

# Influence of groove size and reinforcements addition on mechanical properties and microstructure of friction stir welded joints

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**Abstract.** The butt joints fabricated by friction stir welding were found to have more strength than the joints obtained by conventional joining process. The important outcome of this process is the successful fabrication of surface composites with improved properties. Thus in order to further enhance the strength of the dissimilar alloy joints the reinforcements can be deposited in to the aluminium matrix during the process of friction stir welding. In the present study the multi-walled carbon nanotubes were embedded in to the groove by varying the width during joining of dissimilar alloys AA2024 and AA7075. Four widths were selected with constant depth and optimum process parameters were selected to fabricate the sound welded joints. The results show that the mechanical properties of the fabricated butt joints were influenced by the size of the groove, due to variation in the deposition of reinforcement in the stir zone. The microstructural study and identification of the elements of the welded joints show that the reinforcements deposition is influenced by the size of the groove. It has also been observed that the groove with minimum width is more effective than higher width. The mechanical properties are found to be improved due to the pinning of grain boundaries.

## 1. Introduction

Welding is a significant process of manufacturing to produce the parts of complex configuration which are difficult to be obtained. It is considered as a secondary process which has to be followed by a primary process and cannot be substituted by any manufacturing process. The aluminium alloys were effectively joined by fusion welding process. However, fusion welding process results in reduced mechanical properties in the weld area due to the formation of intermetallic compounds and coarse grains. Also, the excellence of the weld joint deteriorates due to distortion, hot cracking, porosity and formation of oxide layer [1, 2]. Friction stir welding is an alternative method of joining process which avoids many metallurgical reactions [3]. This solid state fusion process enhances the mechanical properties of the weld joints due to dynamic recrystallization (DRX) in the stir zone and the temperatures yielded are less than the fusion welding process [4-6]. In this process the welded joint



was obtained by stirring a rotating tool with pin over the surface of the joint which generates the sufficient heat to plasticize the material [7]. This concept was effectively utilized to fabricate the surface composites by friction stir processing to improve the mechanical properties by the addition of reinforcements [8, 9].

Morisada et al. [10] researched the manufacture of surface composites of AZ31 alloy by depositing multi-walled carbon nanotubes of diameter 20-50nm in to a groove size of width 1 mm and depth 2 mm during friction stir processing. The grain refinement was promoted by the nanoparticles which enhanced the microhardness of surface composite to 78 Hv as compared the base metal. Lim et al. [11] investigated the fabrication of aluminium alloy surface composite by depositing the multi-walled carbon nanotubes during friction stir processing. The reinforcements were incorporated in to a groove of size 0.3 mm depth and 2.3 mm width, which enhanced the microhardness of the surface composite. The carbon nanotubes stability and distribution in aluminium surface composites during multi-pass friction stir processing was reported by Izadi and Gerlich [12]. The carbon nanotubes of diameter 30-50nm were deposited in to a groove of 1.8 mm depth and 2.5 mm width. It was found that after three pass the distribution of carbon nanotubes are uniform which restricted the size of the grains and enhanced the microhardness. Liu et al. [13] studied the fabrication of aluminium matrix composites by varying the amount of multi-walled carbon nanotubes during multi-pass friction stir processing. The reinforcements were inserted in to drilled holes of diameter 2,4,6,8 and 10mm and depth of 3.5mm. The results show that the nanoparticles were distributed uniformly which enhanced the microstructure and mechanical properties with the increase in the amount of reinforcements. The maximum tensile strength of 190.2 MPa was obtained at 6vol% of multi-walled carbon nanotubes. Thangarasu et al.[14] investigated the aluminium surface composite by incorporating TiC particles of 2 $\mu$ m in to groove of depth 5mm and varying width of 0.4,0.8,1.2 and 1.6mm during friction stir processing. The reinforcing particles reduced the grain size which enhanced the wear resistance of the composite. Sathiskumar et al. [15] produced a surface composite by depositing B<sub>4</sub>C particles of average size 4 $\mu$ m in to the groove of size 0.7mm width and 2.5mm depth. The reinforcing particles were distributed homogeneously at higher rotational while the distribution was poor at low rotational speed, and the composite microhardness found to be decreased with increase in tool rotational speed.

Karthikeyan et al. [16] studied the friction stir welding of Al6351 alloy, by incorporating the SiC particles in to the stir zone. The mechanical properties of the welded joints were found to be improved by 33%, than the joints without reinforcements. This was due to pinning effect of the SiC particles which restricted the growth of the grain boundaries. Abnar et al. [17] contemplated the joining of AA3003-H18 aluminium alloy by inserting the reinforcements in the weld zone. He detailed that Cu and premixed Al-Cu powder were embedded between the two metals without making groove. The mechanical properties were observed to be enhanced more for premixed Al-Cu powder, when contrasted to Cu powder. Kumar et al. [18] investigated the influence of post weld warm treatment and B<sub>4</sub>C nano powder addition on hardness, pitting resistance and microstructure of the stir zone during friction stir welding of AA7075 alloy. Abbasi et al. [19] studied the effect of SiC particles on the stir zone during friction stir welding of AZ31 magnesium alloy. The addition of SiC particles influenced the microstructure of the stir zone, which enhanced the corrosion resistance and mechanical properties as compared to the welded joint without reinforcements. Ravinder et al. [20] examined the addition of copper nanoparticles during joining of dissimilar aluminium alloys and found that the mechanical properties of the welded joint enhanced in all the samples.

It is clear from the above literature survey that the researchers have investigated diverse groove sizes for embedding the strengthening particles to fabricate the composites by friction stir processing. Consequently, the present research work concentrates on the influence of groove size and reinforcements addition on mechanical properties and microstructure of dissimilar friction stir welded joints.

## 2. Experimental Details

The base metals utilized as a part of the present examination are AA2024-T3 and AA7075-T6 having measurements of 100 mm  $\times$  50 mm  $\times$  4.85 mm. The chemical composition and mechanical properties of the aluminium alloys were shown in Table1 and Table2. The reinforcements used in the present

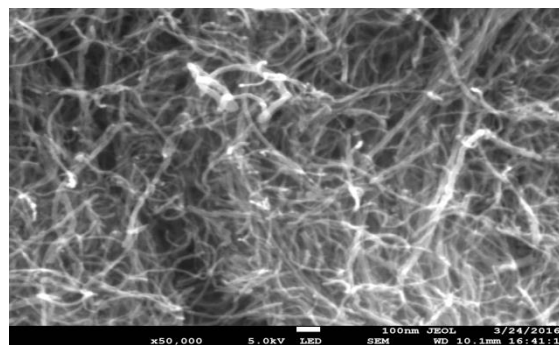
study are multi-walled carbon nanotubes having nominal diameter of 10-20nm and purity more than 90%, which is shown in the Fig. 1. The welded joints of dissimilar alloys with reinforcements were fabricated by using 5T NC FSW machine, and the specimens were fixed in the fixture to avoid their movement. The reinforcements were inserted in to the grooves which are precisely cut in the base metals by a wire cut machine as per the table 3. In order to avoid the sputtering of nanoparticles during the process of joining, a welding tool without pin is moved over the surface of the joint to compact them in to groove. Then the required welded joint with reinforcements was obtained by moving the welding tool with pin over the surface of the metals to be joined. The process parameters selected in the current study are 1400 rpm, 80 mm/min and 1kN. In the present study 4 welded joints with reinforcements were fabricated to understand the mechanical behaviour of the joints. The samples for the tensile test were acquired according to the ASTM-E8 standard by utilizing EDM wire cut machine and the tensile test was done on 12 specimens by INSTRON universal testing machine of 30 kN. The microhardness of the specimens was done by Wilson Vickers hardness tester. The specimens were set up for microstructure examination and etched with Keller's reagent. The microstructures of the stir zone were acquired by optical microscope and identification of elements in weld zone was obtained by FESEM.

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

Material	Cu	Mg	Mn	Zn	Si	Fe	Cr	Al
AA2024-T3	4.46	1.42	0.63	0.05	0.04	0.11	0.001	Balance
AA7075-T6	1.7	2.43	0.08	5.93	0.05	0.12	0.001	Balance

Table 2. Mechanical Properties

Material	Yield Strength	Tensile Strength	Elongation	Hardness
AA2024-T3	376Mpa	446Mpa	17%	144
AA7075-T6	489Mpa	573Mpa	13%	172

**Figure 1.** FESEM image of Carbon nanotubes

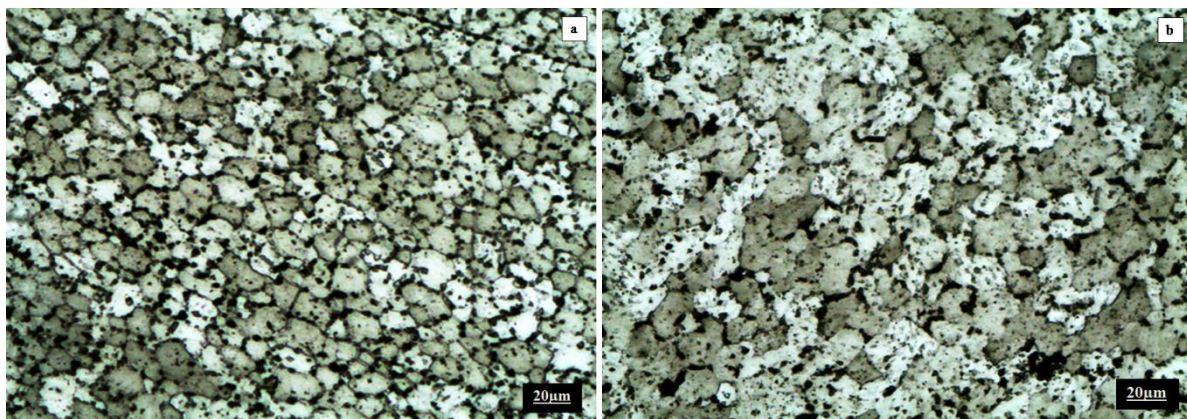
### 3. Results & Discussion

The geometry of weld pool and the quality of weld are observed to be influenced by the size of the groove. The imperfections in the welded joints are formed due to difference of velocity field around the welding tool, and also due to the change in the flow of material at low or high tool rotational speeds. It has been observed that the strength of the friction stir welded joints with nanoparticles is influenced by the variation in groove size. This was because of variation in the quantity of reinforcement availability in the microstructure of the stir zone.

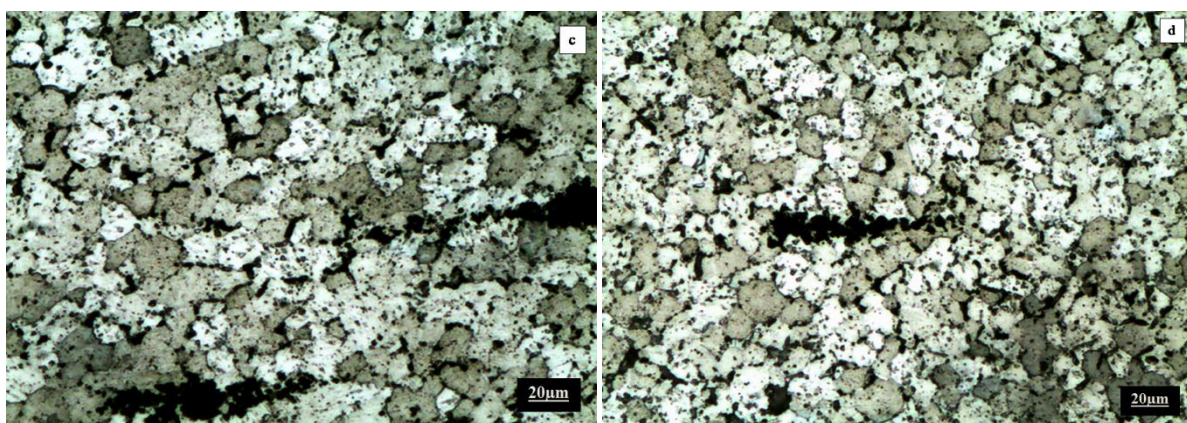


### 3.1 Microstructure

The severe plastic deformation during friction stir welding process at high temperatures results fine grains in the stir zone [10]. The quantity of heat generation during the joining process determines the size of the grains, but the circumstances change as the reinforcements are deposited in the metal matrix [21]. The grain boundaries migration usually occurs at elevated temperatures [22]. Thus the elevated temperatures can be developed by decreasing traverse speed or enhancing the tool rotational speed which yield coarse grains in the weld zone [23]. The addition of reinforcements controls the grain boundary migration by pinning, which results fine grain structure. The microstructures of friction stir welded joints were shown in Fig. 2 and Fig.3. Fig. 2(a) shows the microstructure of the stir zone at groove of width 1 mm. Here the reinforcements are distributed evenly in the metal matrix and the size of the grains was restricted due to pinning effect. Fig. 2(b) shows the microstructure of stir zone for a groove of width 1.6 mm, which shows the combination of fine and coarse grains along with reinforcements. As the groove width was increased it has been observed more amount of reinforcements moved out of groove during the movement of the tool and some accumulation of reinforcements were seen in the microstructure with fine and coarse grains as shown in the Fig. 3(a). Similarly when the width of the groove was enlarged to 3 mm more amount of carbon nanotubes can be deposited, but during the process of welding most of the reinforcements came out of the groove and some accumulation of particles are seen in the microstructure as shown in Fig. 3(b). Thus the compression of nanoparticles by the welding tool without pin was efficient when the groove width was reduced, and enhanced the amount of reinforcements in the weld zone which hindered the dislocations movement and yielded fine grains in the stir zone. This phenomenon depends on volume fraction and size of the particles according to Orowan-Ashby equation [24].



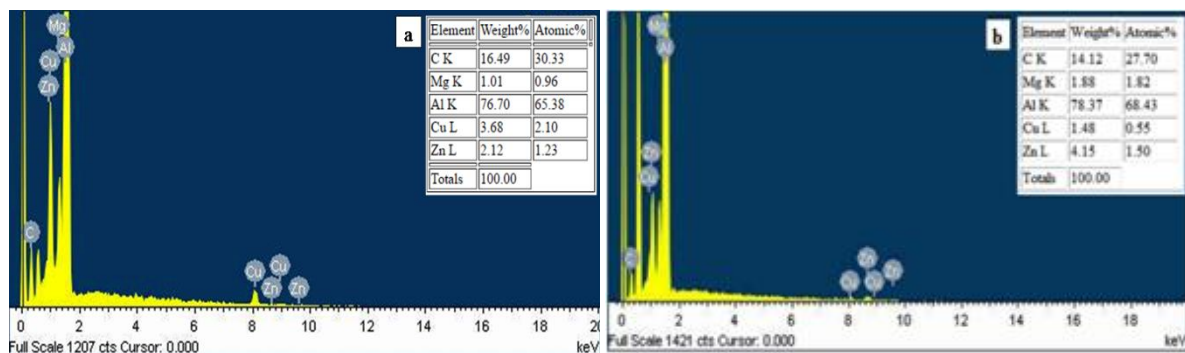
**Figure 2.**Microstructure of Stir zone for groove size (a) 1 mm×2 mm (b) 1.6 mm×2 mm



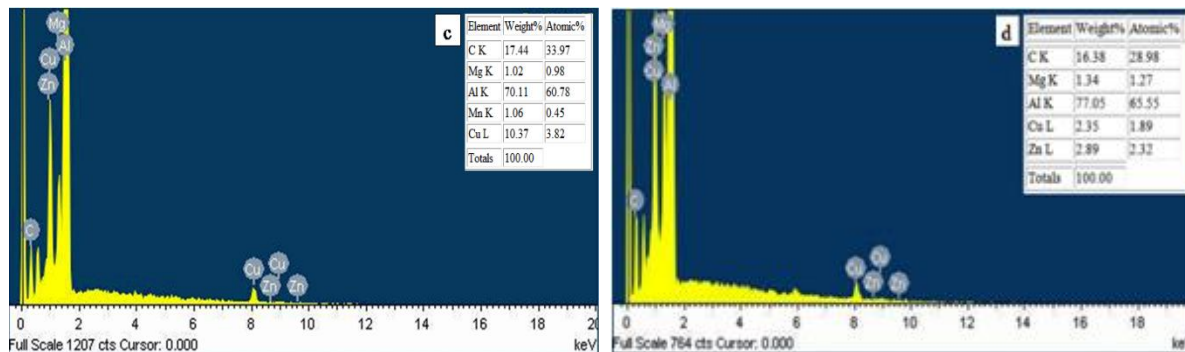
**Figure 3.**Microstructure of Stir zone for groove size (a) 2 mm×2 mm (b) 3 mm×2 mm

### 3.2 EDX Results

Elemental recognition was acquired by Electron dispersive X-ray analysis (EDX) as the amount of elements distribution in the stir zone was not clear from the study of microstructure. Fig. 3 and Fig. 4 shows the stir zone EDX patterns for the groove of varying width. EDX patterns show the deposition of carbon nanotubes in all the specimens, but there is a deviation in the amount of deposition of carbon nanotubes in the stir zone. This was due to variation in groove size as more amounts of reinforcement can be inserted as the width is increased. Fig. 4(a) shows the EDX pattern for groove of 1 mm width and the amount of carbon nanotubes deposited in the stir zone was 16.49 wt%, and 14.12 wt% for 1.6mm groove width as shown in Fig. 4(b). Thus as the groove width was increased some amount of nanoparticles moved out off the groove during the welding process. The maximum amount of carbon nanotubes of 17.44 wt% were deposited for groove of 2 mm width and 16.38 wt% for the groove of 3 mm width. Hence the groove with minimum width is preferable to deposit the nanoparticles uniformly in the stir zone and if more amount of reinforcements are available the accumulation of particles leads to decrease in the properties of the welded joint.



**Figure 4.** EDX results of Stir zone for groove size (a) 1 mm x 2 mm (b) 1.6 mm x 2 mm



**Figure 5.** EDX results of Stir zone for groove size (a) 2 mm x 2 mm (b) 3 mm x 2 mm

### 3.3 Tensile Strength

Tensile tests were carried out to determine the strength of welded joints with nanoparticles. The mechanical properties are influenced by the factors like dislocation density, the interaction among base metals and reinforcements and grain size [8, 9]. The thermal mismatch was large between the aluminium matrix and carbon nanotubes which generates higher dislocation density at the interface and improves the strength of the matrix by work hardening [25]. Thus the carbon nanotubes in the metal matrix hinders the movement of grain boundaries and dislocations, reduces the grain size and Orowan strengthening mechanisms are the factors for enhancing the strength of the friction stir welded joints [17,19,20]. The mechanical properties of the fabricated dissimilar welded joints were shown in the Table 3. The results show that the highest tensile strength of 449.71 MPa was acquired for the joint



with groove dimension of 1 mm width and 2 mm depth. The minimum value of 425.52 MPa was obtained for the joint with groove dimension of 2 mm width and 2 mm depth. This was due to more amount of reinforcement's deposition in the stir zone as compared to minimum groove width. And the accumulation of nanoparticles in the stir zone yielded lower tensile strength. Hence the nanoparticles inserted in to the groove of minimum width enhanced the strength of the welded joint by the homogeneous distribution of the reinforcements in the stir zone.

Table 3. Properties of welded joint

Groove size ( mm)	Tensile Strength(MPa)	Microhardness (Hv)
3×2	429.34	186.4
2×2	425.52	192.3
1.6×2	433.34	181.5
1×2	449.71	189.3

### 3.4 Microhardness

The significant factors which control the metal matrix composite microhardness are heat input, dislocation density and amount of reinforcement distribution and grain size. According to Hall-Petch equation the fine grain size enhances the microhardness [26]. Since the co-efficient of thermal expansion is different for metal matrix and reinforcing phase could generate the dislocations and enhances the microhardness of the specimens with reinforcements [8, 9]. The average microhardness of the samples in the stir zone is shown in Table 3. It is observed that all welded joints exhibited the enhancement of microhardness, due to deposition of nanoparticles in the stir zone. The microhardness was observed to be altering due to change in the quantity of reinforcing particles in the microstructure of stir zone. The maximum microhardness of 192.3 Hv was obtained with a groove of 2 mm width and 2 mm depth, as more amount of reinforcements were present in the stir zone. And the minimum hardness was observed for the joint fabricated with groove of size 1.6 mm width and 2 mm depth. Thus the welded joint fabricated with groove of 1 mm width and 2 mm depth found to be best choice as the nanoparticles were deposited uniformly in the stir zone, which locks the grain boundaries and promotes the fine grains [13, 15].

### 4. Conclusions

Friction stir welding was effectively utilized to fabricate the dissimilar alloy joints by incorporating the multi-walled carbon nanotubes in to groove of varying width. The nanoparticles were deposited in all the samples irrespective of the groove dimensions. The results show that the groove dimensions play an important role to deposit and distribute the nanoparticles uniformly in the stir zone, which increases the mechanical properties of the welded joint. Tensile strength was observed to be highest for the joint with groove of width 1 mm, as the nanoparticles were distributed uniformly in the stir zone which hindered the progress of grain boundaries and dislocations. The hardness was highest for the joint with groove of 2 mm width, but the strength decreased due to accumulation of nanoparticles in the stir zone.

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