping other FSW variables constant, tool pin offset was varied from 1mm, 2mm and 3mm.The plunge load value decreases with increase in tool pin offset, because of the tool pin is immersed into soft material (Al), while at lower pin offset the plunge load increased.

Tensile Strength (TS) values decreases with increase the tool pin offset. Poor tensile properties were obtained at the very large pin offsets, due to the insufficient reaction between the Cu and Al material. Sufficient reaction was achieved in the FSW Al–Cu joints produced at pin offsets of 1mm and 2mm, resulting in the good tensile properties.

The distribution, amount and size of Cu particles strongly depend on tool pin offset. It is observed that content of dispersed particles decreases at larger tool pin offset. When the pin offset was larger, only few Cu pieces with relatively small size were scratched from the Cu bulk. It was easy for the small Cu pieces to mix into the Al base and react with the Al base in the nugget zone, and therefore no proper mixing of Cu with Al matrix. On the other hand, when the pin offset was smaller, more Al–Cu IMCs would be formed because the more Cu pieces were stirred into the nugget zone. Thus the joining between the Al and Cu became poor due to the brittle nature of the IMCs. Research investigation also highlights the fracture location at different tool pin offsets.

Keywords: 1 Friction stirs welding, 2. Aluminum–Copper dissimilar materials, 3. Process parameters, 4. Welding tool, 5. Butt joint.

INTRODUCTION

Friction stir welding (FSW) is a new solid-state joining technique invented at The Welding Institute (TWI) (Cambridge, United Kingdom) in 1991. [1,2] The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of plates, to be joined and then traversed along the line of joint when the shoulder touches the plates (**Fig. 1**). The tool heats the workpieces and moves the material to produce the joint. The heating is achieved by the friction between the tool and workpieces and by the plastic deformation of the material. Localized heating softens the material around the pin and the combination of tool rotation and translation results in the movement of material from the front to the back of the pin. Thus, a welded joint is produced in solid state.

The joints of dissimilar materials are widely used in industrial applications due to their technical and beneficial advantages. Aluminium and copper are two common metals in the electric power industry, and the Al–Cu transition pieces are widely used to transmit the electricity [3]. However, fusion welding of Al alloys to Cu always gives rise to residual stress, cracking and plenty of brittle intermetallic compounds (IMCs) in the weld, so it is seldom used in practice [4].

However, the dissimilar combination of aluminium and copper is generally difficult for fusion welding. This is because of the wide difference in their physical, chemical and mechanical properties, and the tendency to form brittle intermetallic compounds (IMCs). Therefore, the solid-state joining methods, such as friction welding, roll welding, and explosive welding have received much attention [2–4]. These methods, however, have a few drawbacks. Fox example, friction welding and roll welding lack versatility, and explosive welding involves in the safety problems.

In the past decade, much attention has been directed towards friction stir welding (FSW) [2]. Recently, attempts have been made to join dissimilar materials through FSW, such as aluminum to steel and aluminum to copper [3-5]. Since the first paper released by Murr et. al. [6] in 1998, however, sounds welds, i.e. continuous and defect free welds have not been achieved. It was reported that sound dissimilar FSW Al–Cu joints were difficult to achieve, and the joints usually failed at the nugget zone or along the interface between the two materials during the mechanical tests [6-8]. Ouyang et al. [7] attributed the poor weld ability to the various brittle IMCs formed in the nugget zone. Lee and Jung [8] suggested that

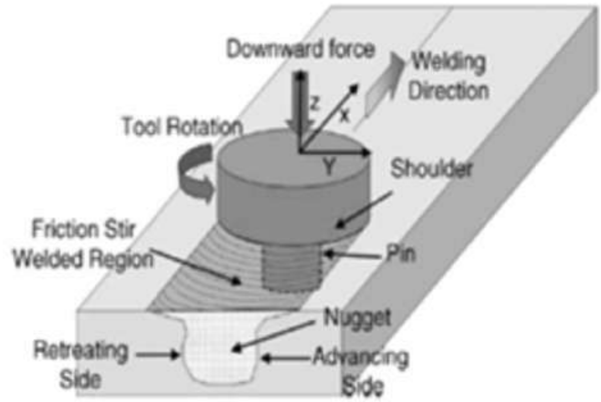


Fig.1 : Schematic drawing of FSW [2]

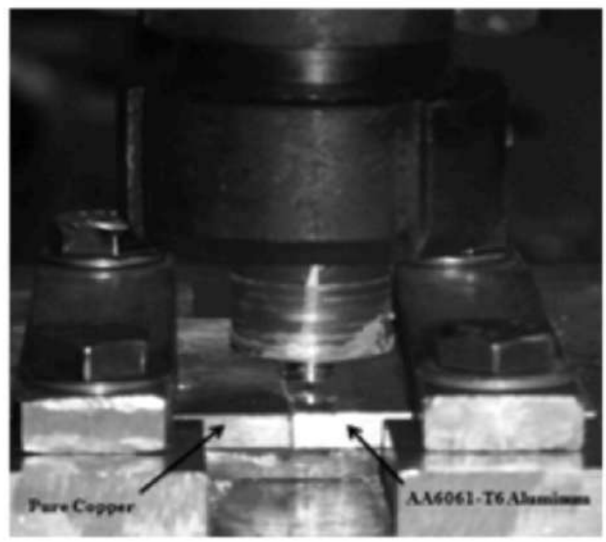


Fig. 2 : Dissimilar frictions stir welding

the formation a thick IMC layer would increase the brittleness of the interface, leading to easier crack initiation and lower tensile strength.

In this paper, sound FSW Al–Cu joints were successfully achieved by offsetting the tool to the aluminum side and controlling the FSW parameters. The purpose of this study is to elucidate the correlation between the offsetting the tool and vertical load.

EXPERIMENTAL PROCEDURE

This experiment uses the AA6061-T6 aluminium alloy plates, available in the market, with a thickness of 6.5 mm, and sections cut to a length of 100 mm by the width 50 mm. Aluminium alloy AA6061-T6 has an ultimate tensile strength with a maximum of 290MPa. Pure Copper plates with a thickness of 6.5 mm, and an ultimate tensile strength of about

230 MPa. Two kinds of base metals, which are aluminium alloy AA6061-T6 and Pure Copper, are both milled to form smooth and flat surfaces for FSW processing specimens.

In this experiment, the material of the FSW tool is made of tool Steel. The tool has a shoulder diameter of 26mm, with the cylindrical pin of 6.3mm with left hand threads of 8mm in diameter. The Pure Copper is placed in the advancing side. The tool rotation is of clockwise direction. Tool tilt angle is tilting backward two degrees. Welds were made with a counter clock-wisely rotating pin at rotation rates of 2000rpm and a constant traverse speed of 40mm/min. With vary the pin offset from 1mm to 3mm. The worktable moves in the X-axis direction and the work pieces are welded. The work pieces clamped for the FSW processes and the FSW dissimilar metals joints are as shown in **Fig. 2.**

RESULTS AND DISCUSSION

The effect pin offset in the surface morphology

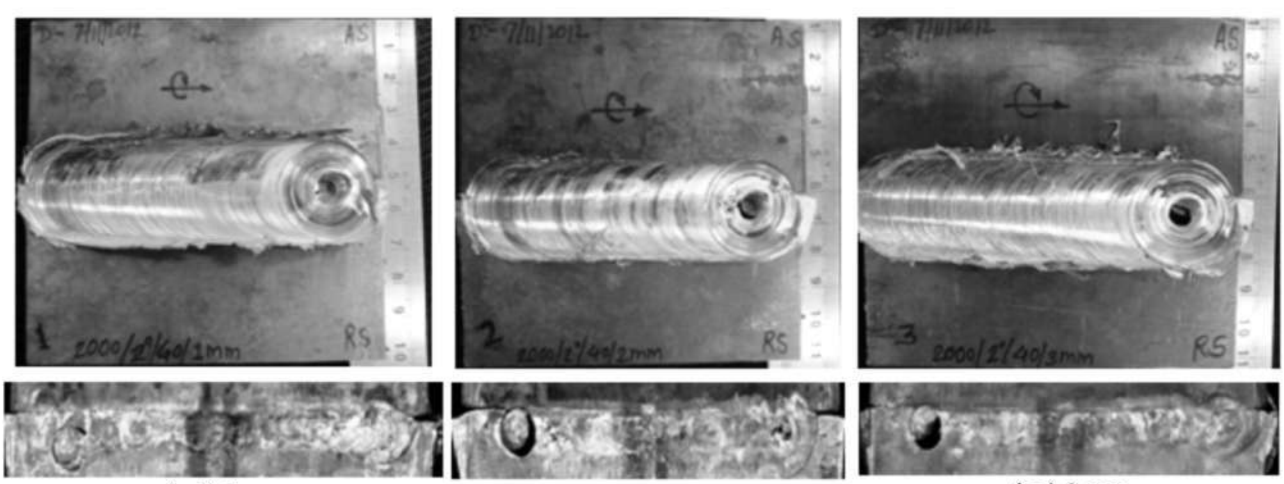
Since the melting point, density and hardness of copper are higher than those of aluminum, aluminum should have better plastic flowability at the same processing temperature. By plunging the stir pin into the aluminum side, Al−Cu dissimilar joint can be formed with abundant material supply during FSW.The surface of the joint is covered by a layer of aluminum alloy and some small flash can be found at the edge of the joint. Amount of the flash forming is increases with increase in the tool pin offset and coz of flash there is reduction in thickness of the plates at joint area. Tool pin offset 1mm and 2mm is better than 3 mm.

Fig. 3 shows the welding surface morphologies at different pin offsets. **Figs. 3 (a), (b)** and **(c)** shows the dissimilar welds front and root side of the joint.

THE EFFECT OF PIN OFFSET ON THE PLUNGE LOAD

FSW is ordinarily conducted through inserting the rotating pin in the weld line of butted plates. In dissimilar FSW, some researchers use pin offset technique to activate the faying surface, avoid intermetallic compounds formation and decrease tool wear. Pin offset means the rotating pin is not inserted into the exact centerline of the abutting edge of the two plates, but around a position some distance away from the faying surface [3, 9]. XUE et al [3] reported that sound Cu−1060 Al dissimilar joints could be produced through pin offset technique. Bonding mechanism between the dissimilar components is strongly dependent on the material flow in dissimilar FSW with pin offset, which is not fully understood up to now.

We chose various pin offsets in this study to investigate the optimum value of the pin offset under a welding parameter of 2000rpm – 40 mm/min. The surface morphologies of the FSW Al–Cu joints for different pin offsets are 1-3 mm shown in **Fig. 3** (a-c). Three preliminary experiments are conducted to determine the appropriate offset of the probe to the butt line. One experiment was performed when the tool probe was entirely immersed into aluminum, the offset 3 mm; the second experiment was conducted 2 mm offset and the third, offset 1 mm of probe to the butt line, as shown in **Fig. 4**.



(a) 1 mm (b) 2 mm (c) 3 mm

Fig. 3 : Surface morphologies of dissimilar joints at 2000rpm – 40mm/min and different offset

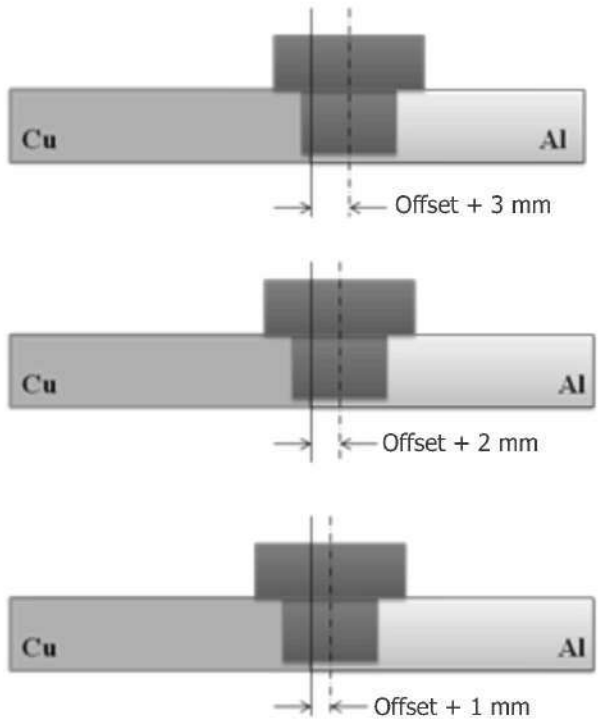


Fig. 4 : Tool Pin offset

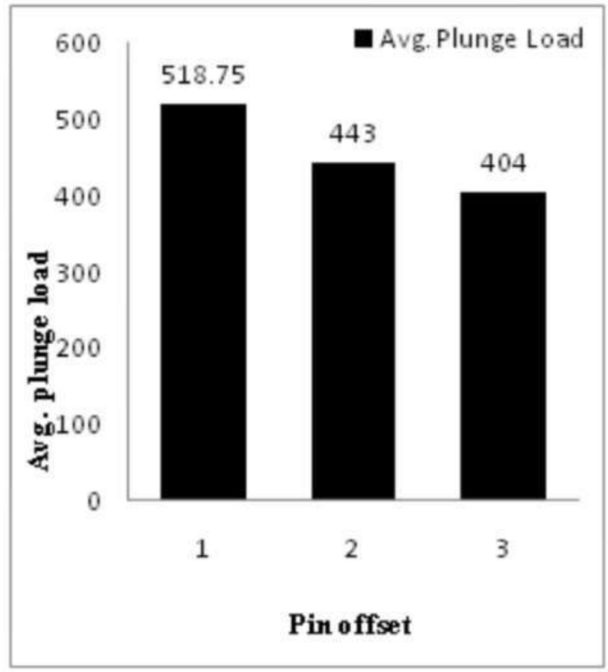


Fig. 5 : Pin offset Vs Avg. Plunge load

In FSW of dissimilar materials, the pin offset was an important parameter influencing the weld quality. The effect of pin offset is also shown on the plunge load, when the pin offset was larger the plunge load is decrease, because of the tool pin is immersed into soft material but the pin offset is smaller the plunge load is increases. This can be observed from results of tool pin offset and plunge load as shown in **Fig. 5**.

THE EFFECT OF PIN OFFSET ON THE MECHANICAL PROPERTIES OF THE JOINTS

Standard test specimens were generated for the tensile testing. These samples were designed and manufactured to conform to ASME (section IX) standards with a sample size of 100x10x6.5 mm. All samples were produced with minimal defects and conformed to specified dimensions with a tolerance of 0.2mm. The test was carried out at rate of loading 3 mm/min with test procedure IS 1608- 2005.

Tensile Strength (TS) values decrease with increase the tool pin offset shown in **Fig.6**. Poor tensile properties were obtained at the very large pin offsets and/or low rotation rates due to the insufficient reaction between the Cu bulk/pieces and Al matrix [3]. Sufficient reaction were achieved in the FSW Al–Cu joints produced at higher rotation rates and proper pin offsets of 1mm and 2mm, resulting in the good tensile properties.

Minor variation in tensile strength and joint efficiency is observed with increase in tool pin offset from 1mm to 2mm. But **Fig. 7** shows the maximum % of elongation is 3.9% at 2mm pin offset. All tensile samples fractured at stir zone as show in **Fig. 9**. Table II shows second tensile sample joints produced with a pin offset of 2mm fractured at the TMAZ on Al side so the %EL is 20%.

THE EFFECT OF PIN OFFSET ON THE MICRO-STRUCTURE OF THE JOINTS

When the pin offset was larger, only few Cu pieces with relatively small size were scratched from the Cu bulk. It was easy for the small Cu pieces to mix into the Al base and react with the Al base in the nugget zone, and therefore no proper mixing of cu with Al matrix. On the other hand, when the pin offset was smaller, more Al–Cu IMCs would be formed because the more Cu pieces were stirred into the nugget zone. Thus the joining between the Al and Cu became poor due to the brittle nature of the IMCs [3]. It is also observed that different microstructures observed in nugget (i.e. from Top to Root). **Fig. 9**. shows the microstructure of the nugget at top and root side. Root side microstructure shows that grains were small compare to grains at Top side of microstructure.

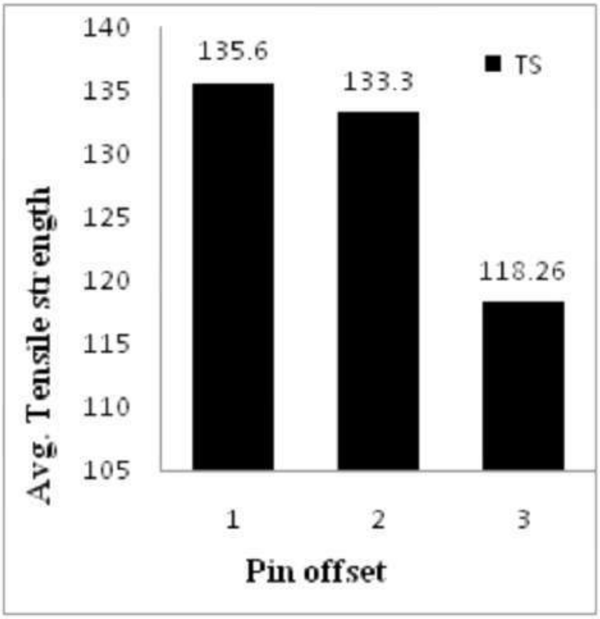


Fig. 6 : Pin offset v/s Avg. tensile strength

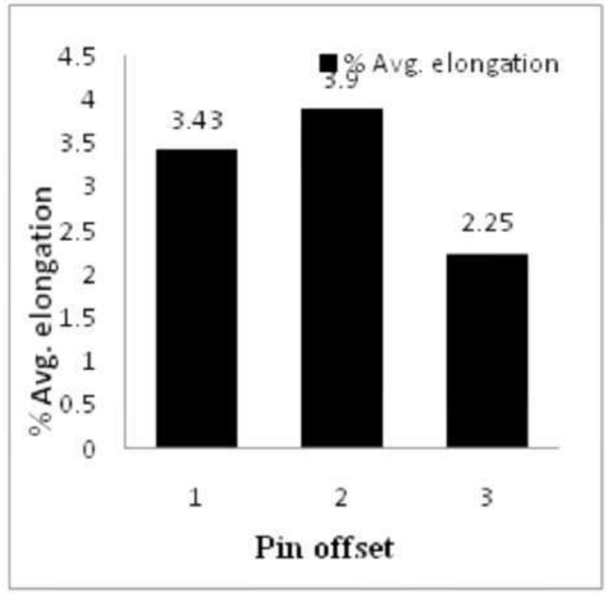


Fig. 7 : Pin offset v/s % Avg. Elongation

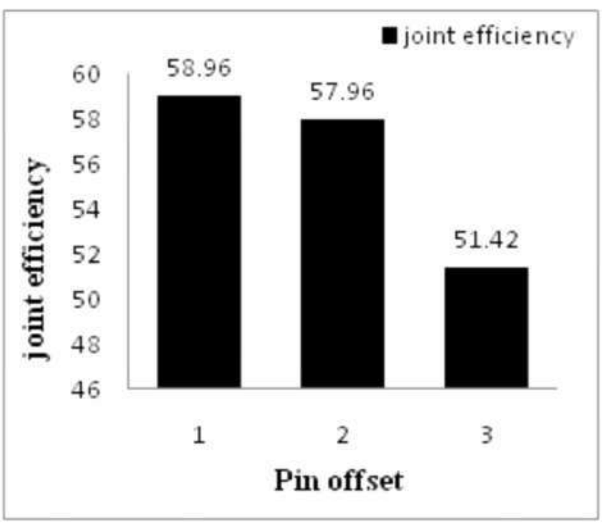


Fig. 8 : Pin offset v/s Joint efficiency (With ref to Copper)

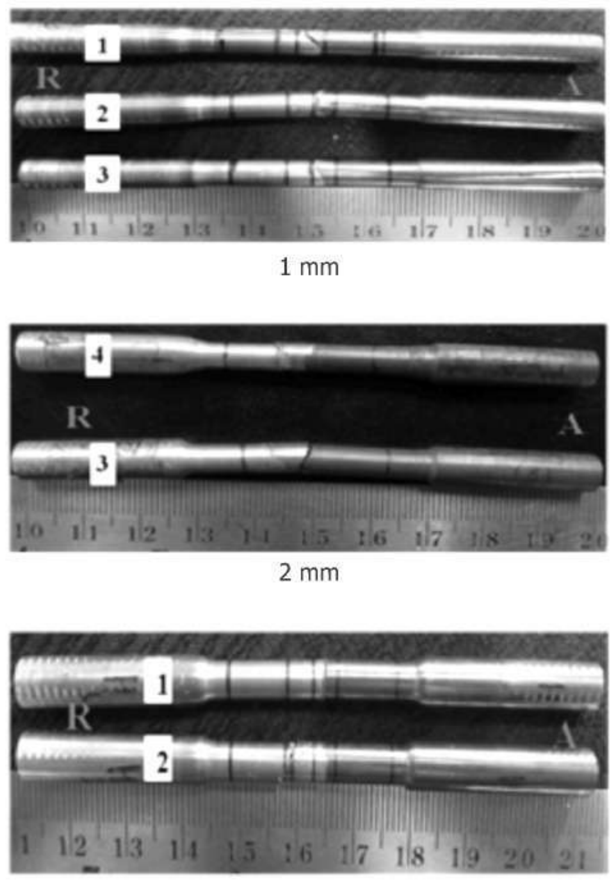
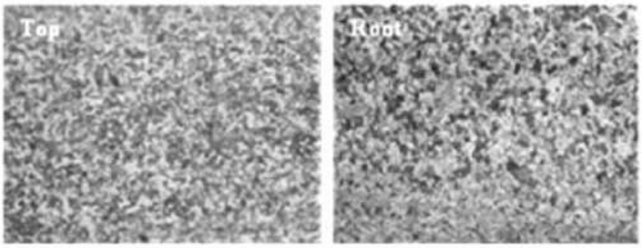


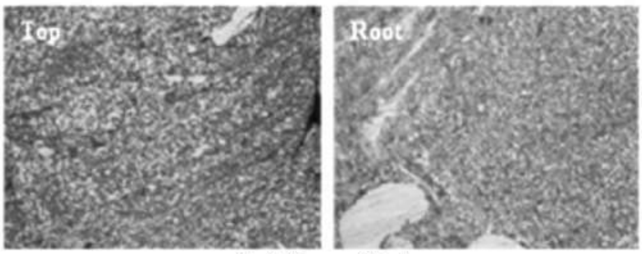
Fig. 9 : Fractured locations of tensile samples at different offset value

The distribution, amount and size of Cu particles strongly depend on tool pin offset. It is observed that content of dispersed particles decreases at increase the tool pin offset. It is also reported that as tool pin offset changes from1mm to 3mm; the grain size at the nugget also changes. Small grains/ Cu particles are observed at 3mm compare to 1mm.

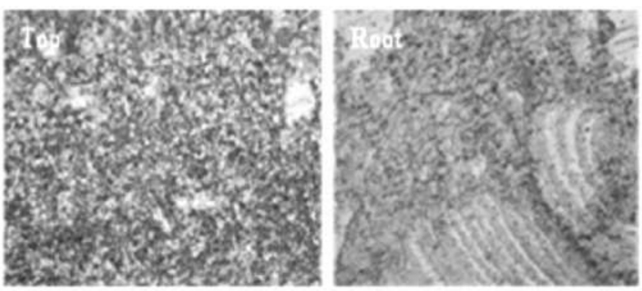
Fig. 9 (c) the pin offset is 3mm is too large in both the modes only few Cu pieces with relatively small size were scratched from the Cu bulk. It was easy for the small Cu pieces to mix into the Al base and react with the Al base in the nugget zone, and therefore sound metallurgical bonding would be obtained at



(a) 1mm offset



(b) 2mm offset



(c) 3mm offset

Fig. 9 : Microstructure of Al-Cu in different pin offset

the Al–Cu interface. In other hand **fig.9 (a**) the pin offset is 1mm many large Cu pieces were stirred into the nugget zone at a smaller pin offset. The Cu pieces were harder than the Al matrix, therefore, the large Cu pieces were hard to deform and flow in the Al matrix, and the mixing between the large Cu pieces and the Al matrix would be very difficult [3]. But in **fig. 9 (b)** the pin offset is 2mm the mixing of Cu pieces in Al matrix is proportionate. So that joint strength is moderate.

COMPARISON OF VHN VALUE AT DIFFERENT OFFSET

The standard specimens were prepared for measurement of the Vickers hardness number. Measurements were carried out across the weld section at 500g load, 10 dwell time. Each indentation is separated by 3mm. specimens prepared for microstructure observations were utilized for VHN measurement. Micro hardness profiles in the mid-thickness of dissimilar joints.

VHN value is higher under nugget zone (pin region), compared to TMAZ (shoulder region) VHN value decreases with increases the tool pin offset.

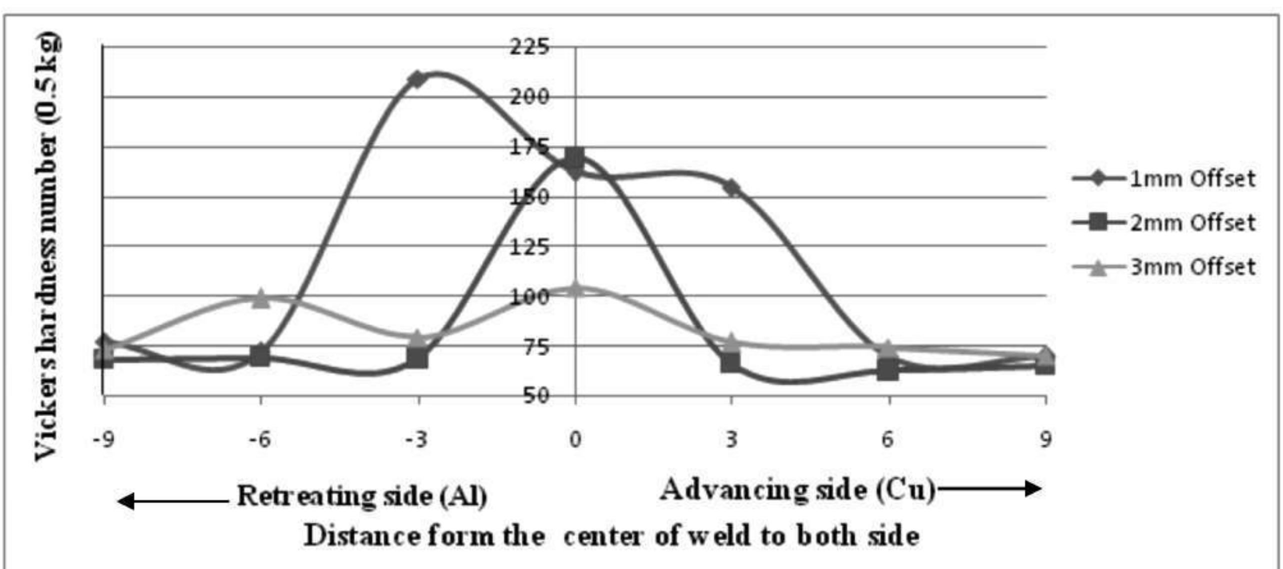


Fig: 10: Effect of Tool Pin Offset on Vickers Hardness Number

CONCLUSIONS

Optimum too pin offset is most important variables to control the quality of the weld including surface morphology and flash.

As pin offset value increases the average plunge load value decreases. As pin offset increases the pin would be more at aluminum side (i.e. at softer material), which requires less load for stirring and mixing as compared to contact the contact with copper.

Poor tensile properties were obtained at the very large pin offsets due to the insufficient reaction between the Cu bulk/pieces and Al matrix. Sufficient reaction were achieved in the FSW Al–Cu joints produced at higher rotation rates and proper pin offsets of 1to2mm, resulting in the good tensile properties.

Microstructure stir zone consists of composite structure with variously sized particles dispersed in the Al matrix. The distribution, amount and size of Cu particles strongly depend on tool pin offset.

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