Experimental Investigation of Process Parameters on Defects Generation in Copper to AA6061-T651 Friction Stir Welding

Kush P. Mehta[1*], and Vishvesh J. Badheka[2]

***Abstract*—** Dissimilar materials copper and aluminum joining is difficult to achieve by friction stir welding due to the enormous difference of their thermo-physical performances. Present investigation provides a study on friction stir welding defects under different process parameters of dissimilar copper-aluminum system. Effect of tool design, tool pin offset, welding speed and tilt angle on defects formation studied experimentally. Visual observations and macrostructure examinations were performed to study the different defects for dissimilar copper-aluminum friction stir welding system. Voids, pores, cracks, surface lines and flash effects were observed due to inappropriate parameters of friction stir welding. Tool pin profile, shoulder diameter, tool pin offset, welding speed and tilt angle affect the quality of dissimilar copper-aluminum friction stir welding.

***Keywords*—** Aluminum, copper, defects, dissimilar, friction stir welding, process parameters

I. Introduction

FRICTION stir welding (FSW) is a solid state process invented by W. M. Thomas in 1991 for aluminum and its alloys [1]. Specially designed non-consumable rotating tool (consists of shoulder and pin) rotated and inserted into the workpiece surfaces and travelled along the transverse direction which deforms material plastically. The movement of this deformed material around the tool pin occurs as the tool moves which lead it to joint [1]. FSW avoids solidification defects like porosity and hot cracking because of solid state nature. However, FSW defects like voids, tunnel, flash out, oxide entrapment, lack of fill etc. are commonly reported under similar material system because of inappropriate parameters [2].

Joining of dissimilar materials is feasible by FSW due to process falls under solid state classification [3]. Copper (Cu) and aluminum (Al) are difficult to join together even by conventional FSW parameters because of the enormous difference of their thermo-physical performances [4]. Tool pin offset [5, 6], material position [7], tool design [8], rotational tool speed [9] and tool travel speed [9, 10] are the process parameters which affect the quality of dissimilar Cu-Al FSW [11-13]. Limited articles are available in the area of FSW defects especially for dissimilar Cu-Al system.

In the present study, the experimental investigations were carried out to elucidate the FSW defects under different process parameters like tool designs (especially tool pin profiles), tool pin offsets, rotational speeds, welding speeds and tool tilt angles for dissimilar Cu-Al FSW joint.

II. Experimental procedure

Dissimilar materials such as AA6061-T651 and electrolytic tough pitch Cu of 6.3 mm thickness were used in present investigation. Heat treated tool steel (M2 grade) was utilized as a tool material. The experiments were carried out on FSW setup that was developed under the sponsored project NFP/MAT/A 10/04 Institute for Plasma Research (IPR). Experiments were carried out under different process parameters such as different tool designs (Tool design: 1 – Fig. 1 and Tool design: 2 – Fig. 2), tool pin offsets (1, 2 and 3 mm), welding speeds (40, 55, 70, 95 mm/min) and tool tilt angles (0˚, 1˚, 2˚, 3˚, 4˚). All the experiments were carried out by keeping Cu at advancing side and Al at retreating side. After the welding, the test coupons were subjected to visual inspection and macro examination to evaluate the quality of welds. Visual examination was carried out from front and back side of welded specimens. Macro examinations were carried out after mechanical grinding and polishing on different grit papers.

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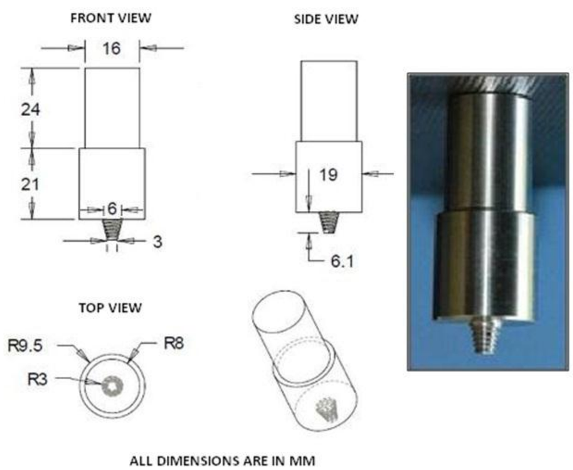

Fig. 1 Tool design: 1 (taper pin profile)

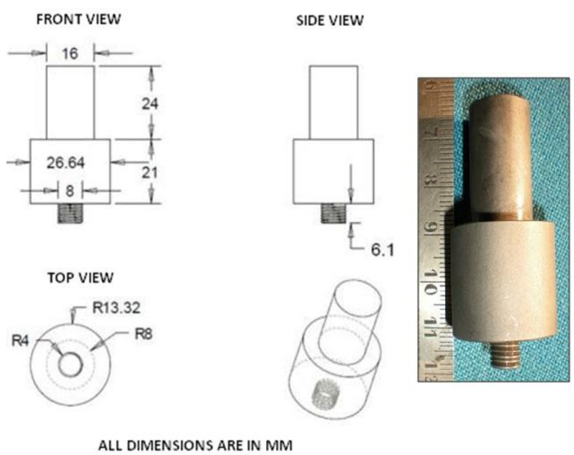

Fig. 2 Tool design: 2 (cylindrical pin profile)

III. RESULTS AND DISCUSSION

Results of visual examination of welded coupons by tool design: 1 for different tool pin offsets 1, 2 and 3 mm are shown in Fig. 3 wherein rest of the parameters were kept constant (such as rotational speed of 1500 rpm, welding speed of 40 mm/min and tilt angle of 0˚). Surface lines were observed on the front surface of sample welded under tool pin offset of 2 mm as shown in Fig. 3 (b). Lack of fill was observed throughout the length on the front surface of sample in the weld made by tool pin offset of 3 mm, which was looked like surface tunnel as indicated in Fig. 3 (c). Besides this, the defects free surfaces were noticed on the sample of pin offset: 1 mm [refer Fig. 3 (a)]. Hence, it can be interpreted that as pin offset increases the surface defects also increases which may be because of lack of heat input. The diameter of the shoulder may be the reason for the lack of heat input as the other parameters were kept constant. Additionally, it was proven that, the shoulder diameter provides maximum heat by friction in FSW technology [1, 11]. Increase in pin offset have displaced of the tool more towards aluminum material that may have produced less frictional heat at the joint interface. Cross sectional view of welded specimens produced by tool design: 1 for different pin offsets such as 1, 2 and 3 mm are shown in Fig. 4. Big voids were observed at root in the samples of pin offsets 1 and 2 mm as shown in Fig. 4 (a) and (b) respectively, while there were no joint formation found at all from root side for pin offset of 3 mm as shown in Fig. 4 (c). The reasons behind void formation in FSW are either low heat input or low axial pressure of tool or both [1, 2, 13]. Here, in dissimilar Cu-Al FSW system, the void formation was improper mixing of large Cu particles and Al matrix. Furthermore, the tool shoulder diameter was relatively smaller than required for FSW of Cu which generates less heat at Cu side. Additionally, taper tool pin profile may have not allowed a uniform scratching of Cu particles that leaded to the formation of pores at the root side in samples of pin offsets 1 mm and 2 mm. Moreover, there were no joining at all found in the sample made by offset 3 mm wherein the root area of tool pin remain totally in aluminum because of comparatively large pin offset.

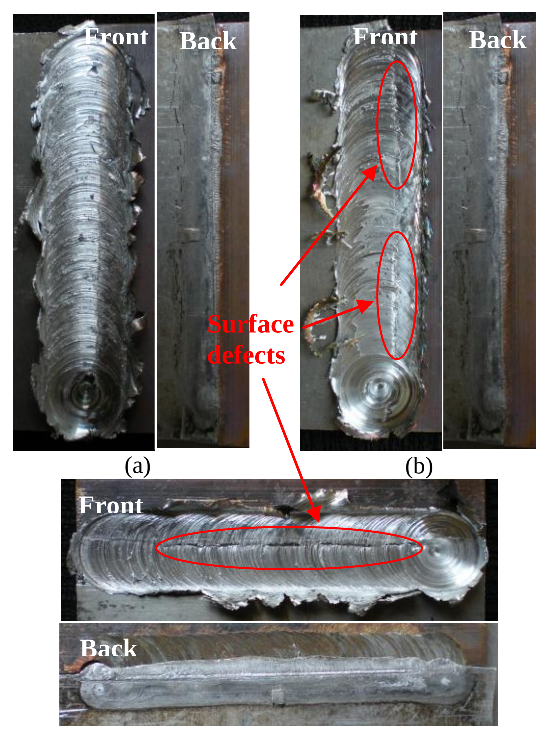

Fig. 3: Visual examination of specimens welded under tool design: 1 for tool pin offsets (a) 1 mm, (b) 2 mm and (c) 3 mm

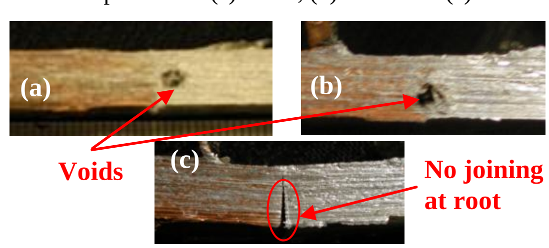

Fig. 4: Cross sectional view of specimens welded under tool design: 1 for tool pin offsets (a) 1 mm, (b) 2 mm and (c) 3 mm

Results of welded coupons under different welding speeds 40, 55, 70, 95 mm/min by tool design: 2 are shown in Fig. 5 wherein other FSW parameters were kept constant (such as rotational speed at 1500 rpm, tool pin offset of 2 mm and tilt angle of 2˚). Surface defects (especially lines) were noticed on the front surface of specimens welded by 55, 70 and 95 mm/min as shown in Fig. 5 (b), (c) and (d). Probable reason was heat input [2, 11-13]. Increase in welding speed leads to decrease in heat input that generally cause surface defects. Here, the shoulder diameter was increased as shown in Fig. 2 relative to previous tool design: 1 (see Fig. 1). Therefore, it can be interpreted that, the shoulder diameter was not responsible for lower heat input in previous set of experiment.

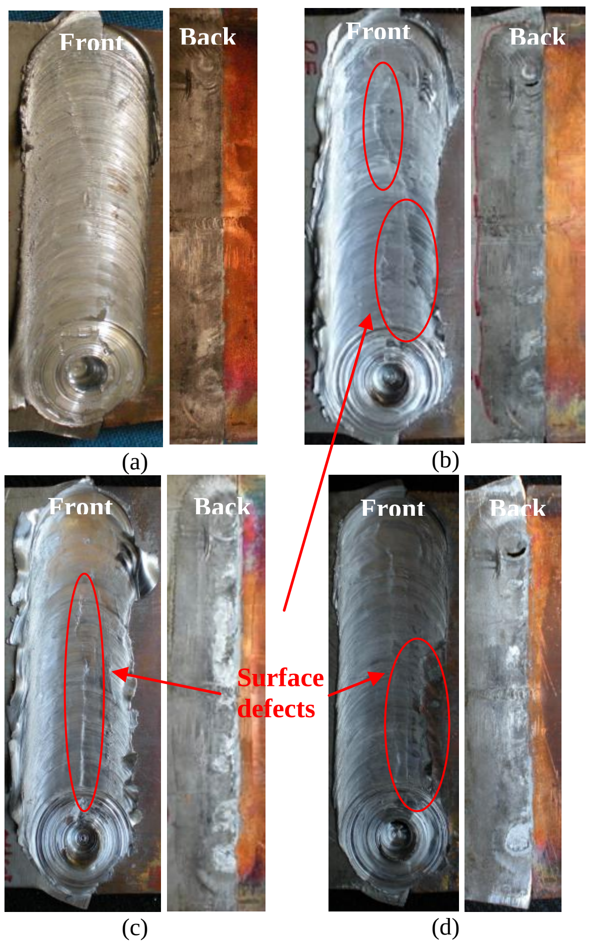

Fig. 5: Visual examination of specimens welded under tool design: 2 for welding speeds (a) 40, (b) 55, (c) 70 and (d) 95 mm/min

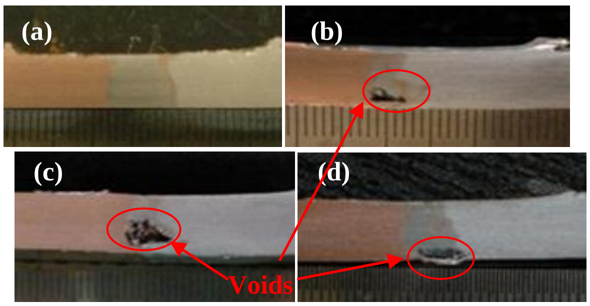

Fig. 6: Macrostructure examination of specimens welded under tool design: 2 for welding speeds (a) 40, (b) 55, (c) 70 and (d) 95 mm/min

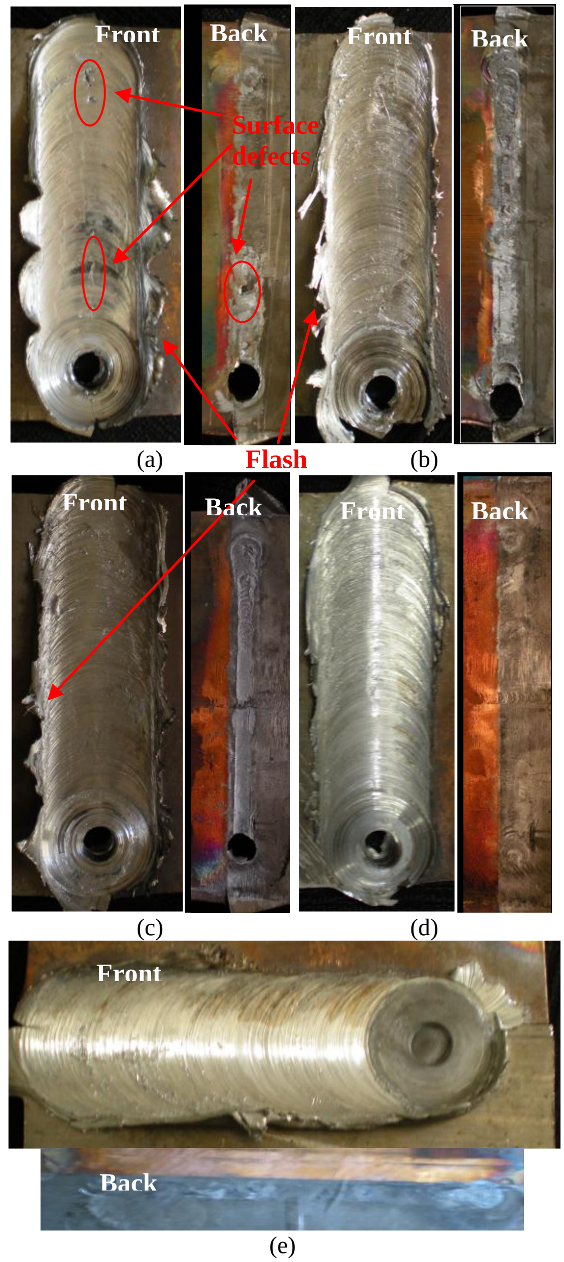

Fig. 7: Visual examination of specimens welded under tool design: 2 for tilt angles (a) 0˚, (b) 1˚, (c) 2˚, (d) 3˚ and (e) 4˚

Macrostructure results of specimens produced from tool design: 2 for different welding speeds 40, 55, 70 and 95 mm/min are shown in Fig. 6. Defect free sound joint was noticed at welding speed of 40 mm/min while defects (voids) were observed at 55, 70 and 95 mm/min. The lower heat was produced because of higher welding speed and that was the prominent reason behind generation of these voids. Less heat may have affected the material flow inside the stir zone and that could not allow proper mixing of Cu particles with the Al matrix. Therefore, this improper material flow may have resulted in voids. Improved mixing of Cu and Al was achieved at 40 mm/min because it has provided appropriate enough heat to improve metallurgical bonding of both materials. Such low welding speed may have given sufficient time for softening and deformation which have sated easiness for Cu particles to flow easy in Al matrix and subsequently resulted in defect free joint.

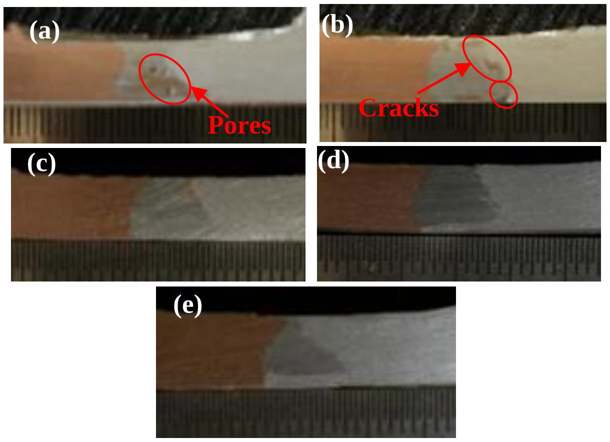

Fig. 8 Macrostructure examination of specimens welded under tool design: 2 for tilt angles (a) 0˚, (b) 1˚, (c) 2˚, (d) 3˚ and (e) 4˚

Results of welded coupons from tool design: 2 for different tool tilt angles (a) 0˚, (b) 1˚, (c) 2˚, (d) 3˚ and (e) 4˚ are shown in Fig. 7 wherein other parameters were kept constant (such as rotational speed at 1500 rpm, welding speed of 40 mm/min and tool pin offset of 2 mm). Flash effect was observed maximum in the sample of 0˚ tilt angle as shown in Fig. 7 (a) and it was found minimum at a 4˚ tilt angle as shown in Fig. 7 (e). Surface pores were observed on the front and back side of sample welded at 0˚. These defects were noticed due to lower axial plunge load and higher flash effect. Higher tilt angle may have helped deformed material to forge downward and fill the surface pores.

Macrostructure results of specimens produced by tool design: 2 for different tool tilt angles (a) 0˚, (b) 1˚, (c) 2˚, (d) 3˚ and (e) 4˚ are shown in Fig. 8 wherein other parameters were kept constant. Small pores were noticed in the nugget of sample welded at 0˚ because of the lower forging force while minor cracks were observed in nugget due to improper mixing of Cu particles in Al matrix. Defect free macrostructures were noticed for samples welded at tilt angles 2˚, 3˚ and 4˚ because of improved material flow [12].

IV. Conclusions

FSW defects for dissimilar Cu-Al system investigated under different process parameters. Following conclusions can be made from present investigation.

- Taper tool pin profile generates large voids at root side.
- Tunnel defect was noticed at larger tool pin offset with small shoulder diameter.
- Small shoulder diameter and higher welding speed results in surface line at joint area.
- Pores were observed at lower tilt angles on front surface as well as inside the joint.
- Flash effect reduces as tilt angle increases.

Acknowledgment

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