

# Fabrication and Characterization of Nano Composite Layer on Aluminum Matrix through Friction Stir Process

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**Abstract:** Friction stir process has proven to be a promising approach for joining aluminium matrix composites. Aluminium matrix composites are progressively replacing conventional monolithic alloys in several applications such as in aircraft, automotive and marine industries to enhance the product capabilities. Friction Stir Process (FSP) is a potential candidate to make AMC layer on matrix material without any defect. In order to improve the various mechanical and wear properties of the aluminium matrix material, the composite layers will be made through FSP with different volume fraction and various (Micro and nano scale) ceramic particle sizes. Since the quality of the composites depends on process parameters of FSP. This review paper provides an overview of the FSP of AMC materials. Specific attention and critical assessment have been given to: (a) the macrostructure and microstructure of AMC joints, (b) the evaluation of mechanical properties of joints, and (c) the wear of FSP tools due to the presence of reinforcement materials in aluminium matrices

**Keywords:** AMC:FSP

## 1. Introduction

Friction stir processing (FSP) is a promising grain refinement technique. This method comes from the FSW (Friction Stir Welding) technology developed in 1991 by Wayne Thomas from the Welding Institute in Cambridge. The FSW method consists in friction welding with the stirring of the material, and it is used for joining materials in a solid state. In both methods the same scheme is used: the heat generated as the result of the friction between the working tool and the material surface heats up and plasticizes the material. The tool is normally made of high-speed steel, the tool steel for hot work, or polycrystalline cubic boron nitride, and also wolfram alloys. After the tool shank is put in rotation it sinks slowly into the joint area into the material being modified. In the first phase, only the front surface of the shank has contact with the material being modified, and then the side surface of the shank and the surface of the retaining collar.

During the reaction between the tool and the material a series of complicated thermodynamic processes occur, including heating up and cooling down of the material with different rates, plastic strain, as well as physical flow of the processed material around the tool. The heat plasticizes the friction stir processed material below the melting point. The thermal effect arising in the material and accompanying structural changes, including the shape and the dimensions of the zone being modified, depend on the treatment parameters (e.g. rotational speed of the tool), but also on the dimensions and construction of the working tool. The heat generated by the friction between the shank and the material surface constitutes 20% of the heat generated during the process, the rest is the heat given off due to the friction between the material surface and the front surface of the retaining collar. At this point, it is worth mentioning that during the treatment of the surface with the FSP method or the joining of materials in the FSW method the melting temperature of the materials being modified or joined is not exceeded, the process is of single-stage type, and because

the thermal energy source is the friction process, the FSW and FSP technologies represent entirely ecological solutions.

The attempts to modify the structure of materials with the FSP method are carried out on aluminum alloys, magnesium alloys, steels, and also composites with a metallic matrix. The FSP method may be used also for the creation of composite structures in the surface layer of the material by the introduction of a strange phase, e.g. carbon nanotubes, SiC, Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> particles, and others. An interesting research issue of the high application potential is the modification of the structure of magnesium alloys. Magnesium alloys are modern construction materials which due to advantageous mechanical properties and the lowest density when comparing with all other known technical alloys more and more effectively compete with aluminum alloys, steels, and even plastics.

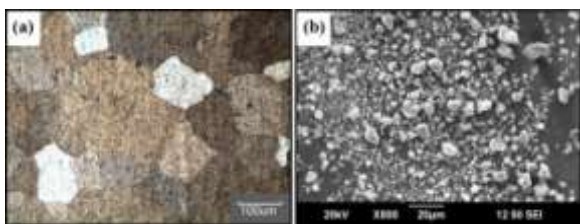
The decisive aspect for their application potential is low density (about 1.8 g/cm<sup>3</sup>), a one-third lower than the density of aluminum alloys, and almost 80% lower than steel density. This places magnesium alloys in the group of the most attractive and prospective metallic materials. Magnesium alloys are widely used in the automotive industry, aviation, electronics and electrical engineering. The changes in the structure of magnesium alloys occurring during the treatment with the FSP method, and in particular the refinement and homogenization, may contribute to the improvement of the plasticity and deformability of those alloys, and by this to the increase of their application attractiveness. Magnesium alloys are characterized by very limited ductility accompanied by brittle-like behavior at room temperature due to its intrinsic hexagonal close-packed crystal structure and a limited number of available slip systems. Taking into account the growing interest in magnesium alloys, as well as some application limitations for those materials, in this study an attempt was made to modify the AM60 alloy structure with the FSP technique, and to assess the structural changes and the changes of

selected properties of AM60 magnesium alloy generated by the treatment process.

## 2. Experimental set up

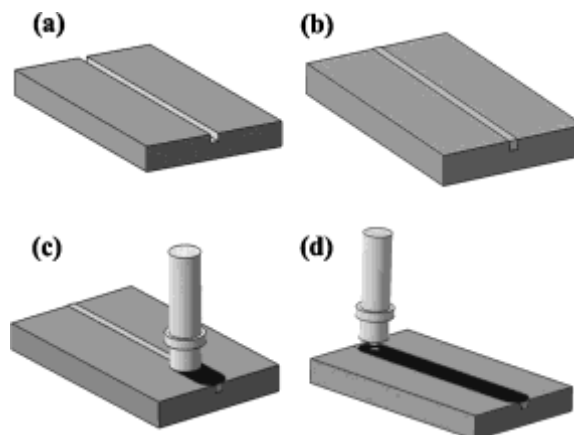
Friction stir processing reduces grain size by about 10 fold and improves the uniformity in grain structure. Friction stir processing of AA7039 increases ductility from about 13.5% to 23.6% while the ultimate and yield strength are adversely affected. 3. Friction stir processing of the 7039 alloy results in higher ductility longitudinal direction than the traverse direction. 4. The multi-pass friction stir processing produces higher hardness than the single pass friction stir processing. 5. Hardness of friction stir processed AA 7039 was lower than the unprocessed alloy. Aluminium alloy AA6082 plates of size 100 mm 50 mm 10 mm were used for this study. The optical photomicrograph of as received AA6082 plate is shown in Fig 1. A groove of 5 mm deep was made along the centre line of the plates using wire cut electrical discharge machining (EDM) and compacted with TiC powder.

Another plate without groove at the centre was also used in this study. The average size of TiC particles used in this work was 2 μm. The SEM micrograph of TiC particles is shown in Fig. 1b. A pinless tool was initially employed to cover the top of the groove after filling with TiC particles to prevent the particles from scattering during FSP. The tool had a shoulder diameter of 18 mm, pin diameter of 6 mm and pin length of 5.5 mm. The FSP was carried out on an indigenously built FSW machine. The process parameters employed were tool rotational speed = 1200 rpm; traverse speed = 60 mm/min and axial force = 10 kN. The FSP procedure to produce the composite is schematically shown in Fig. 3. FSP was processed using five such plates, varying the width of the groove (0, 0.4, 0.8, 1.2 and 1.6 mm) to have five level volume fractions of TiC particles (0, 6, 12, 18 and 24 vol.%). The theoretical and actual volume fraction of TiC particles are calculated using the following expressions:



**Figure 1.1:** (a) Optical photomicrograph of as received rolled (a)AA6082 and (b) SEM micrograph of TiC particles

The polished as per the standard metallographic procedure and etched with Keller's reagent. The digital image of the macrostructure of the etched specimens was captured using a digital optical scanner. The microstructure was observed using a metallurgical microscope and a scanning electron microscope. The micro hardness was measured using a micro hardness tester at 500 g load applied for 15 s at various locations in the composite. Mini tensile specimens of gauge length 21 mm and diameter 4 mm were prepared as per ASTM B557M-10 standard from the FSP zone. The ultimate tensile strength (UTS) was estimated using a computerized tensile tester.



**Figure 3:** FSP procedure to fabricate surface composite: (a) cutting a groove, (b) compacting the groove with ceramic particles, (c) processing using a pinless tool and (d) processing using a tool with pin.

The sliding wear behaviour of AA6082/TiC AMCs was evaluated using a pin-on-disc wear apparatus (DUCOM TR20- LE) at room temperature according to ASTM G99-04A standard. Pins of size 6 mm 5 mm 40 mm were prepared from the FSP zone of AMCs by wire EDM. The wear test was conducted at a sliding velocity of 1.0 m/s, normal force of 25 N and sliding distance of 2500 m. The polished surface of the pin was slid on a hardened chromium steel disc. A computer aided data acquisition system was used to monitor the loss of height. The volumetric loss was computed by multiplying the cross sectional area of the test pin with its loss of height. The wear rate was obtained by dividing volumetric loss to sliding distance. The worn surfaces of the test specimen were observed using SEM.

## 3. Results and Discussion

A typical crown appearance of friction stir processed aluminium with TiC particles will not be having no imperfections such as voids, cracks etc. on the surface. The top surface appears to be even and fine finish with no depression. The crown represents a smooth appearance. The top surface, i.e. crown of the friction stir processed zone contains a curved structure. This structure is similar to the conventional milling process, because FSW was derived based on the conventional milling process. Several trial experiments were conducted initially to select a set of optimized process parameters which were used for the production of the composites. The aforesaid defect free crown appearance is an evidence for the appropriate selection of the process parameters. A smooth crown appearance is essential in the processed zone, because surface imperfection in the crown causes various internal deficiencies in the AMC.

The effect of volume fraction of TiC particles on the macrostructure of AA6082/TiC AMCs is shown. The boundary of the FSP zone, which contains the AMC is marked using a continuous black line. It is evident from the figure that the area of the AMC decreases when the volume fraction of TiC particles is increased. The area of the AMC was measured using an image analyzing software. The area of the AMC was computed to be 65 mm<sup>2</sup> at 0 vol.% TiC and

34 mm<sup>2</sup> at 24 vol.% TiC. The reason for the reduction in the area of the AMC with the increase in volume fraction of TiC is detailed as follows. TiC particles were initially compacted into the groove along the centre line of the plate and the same tool is used without change in dimensions for FSP of all plates. The increase in volume fraction of TiC particles was achieved by increasing the width of the groove. The wider the groove, the more particles can be packed into the groove. Since the same tool was used, the theoretical area of the AMC matches with the projected area of the tool pin. The increased volume fraction of TiC particles is due to increase in groove width causes the following: (i) the content of TiC particles increases and (ii) the available aluminium matrix to be plasticized reduces. The increased content of TiC particles increases the flow stress to cause the plasticization of the AMC. This is due to non-deformable TiC particles, which resists the free flow of the Macrostructure of friction stir zone at groove width: (a) 0 mm (0 vol.%), (b) 0.40 mm (6 vol.%), (c) 0.80 mm (12 vol.%), (d) 1.20 mm (18 vol.%) and (e) 1.60 mm (24 vol.%).

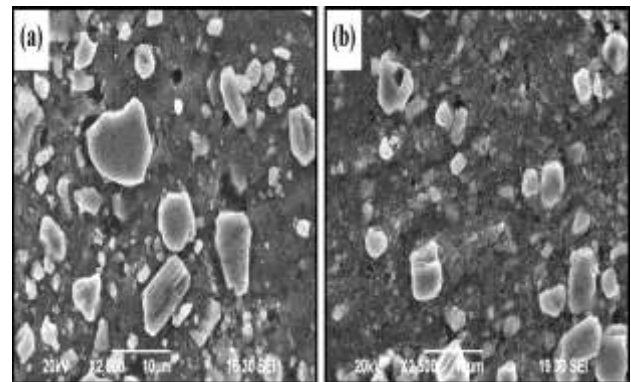
Plasticized aluminium. Further, the generated frictional heat drops down when the content of TiC particles is increased. TiC particles act as a heat sink and absorb the generated frictional heat, resulting in reduction in temperature of FSP zone. To plasticize the AMC, the net effect of higher flow stress is needed. Therefore, the area of the AMC reduces when TiC volume fraction is increased. The geometry of the AA6082/TiC AMCs is symmetrical about the axis of tool rotation. This can be attributed to the material flow characteristics at the selected process parameters. The width of the AMC reduces from the top surface to the bottom surface. Kumar and Kailas reported two different modes of material flow in the formation of FSP zone namely "pin driven flow" and "shoulder driven flow". The magnitude of resultant material flow varies across the depth. The shoulder driven flow of material is high at the top and less at the bottom. Therefore, the width of the AMC is lowest at the bottom. Typical FSW defects, including tunnel, pin hole or worm hole, etc. are not observed in the macrostructure of the AMCs. This indicates that the selected set of process parameters is appropriate to produce sound AMCs. Microstructure of AA6082/TiC

The optical micrographs of the prepared AMCs and in particular, indicates very fine equiaxed grains formed in the base alloy due to dynamic recrystallization during FSP. The intense plastic deformation and exposure to elevated temperature cause dynamic recrystallization which refines the grains of aluminium alloy AA6082. Dynamic recrystallization is a well-known established phenomenon in FSW and FSP. The optical micrograph of as received AA6082. Comparison of theoretical and actual volume fraction of TiC particles in AA6082/TiC AMCs close to the centre of the AMC. The threaded tool causes a vertical flow of the plasticized composite. The trapped TiC particles during the vertical flow might have formed the agglomeration while the particles in groove were mixed with plasticized aluminium.

The grains are not clearly visible because they are ultra-fine in nature. The grain size in the AMC is significantly lower compared to friction stir processed AA6082. The grain

refinement can be attributed to the presence of TiC particles in the AMC because TiC particles acted as an effective grain refiner. The TiC particles pin the movement of the grain boundary and retard the grain growth subsequent to dynamic recrystallization. This is known as pinning effect which produces finer grains in AMCs. The stirring action of the tool and the intense plastic strain were known to break the ceramic particles during FSW/FSP and change their size and morphology. But there is no appreciable change in size and morphology before and after FSP comparing. TiC particles retained the original size and morphology, which can be attributed to their initial smaller size. This result agrees with the findings of Chen et al.] who did not observe fragmentation of B<sub>4</sub>C particles in FSW of AA6063/B<sub>4</sub>C AMC due to its smaller size.

The details of the interface between the TiC particles and the aluminium matrix can be observed at higher magnification provided in SEM micrographs. It is observed from the figure that the interface is very clear without the presence of any reaction products or micro pores. A clean interface increases the load bearing capacity of the AMC. The plasticized aluminium matrix might have wetted or spread over the entire surface of the TiC particles during mixing, which may avoid the formation of micro pores. The temperature of the process plays a key role to initiate any kind of reaction between the TiC particle and the matrix. Lee et al. exclusively analyzed the various reaction products at the interface of TiC and aluminium matrix in Al/TiC AMCs prepared by infiltration casting route. The local temperature developed during FSP is very low compared to liquid metallurgy routes to initiate interfacial reaction.



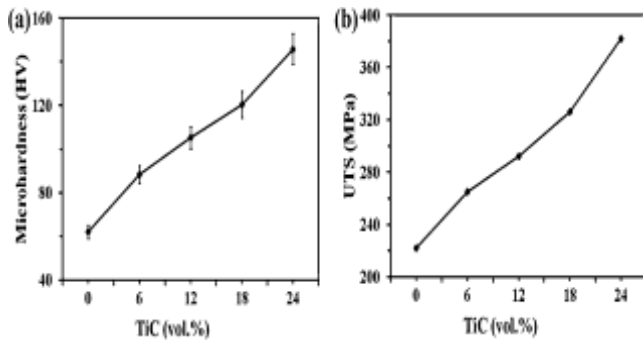
**Figure 9:** SEM micrograph of AA6082/TiC AMCs at higher magnification containing: (a) 18 vol.%, and (b) 24 vol.%

Effect of TiC content on: (a) microhardness and (b) tensile strength of AA6082/TiC AMCs matrix alloy. The thermal mismatch and differential deformation creates additional dislocations in the AMC. The increased dislocation density raises to the resistance to the motion of dislocation across the material. The excellent interfacial bonding between the aluminium matrix and the TiC particle brings the load transferring mechanism into operation. The effective transfer of load from the aluminium matrix to the TiC particles strengthens the AMC. Further, the grain size of aluminium matrix is reduced by the TiC particles. The smaller grain in the AA6082/TiC AMC increases the area to resist the tensile load. Therefore, the mechanical properties of the AMCs are improved. typical tensile specimen before and after the tensile testing. The effect of the above discussed



mechanisms increases as the volume fraction of TiC particles increase. For instance, the average inter-particle distance decreases with the increased volume fraction which will provide more resistance to the movement of dislocation. Hence the mechanical properties of the AMC increase with the increase in volume fraction of TiC particles.

The fracture surface of AA6082/TiC AMCs at various volume fractions of TiC particles is found from the figure that a network of fine dimples is observed on the fracture surface of friction stir processed aluminium alloy AA6082 It indicates that the fracture mode is ductile



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#### Conclusion

AA6082/TiC AMCs were synthesized using the novel method of FSP and the effect of TiC particles along with its volume fraction on microstructure, mechanical and sliding wear behaviour was analyzed. The following conclusions are derived from the present work. The volume fraction of TiC particles influenced the area of the composite. The area of FSP zone was observed to be 65 mm<sup>2</sup> at 0 vol.% and the area of the composite was 34 mm<sup>2</sup> at 24 vol.%.The

distribution of TiC particles was fairly homogenous in the composite irrespective of the volume fraction. AA6082/TiC AMCs exhibited a reduction in the average grain size.

TiC particles retained the initial size and morphology without fragmentation during FSP. A clean interface was noticed between TiC particles and the aluminium matrix.

TiC particles strengthened the AMC. Both the microhardness and the UTS increase when the volume fraction of TiC particles was increased. The microhardness was found to be

62 HV at 0 vol.% and 149 HV at 24 vol.%. The UTS was estimated to be 222 MPa at 0 vol.% and 382 MPa

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