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EFFECT OF GROOVE SIZE ON MECHANICAL PROPERTIES AND MICROSTRUCTURE DUE TO REINFORCEMENT ADDITION IN FRICTION STIR WELDED DISSIMILAR ALLOYS

Ravinder Reddy Baridula[1], Ramgopal Varma Ramaraju[2], Che Ku Mohammad Faizal Bin Che Ku Yahya[1] and Abdullah Bin Ibrahim[1]

[1]Faculty of Engineering Technology, Department of Manufacturing Engineering Technology, University Malaysia Pahang, Gambang, Malaysia

[2]Faculty of Technology, Department of Mechanical Engineering, Stanford International College of Business and Technology, Toronto, Canada

Email: baridula@gmail.com

ABSTRACT

Friction stir welding is a solid state joining technique, which improves the strength of the welded joint when compared to the fusion welding process. The strength of the welded joint can be further enhanced by the addition of reinforcements into the metal matrix during friction stir welding. In the present research, the dissimilar aluminium alloys AA5052 and AA6063 were welded by varying the groove size in order to estimate the strength of the joint due to reinforcements. The results show that varying the groove size influences the mechanical properties of the welded joint due to the variation of reinforcement's deposition in the stir zone. The microstructure and elemental identification also show that the deposition of reinforcements was dependant on the groove size. Also, the width of the groove size plays a significant role on the strength of the welded joint, and maximum microhardness was found to be 150.08Hv for the groove size of 1 mm×2 mm.

Keywords: AA5052, AA6063, Cu nanoparticles, mechanical properties, dissimilar aluminium alloys.

1. INTRODUCTION

In many manufacturing applications the wrought aluminium alloys were effectively welded by Friction Stir Welding (FSW) process, which has been invented by The Welding Institute (TWI) in the year 1991. This sold state joining process results in reduced residual stresses and less distortion in the welded joint [1]. In friction stir welding process the welded joint was obtained by the frictional heat generated between work piece and the shoulder of rotating tool with pin, which moves along the surface to be welded. Here the material flow stress reduces due to frictional heat and the material flow takes place from advancing side to the retreating side. In conventional fusion welding process the weldability of dissimilar materials was poor, which can be improved by FSW process, due to dynamic recrystallization (DRX) in the stir zone [2-4].

Chen Ti-jun *et al.* [5] investigated the fabrication of thixoformed AZ91D magnesium alloy plates of thickness 15mm with Al-rich surface layer by friction stir processing. It has been reported that the aluminium powder of mean diameter 10µm was inserted in to three grooves of size 1.25mm in width and 4.2mm in depth, which improved the corrosion resistance. Jafari *et al.*[6] reported the influence of Carbon nanotube reinforcements of inner diameter 20-30nm which were deposited by friction stir processing in to copper plates of 6mm by taking the groove size 0.3mm in depth and 1.5mm in width. It has been found that there was an enhancement of microhardness and wear properties of nanocomposite. Lim *et al*. [7] studied the aluminium alloy composite fabricated by friction stir processing. He reported that the multi-walled carbon nanotube reinforcements were inserted in to a groove of size 0.3mm in depth and 2.3mm in width, which improved the hardness of the composite. Shafiei-Zarghani *et al.* [8] reported the fabrication of AA6082 aluminium alloy nanocomposite by friction stir processing. This was accomplished by incorporating Al_2O_3 nanoparticles of an average diameter of 50nm in a groove of size 4mm in depth and 1mm in width. It has been reported that the multi-pass FSP improved the distribution of nanoparticles which enhanced the microhardness and wear resistance. Azizieh *et al*. [9] studied the effect of probe profile and rotational speed on hardness and microstructure of AZ31 composites fabricated by friction stir processing, by incorporating different nanosized Al_2O_3 particles in to a groove size of 1.2mm in width and 5mm in depth. The grain refinement and Al_2O_3 particles distribution was found to be improved with each FSP pass and increase of rotational speed. The material flow was reduced by using three-fluted and nonthreaded probes which yielded microvoids and cavities in the composite. Alidokht *et al.* [10] investigated the surface hybrid composite fabricated by incorporating reinforcement particles SiC and MoS_2 in to the metal matrix of A356 aluminium alloy. The groove size selected to insert the reinforcements during friction stir processing was of depth 3.5mm and width 0.6mm. The hybrid composite exhibited higher hardness due to the uniform distribution of reinforcements in the stir zone. Asadi *et al*. [11] studied the fabrication of magnesium based nanocomposite by inserting the nanoparticles SiC and Al_2O_3 having an average diameter of 30nm, in to a groove of size 0.8mm in width and 1.2mm in depth. The nanocomposite produced by SiC particles exhibited higher mechanical properties and refined grain size, when compared to the composite produced by Al_2O_3 particles. Also by increasing the number of pass in FSP found to improve the distribution of particles in the stir zone. Byung-wook *et al*. [12] reported that AA5083-H32 aluminium alloy composite fabricated with SiC particles of mean diameter 4μm, which were inserted in to the groove of size 2mm in width and 1mm in depth. The particle distribution in the stir zone was found to be uniform after two passes with refinement in the grain size due to pinning effect, which improved the microhardness of the composite. In the works of Don-Hyun CHOI *et al*. [13], the SiC particles were inserted in to the metal matrix of AA6061-T4 aluminium alloy. During FSP these particles were deposited in to the groove of size 2mm in width and 1mm in depth, which yielded grain refinement due to uniform distribution of SiC particles and improved the microhardness of the composite by 80HV. Dolatkhah *et al.* [14] investigated the FSP of AA5052 composites produced by micro and nanoparticles. The SiC particles with average mean diameter of 50nm and 5μm were inserted in to the groove of size 2mm in width and 1mm in depth, to produce the composites. The nanocomposite exhibited improved hardness and wear properties with the increase in the number of passes and by changing of tool rotational direction between the passes. Izadi *et al.* [15] studied the multi-pass FSP of AA5059 alloy by inserting the carbon nanotubes of mean diameter 30-50nm in to the groove of size 2.5mm in width and 1.8mm in depth. After three passes the reinforcements were distributed uniformly in the stir zone of the nanocomposite which restricted the grain size and yielded higher microhardness. Morisada *et al.* [16] reported the fabrication of AZ31 surface composites by Multi-walled carbon nanotube reinforcements having an outer diameter of 20-50nm. The reinforcements were inserted into a groove of 1 mm in width and 2 mm in depth. It has been shown that the carbon nanotube reinforcements restrict the grain size, and the composite exhibited improved microhardness. Morisada *et al.* [17] also investigated AA5083 composites fabricated by fullerene powder of mean grain size 25.4 μm in to a groove of size 1 mm in width and 2 mm in depth during friction stir processing. Abnar *et al.* [18] studied the friction stir welding of AA3003-H18 aluminium alloy by depositing the reinforcements in the stir zone. He reported that Cu and premixed Al-Cu powder were inserted between the two metals without making groove. The mechanical properties found to be improved more for premixed Al-Cu powder, when compared to Cu powder.

It is evident from the above literature review that different researchers have explored different groove sizes for inserting the reinforcing particles to produce the composites by friction stir processing. Hence, the present research work focuses on the effect of groove size on microstructure and mechanical properties of the dissimilar aluminium alloys AA5052 and AA6063, due the addition of reinforcements in the welded joint.

2. EXPERIMENTAL DETAILS

The dissimilar aluminium alloys AA5052 and AA6063 were selected as base metals, having dimensions of 100 mm× 50 mm× 6mm. Table-1and Table-2 shows the chemical composition and mechanical properties of the aluminium alloys. Commercially available Cu nanoparticles of mean diameter 40nm were used as reinforcement in the stir zone, which were inserted in to the grooves as per the Table-3. The plates were welded by using a position controlled NC 5T FSW machine and butt joint configuration was obtained by a single pass. During the welding process the sputtering of nanoparticles and their ejection from the groove can be controlled by moving the rotating tool without pin over the joint surface which compresses the reinforcements in to the joint. Then the welded joint was fabricated by inserting the rotating tool with pin in the joint surface. The rotating tool used welding process is made of high carbon steel with a hardness of 52HRC. The dimensions of the welding tool used are having a shoulder diameter of 18mm, cylindrical pin diameter of 5mm and height of the pin is 5.8mm. In the experiment, the process parameters selected are 1400 rpm, 200 mm/min and 1.5kN. A total of four weld joints were fabricated with copper nanoparticles and a set of 12 tensile specimens (ASTM-E8) were extracted by Mitsubishi EDM wire cut machine and the tensile test was performed using INSTRON universal testing machine of 30kN and micro-indentation is carried out using Wilson computerised hardness tester. The samples were etched with weck's reagent for microstructural study by using an optical microscope and EDX analysis for elemental identification.

Table-1. The chemical composition of the alloys in this work (%wt).

Alloy material	Mg	Mn	Cu	Cr	Si	Fe	Zn	Al
AA5052	2.2	0.1	0.1	0.15	.25	0.4	.1	Bal.
AA6063	0.45	0.1	0.1	0.16	0.2	.35	.1	Bal.

Table-2. Mechanical properties.

Base material	Yield strength	Tensile strength	Elongation	Hardness (Vickers)
AA5052	89.6Mpa	193MPa	21%	54
AA6063	43Mpa	82MPa	28%	38

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Table-3. Groove size in mm.

Width	**3**	**3**	**2**	**1**
Depth	1	2	1	2

3. RESULTS AND DISCUSSIONS

During friction stir welding process the weld pool geometry and weld quality are observed to be effected by groove size. In friction stir welds the defects are formed due to change in material flow at low or high rotational speeds, and also due to velocity field variation around the rotating tool. In the stir zone the flow lines are observed in the weld at different positions and the material layer undergo different levels of plastic deformation. It has been observed that the strength of the welded joint has been affected by the change in groove size, with nanoparticles. This may be due to variation in the amount of reinforcements present in the microstructure of the stir zone.

3.1 Microstructure

The microstructures of the welded joints with reinforcements are shown in the Figure-1 to Figure-4. The reinforcements restrict the grain growth due to pinning of grain boundaries. In the stir zone because of frictional heating the plastic deformation takes place and a fine recrystallized zone was formed. The highly deformed grains are seen on both sides of thermo-mechanically affected zone due to the rotating tool stirring action in the stir zone. The velocity fields on the retreading side have same direction where as the velocity fields are in opposite direction on the advancing side [1, 2, 4]. Thus the original grains and subgrains of the parent metal are replaced by fine equiaxed grains in the stir zone due to the mechanism of recrystallization associated with high strain rate deformation. Figure-1 and Figure-2 shows the microstructure of stir zone with copper nanoparticles inserted in a groove of 3 mm×1 mm and 3 mm×2 mm. It has been observed that the Cu nanoparticles distribution improved by increasing the depth of the groove and the grain size was restricted due to more amount of reinforcements in the microstructure as shown in Figure-2. As the width is more during tool movement the reinforcements moved out during friction stir welding and the microstructure show less reinforcements deposition in the matrix with fine and coarse grains as shown in the Figure-1. The microstructures of the stir zone with groove size 2 mm×1 mm and 1 mm×2 mm are shown in Figure-3 and Figure-4. It has been observed that compressing of nanoparticles by rotating tool without pin was effective when the width of the groove was decreased, and more reinforcements can deposited in to the stir zone. Thus it is clear from the microstructure shown in Figure-4; more reinforcements are deposited in the stir zone which enhanced the mechanical properties of the welded joint. The copper nanoparticles are dispersed effectively in the weld nugget zone as precipitates, which hinders the movement of dislocations and promote fine, equiaxed grains along with Mg_2Si fine hardening precipitates along the grain boundaries [17, 19].

Figure-1. Microstructure of Stir zone for groove size of 3 mm×1 mm.

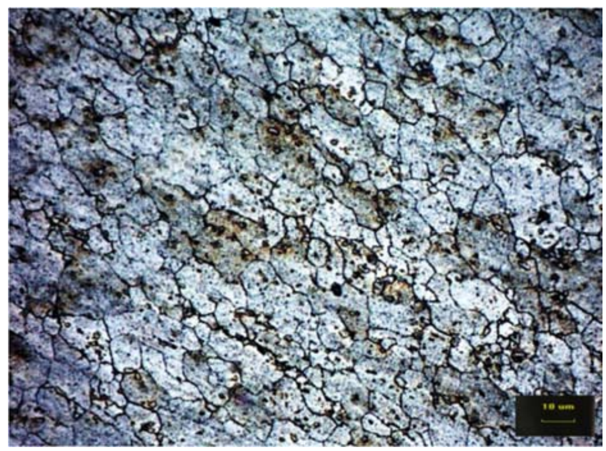

Figure-2. Microstructure of Stir zone for groove size of 3 mm×2 mm.

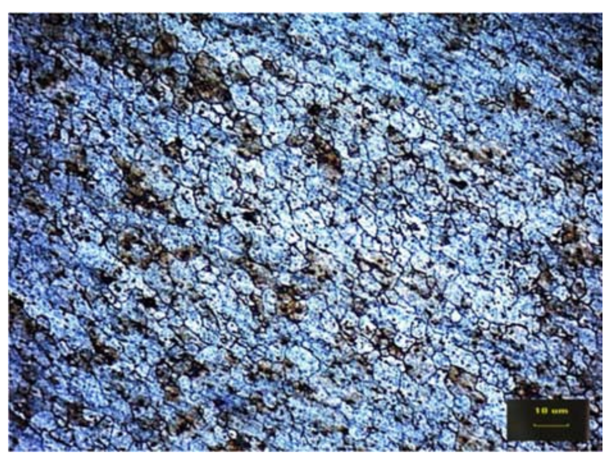

Figure-3. Microstructure of Stir zone for groove size of 2 mm×1mm.

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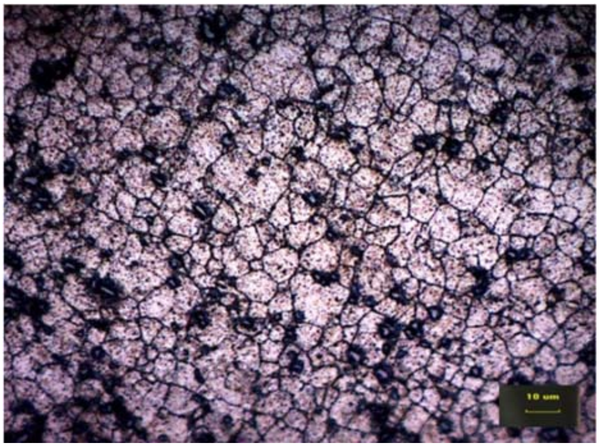

Figure-4. Microstructure of Stir zone for groove size of 1 mm×2 mm.

3.2. EDX results

Optical micrographs does not show clearly strengthening precipitates distribution and in order to identify phases in the weld nugget of the joints prepared and Electron dispersive X-ray analysis (EDX) was performed, and the patterns are shown in the Figure-5 to Figure-8. The solid solubility Copper and magnesium in aluminium is good, and with increase in temperature the solubility increases. The second-phase ingredients are formed after the alloying element content reaches the solid-solubility limit. Thus intermetallic compound or alloying ingredient phases are formed. In aluminium alloys, due to high electro negativity of aluminium more number of intermetallic phases is formed. Under these metastable conditions, the equilibrium diagrams does not represent some of these phases. As the temperature increases due to friction between the rotating tool and work piece, causes some reactions between the alloying elements. Thus copper nanoparticles reacts with aluminium and magnesium which yields intermetallic phases, and remaining copper is precipitated in the stir zone and has pinning effect on grain growth in the specimens with copper nanoparticles. The precipitates of FSW joint as shown in figure below contains 7.72 wt% of copper for a groove size 3 mm×1 mm and maximum amount of 18.30 wt% copper for a groove size 1 mm×2 mm for the given process parameters.

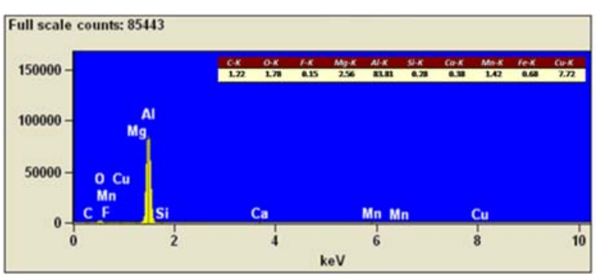

Figure- 5. EDX results of Stir zone for groove size of 3 mm×1 mm.

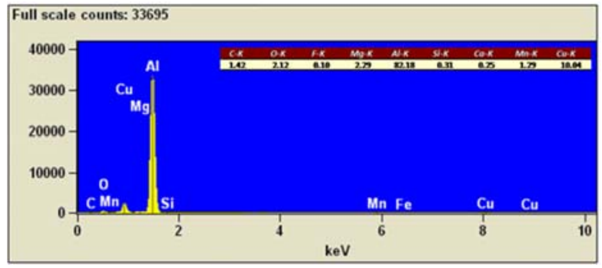

Figure-6. EDX results of Stir zone for groove size of 3 mm×2 mm.

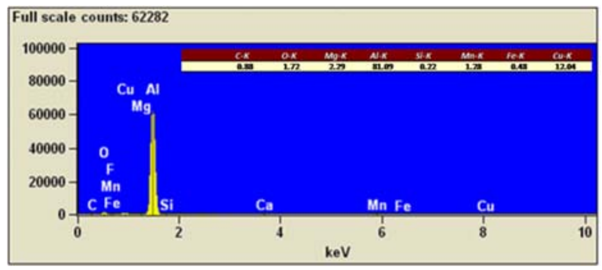

Figure-7. EDX results of Stir zone for groove size of 2 mm×1 mm.

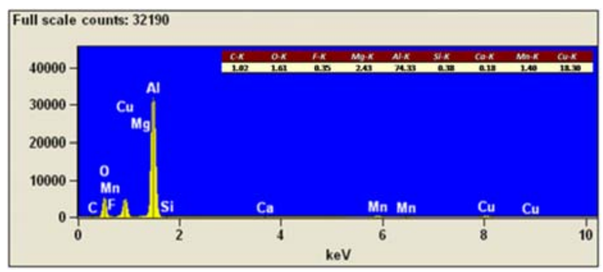

Figure-8. EDX results of stir zone for groove size of 1 mm×2 mm.

3.3. Tensile strength

The strength of the welded joint with reinforcements was determined by conducting tensile tests. It has been observed that the welded joint strength improved by decreasing the width of the groove. The tensile strength of the joint with a groove size of size 3 mm in width and 1 mm in depth yielded lower value due to less reinforcements deposition in the stir zone. As the depth of the groove is increased and by decreasing the width, the tensile strength of the joints found to be improved as shown in the Figure- 8. Since the stir zone experiences higher temperature due to frictional heating of rotating tool, tends to dissolve large amount of solute and coarse precipitates in the solution [18]. But the deposition of nanoparticles in the stir zone pins the grain boundaries and yield fine grains in the microstructure. Thus the dispersion of the nanoparticles restrict the movement of dislocations and grain boundaries, decreases the grain size, thermal mismatch increases the dislocation density and Orowan strengthening mechanisms are the reasons for the increase of yield and tensile strength of the welded joints [16,18,19]. The elongation values are dependent on the

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dislocation density and grain size, but the dominant factor is the grain size which improves the elongation behaviour with decrease in grain size. The maximum tensile strength of 109.14 MPa was obtained for the welded joint with groove size of 1mm in width and 2mm in depth

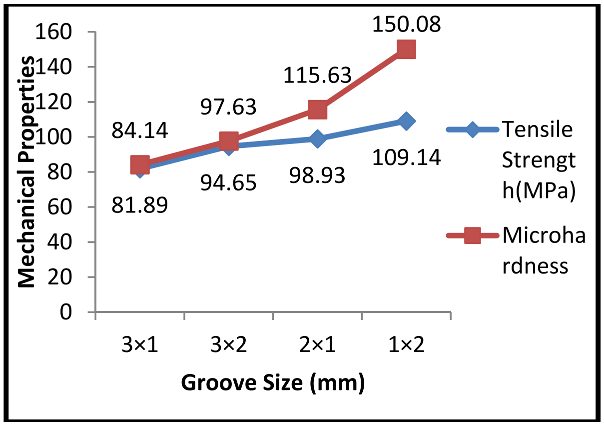

Figure-9. Mechanical properties of welded joint.

3.4. Microhardness

The welded specimens with copper nano-particles produced with different groove size show that micro hardness of the welded zone increases in all the specimens [10, 11, 13, 14 and 15]. According to Hall-Petch equation due to decrease in grain size causes an enhancement in hardness values [16]. The hardness values in the stir zone are more for the groove size 1 mm×2 mm as more reinforcements are present in the microstructure which restricts the grain growth. The microhardness values in TMAZ and HAZ have been reduced because of annealed-induced grain growth. But in the stir zone due to the stirring action of the pin leads to a dynamic recrystallization which reduces the grain size, enhances the dislocations, which in turn improves the microhardness values. The hardness values obtained for groove size 3 mm ×1 mm was less as few reinforcements are embedded in the stir zone. The Figure-8 shows the microhardness values of the welded joint for different groove size at tool rotational speed of 1400 rpm and the maximum hardness obtained was 150.08Hv.

4. CONCLUSIONS

The mechanical properties of the welded joint are enhanced in all the specimens with Cu nanoparticles addition. The microstructures of the nugget zone show a refined and homogenized grain structure due to dynamic recrystallization and reinforcements in the grain structure. Tensile strength and hardness values are observed to be maximum for the groove size 1mm × 2 mm, when compared to the specimen with groove 3 mm × 1 mm. Thus, the fine grain size observed in the microstructures due to the dispersion of nanoparticles locks the dislocations movement and enhances the strength of the welded joint.

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