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Effect of Rotational speed on mechanical properties and microstructure due to the addition of reinforcements on friction stir welded dissimilar aluminum alloys

Ravinder Reddy Baridula, Abdullah Bin Ibrahim and Mohammad Faizal Bin Che Ku
Faculty of Engineering Technology
Department of Manufacturing Engineering
Universiti Malaysia Pahang
26300 Gambang, Pahang, Malaysia
baridula@gmail.com, abi@ump.edu.my, mfaizal@ump.edu.my

Ramgopal Varma Ramaraju
Department of Mechanical Engineering
Faculty of Engineering
Stanford International College of Business and Technology
Toronto, Canada
ramarajuramgopal@yahoo.com

Abstract— The Friction Stir Welding is a solid state joining process, which has many advantages in welding similar and dissimilar aluminium alloys when compared with the traditional fusion welding process. In the present investigation dissimilar aluminium alloys AA5052 and AA6063 were joined by friction stir welding by inserting Cu nanoparticles as reinforcements to study the effect of the same. Butt joints were obtained in 6mm thick plates with a longitudinal speed of 200 mm/min, and at a load of 1.5kN with a rotational speed of 1200 and 1400 rpm. In order to determine the effect of process parameters due to the addition of Cu nanoparticles on microstructure and mechanical properties in dissimilar aluminium alloys was investigated. The result shows that due to the addition of reinforcements, the mechanical properties were improved, as the process parameters are changed. This behaviour was further supported by Electron dispersive X-ray analysis (EDX) studies, which provides elemental identification and quantitative compositional information.

Keywords— AA5052, AA6063, Cu nanoparticles, EDX images, Mechanical Properties, Dissimilar Aluminium alloys.

1. Introduction

Friction stir welding (FSW) after invented by the welding institute (TWI) in 1991 [1], came into existence and widely employed in many fields of engineering like aerospace, automobile and shipbuilding. It possesses many advantages, such as it doesn't require filler, low melting, low defect and low distortion, etc. FSW employed to join thick and thin sections. The process of FSW includes in a rotating cylindrical tool with a pin and a shoulder which is forced into the plates to be welded and moved along the line of contact of the plates. Most of the earlier studies on friction stir welding are mainly concentrated on welding similar aluminium alloys. Though, FSW was invented to join and improve the quality of the welded joints in aluminum alloys, has developed systematically and the weld technique extended to weld materials like steels [2] and copper[3], composites, polymers and to dissimilar metals. Defect-free welds have now been made by FSW in the joining of different Al alloys[4,5], Al/steel[6,7], Al/copper[8,9] and Al/Mg[10]. Heat treatable aluminium alloy AA2024 extensively used in the aircraft industry because of its high strength and good ductility whereas AA5083 exhibits medium strength and high ductility[11] their applications were limited to structural applications, marines and automotive industries. Joining of dissimilar aluminium alloys Shanmuga sundaram[12], Palanivel[13] have conducted experimental procedures by varying pin profiles under FSW and explained the tensile behavior of welded dissimilar aluminium alloy joints with respect to the varying process parameters. The varying process parameters in FSW, M. Jayaraman[14] have conducted experiments to examine microstructural properties and tensile strengths of A356 Al Alloy joints. Varying rotational speeds, axial force and traverse speed a set of twelve joints were fabricated to study the hardness and tensile tests. Each joint has been examined for the better strengths at optimum parameters and observed Defect-free weld region, fine hardness regions found to be important giving better strength to the joints. The mechanical properties of FS welded dissimilar Al Alloy joints were examined by Ramaraju Ramgopal Varma[15], and optimized parameters have been predicted for obtaining the strength of the joint in comparable to the base metal. Taguchi technique was used to optimize the process parameters, an L-8 orthogonal array consisting of eight experimental runs taken at two levels considering tool rotational speed, axial force and traverse speeds. S. Kundu[16], conducted experiments on joining two different metals like Interstitial free steel and commercial pure aluminium by the use of FSW. At three levels of rotational speeds are 600, 900, 1200 and at constant traverse speed 100 mm/min. The investigations helps to identify microstructure and micro-hardness of the weld interface and SEM images explain the formation of intermetallic compound Al_3Fe in the weld interface, with an increase in the tool rotational speed weld strength decreases gradually this is due to increase in thickness of intermetallic compound. The use of Response surface methodology based on a central composite rotatable design A. Heidarzadeh[17], have experimented by taking three parameters at five levels and twenty runs. Developing a mathematical model based on design plan for predicting the tensile properties of friction stir welded aluminium AA6061 alloy the microstructural characterisation and factography analyses were explained. A high quality of welds were achieved within the operational range of process parameters, considerable results are obtained with RSM based mathematical model for predicting ultimate tensile strength of welded joints of Aluminium AA6061 alloy. Ultimate tensile strength of the weld joints are observed to be increasing with an increase in the tool rotational speed, welding speed and axial force to its maximum limit and then it decreases.

The results of A356/Al_2O_3 surface composite indicated that Al_2O_3 particles were distributed uniformly in A356 matrix, which improves the mechanical properties due to Orowan mechanism reported by [18]. Sharifitabar [19], reported that the tensile and yield strength were higher and lower elongation for three and four passes due to uniform dispersion of nano-sized Al_2O_3 particle, when compared to materials produced by without powder. Byung-wook [20], reported that the microhardness has improved after two passes and the paricle distribution was uniform, which facilitates the grain refinement due to pinning effect in the stir zone. Don-Hyun CHOI [21], studied the FSP of AA6061-T4 alloy with SiC particles, and reported that due to fine distribution of the SiC particles the microhardness improved to 80HV due to grain refinement. Dolatkhah [22] reported that change of tool rotational direction between FSP passes, increase in number of passes and decrease of SiC particles size enhances wear and hardness properties. Izadi [23], investigated distribution and stability of carbon nanotubes during multi-pass FSP of AA5059 alloy. It has been reported that the microhardness of the composite was two times higher than the original alloy after three passes, due to reinforcing phase was distributed uniformly which yielded grain refinement. Zohoor [24], studied the effect of process parameters on AA5083 aluminium alloy with reinforced layers by using copper particles by FSP. The results show that the tensile strength and hardness improved in the composite with nano-sized particles. Abnar [25], reported that Cu-Al powder in the stir zone resulted in higher longitudinal tensile strength, due to the formation of more Al-Cu intermetallic compounds.

Hence, the present research work focuses on the effect of rotational speed on mechanical properties and microstructure of the dissimilar aluminium alloys AA5052 and AA6063, due the addition of reinforcements in the welded joint.

2. Experimental Details

Friction Stir Welding was performed on plates of AA5052 and AA6063, having dimensions of 100 mm× 50 mm× 6mm. The chemical composition and mechanical properties of the aluminium alloys employed in the experiment are given in Table 1and Table 2. The plates were welded in single pass, normal to the rolling direction, with butt joint configuration by employing a position controlled NC 5T FSW machine. The initial joint configuration is obtained by securing the plates in position and Cu nano-particles are added in to this joint and mechanical clamping is done so that the Cu nano-particles stay in between the two plates. The welding tool used in the experiment is made of high carbon steel with a hardness of 52HRC. The welding tool is having a shoulder diameter of 12mm and a cylindrical pin of diameter 6mm and the height of the pin is 5.8mm. In the experiment a total of two weld joints were fabricated with nanoparticles, and the process parameters are 200 mm/min, 1.5kN, 1200 and 1400 rpm. A set of 10 tensile specimens (ASTM-E8) were extracted by Mitsubishi EDM wire cut machine and tensile test were performed using INSTRON universal testing machine of 30kN and micro-indentation was carried out at various points from the weld centre using Wilson computerised hardness tester. The samples were etched with keller’s reagent for microstructural study by using optical and scanning electron microscopy (SEM).

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

Alloy Material	Mg	Mn	Cu	Cr	Si	Fe	Ti	Zn	Al
AA5052	2.2	0.1	0.1	0.15	0.25	0.4	-	0.1	Balance
AA6063	0.45	0.1	0.1	0.16	0.2	0.35	0.1	0.1	Balance

Table 2. Mechanical Properties

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

3. RESULTS AND DISCUSSION

The weld quality and weld pool geometry are observed to be effected by rotational speeds at longitudinal feed of 200mm/min and at 1.5kN. During FSW, defects may be formed due to variation in the velocity field around the rotating tool. Defects may also be formed due to the material flow at high or low rotational speeds. The flow lines within the stir zone are observed to be formed at different positions of the weld as the material layers undergo different levels of plastic deformation. It has been observed that by increasing the rotational speed the strength of the welded joints increased, with nano-particles. This may be due to reinforcements present in the microsture.

3.1 MICROSTRUCTURE

The microstructures of the welded joint are shown in the figure 1. The stir zone consists of fine, equiaxed grains. In the weld nugget, because of heavy plastic deformation a fine recrystallized zone is formed which is followed by dynamic recrystallization due to thermo-mechanical processing. Due to the stirring action of the rotating tool in the stir zone, which is followed by thermo-mechanically affected zone on both sides contains highly deformed grains. Since the velocity fields on the advancing side have opposite direction, whereas on the retreading side the velocity fields have same direction, which yields lack of symmetry along joint line of the welded joint. Thus high strain rate deformation leads to recrystallization mechanism in friction stir welding and the fine equiaxed grains are formed by replacing parent metal original grains and subgrains. The microstructure of the weld nugget zone shows that copper nanoparticles are dispersed as precipitates, which pins the movement of dislocations and promote fine, equiaxed grains along with Mg_2Si fine hardening precipitates along the grain boundaries.

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 2. 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 2 contains 6.10% and 18.46% copper at rotational speeds of 1200 rpm and 1400 rpm.

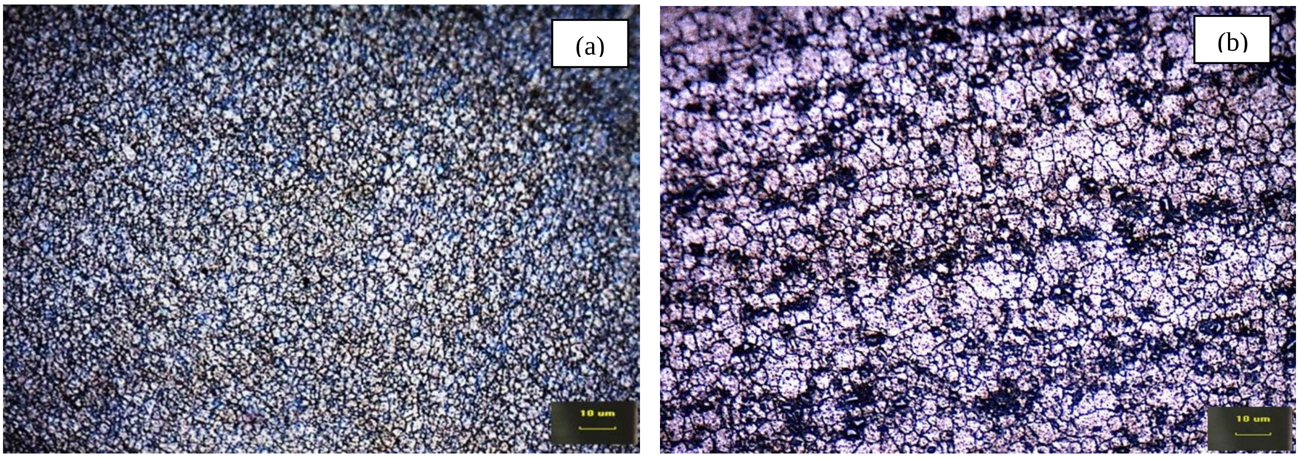
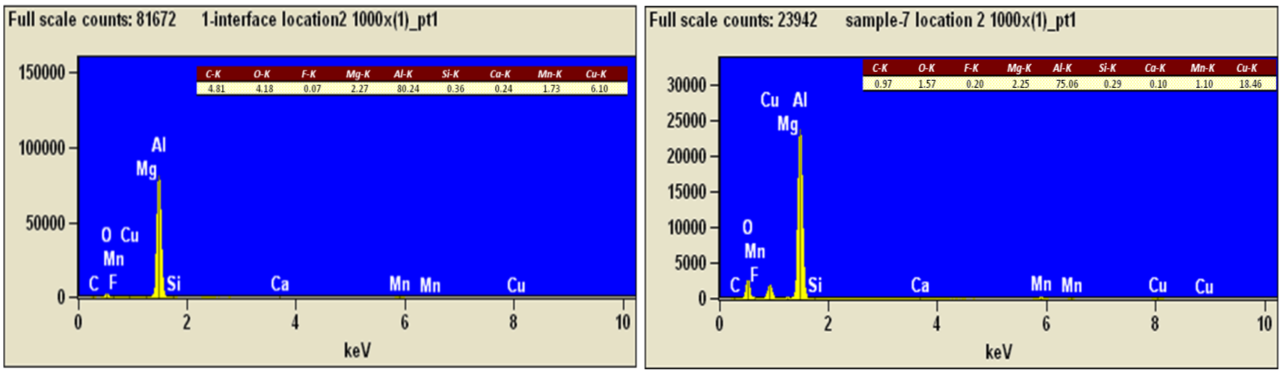


Figure 1: Microstructure of Stir zone at (a) 1200 rpm (b) 1400 rpm



(a) (b)

Figure 2: Elemental identification of the stir zone at (a) 1200rpm (b) 1400rpm

3.3 TENSILE PROPERTIES

Tensile tests were conducted to determine the effect of nano-particles on the strength of welded joint. It can be seen that with higher rotational speed of 1400rpm produce the weld metal with higher strength in comparison with rotational speed of 1200 rpm. It has been observed that at rotational speed of 1200rpm the tensile strength is low due to the high density of coarse precipitates present on the grain boundaries, this is because of less heat generation. As the speed increases by 1400 rpm, the heat generation can be improved it is observed that there is increase in tensile strength and yield strength with nano-particles. At 1400 rpm, as the more heat is generated in the weld zone, which dissolves the coarse precipitates and a large amount of solute is formed in the solution, but due to nano-particles present in the solution which leads to dynamic recrystallization and fine grains are formed in the weld zone. The reasons mentioned for the specimens with copper nano-particles, such as decreasing the grain size, increasing the dislocation density due to thermal mismatch, restriction of movement of grain boundaries and dislocations and Orowan strengthening mechanisms due to fine dispersion of nano-particles cause a significant increase in yield and tensile strength. Fine grain size leads to better elongation behaviour but increasing the dislocation density causes a decrease in elongation values. But the dominant effect is decreasing the grain size which improves the elongation behaviour. The tensile strength at 1200 rpm and 1400 rpm are observed to be 93.34 MPa and 109.14MPa. The figure 3 and figure 4 shows the fractured tensile specimens at 1200rpm and 1400rpm. The properties of the welded joint at different rotational speeds are shown in Table 3.

Figure 3: Fractured Tensile specimens at 1200rpm

Figure 4: Fractured Tensile specimens at 1400rpm

Table 3. Properties of welded joint

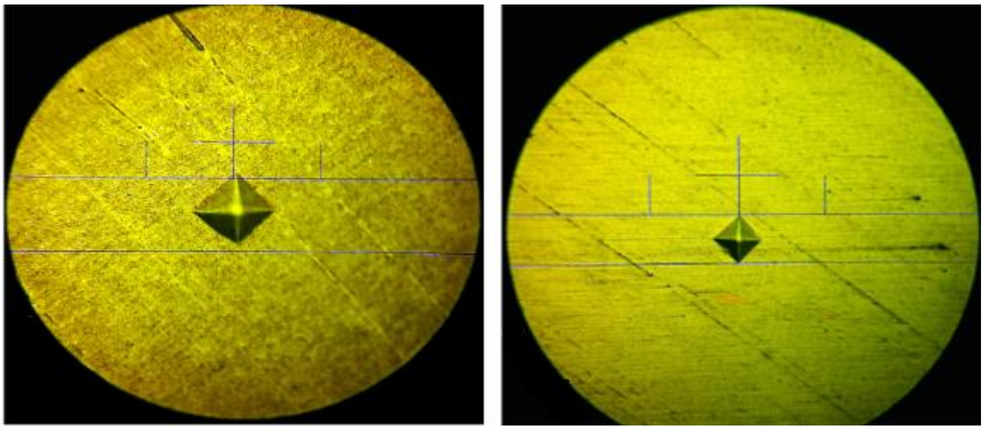
Rotational Speed(rpm)	Tensile Strength(MPa)	Microhardness
1200	93.34	61.58
1400	109.14	150.08

3.4 MICROHARDNESS

The specimens with copper nano-particles produced at the rotational speeds of 1200 rpm and 1400 rpm show that the hardness of the welded zone increases in all the specimens. According to Hall-Petch equation due to decrease in grain size causes an enhancement in hardness values. The hardness values in the stir zone are more at rotational speed of 1400 rpm, longitudinal speed of 200 mm/min and at a load of 1.5 kN. The microhardness values in TMAZ and HAZ have been reduced because of annealed-induced grain growth [2, 3]. 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 at 1200 rpm and 1400 rpm are 61.58 and 150.08. The figure 5. Shows the microhardness indentation at different tool rotational speed.

4. CONCLUSIONS

Frictions stir welding a solid state technique which alters the microstructures of the nugget zone, which shows a refined and homogenized grain structure. The mechanical properties of the welded joint are enhanced in all the specimens with Cu nano-particles. Tensile strength and hardness values are observed to be maximum at rotational speed of 1400 rpm when compared to the specimen at 1200 rpm. 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.



(a) (b)

Figure 5: Microhardness Indentation at (a) 1200 rpm (b) 1400 rpm

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