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# Production of Surface Composites by Friction Stir Processing -A Review*

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**Abstract**

Friction Stir processing (FSP) is a novel method derived from friction stir welding process in which a groove or hole was made was made in the matrix material in which reinforcement particles are dispersed using a tool. This paper gives the information on the various matrix material and reinforcement particles used. The Microstructure using scanning electron microscope (SEM), micro hardness using Vickers hardness testing technique, tool material used and effect of parameters like tool rotational speed and traverse speed were studied. Important suggestions for the new researchers to produce efficient surface composites that are useful for practical applications of friction stir processing.


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*Keywords:* Surface Composites, SEM, Micro hardness.

## 1. Introduction

Friction stir processing is a novel solid state technique which is derived from friction stir welding for producing surface composites by the changing surface microstructure. In this method a non consumable material is used as a rotating tool with a pin and shoulder, which is plunged into a work piece and moved in the direction of interest. The axial force on the tool makes the tool and work piece to contact producing heat. This heat generated by rotating


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shoulder makes the material soft and flow around the tool resulting in the plastic deformation and grain refinement leading to the production of ultra fine grained material. Reinforcement particles were incorporated in the matrix surface by two ways one is making a groove and the other is by drilling a hole. The wastage of reinforced particles during friction stir processing was limited by using shoulder and a pin type tool. In this review paper the various matrix material and reinforcement particles used, microstructure using scanning electron microscope (SEM), micro hardness using Vickers hardness testing technique, tool material used and effect of parameters like tool rotational speed and traverse speed were discussed.

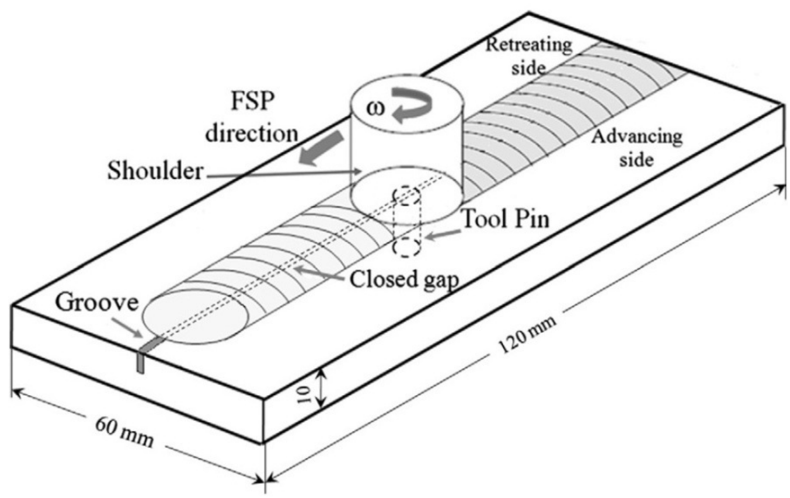


Fig.1 Schematic Diagram of FSP setup

**Nomenclature**

| | |
|---|---|
| FSP | Friction Stir Processing |
| SEM | Scanning Electron Microscope |
| XRD | X Ray Diffraction |
| TEM | Transmission Electron Microscope |
| SZ | Stir Zone |
| TMAZ | Thermo Mechanically Affected Zone |
| BM | Base Metal |

## *2. Literature Survey on Experimental Details*

H. G. Rana quoted that the dimensions of base plate Al7075 were 6.5 mm thick with 100 mm length and width. A groove of 1.2x2.5x100 mm was made on the base plate for reinforcement using a shaper machine, B4C was filled in the groove with size 12-15µm. A pin less tool is used to close the groove cavity and pin having a taper cylindrical profile were used for stirring passes. Tool tilt angle of $3^0$ and traverse speed of tool is varied by keeping tool rotational speed constant at 545 rpm [1]. H.Eskandari.et al. quoted that Al alloy as a matrix $TiB_2$, $Al_2O_3$ Nano particles as reinforcement were used for producing high wear resistance, high specific strength and high elastic modulus surface composites. 8026 Al alloy plate with 5 mm thickness and mixtures of $TiB_2$ with an average size of 5µm and $Al_2O_3$ powder particles size of 70 nm were used. Pin and Shoulder type tool was used with length and diameter of pin equal to 5 mm and diameter of the tool shoulder as 18 mm. The material of the tool was H13 tool steel with 52RC hardness. A groove was made with dimensions, depth 4.2 mm and 1.2 mm width [3]. Ranjit Bauri et al. investigated that Al 5083 alloy was the matrix and Ni particles with average particle size of 70 µm as reinforcement. A groove of 1 mm wide and 2 mm depth with 50 mm length was made on the plate on which Ni particles were filled. The tool used was made up of hardened steel with pin length 3.5 mm, pin diameter 5 mm and shoulder diameter 15 mm. [4]. Akash Gupta et al. gave the effect of tool profiles such as cylindrical and truncated probe tool to analyze the defects produced at two different feed rates 40 mm/min and 50 mm/min. They observed that the defects produced by truncated tool profile are lesser than cylindrical tool profile. Friction stir processing was done on AZ31 Magnesium alloy which has very good strength to weight ratio. The tool material used was H13 with shoulder diameter 18 mm pin diameter 6 mm and pin length 5.36 mm. A constant tilt angle of $1.8^0$ was given for effective stirring action of the tool and avoids rubbing action of leading edge of shoulder [5]. R. Ramesh et al. Investigated the average hardness of friction stir processed surface composite which was 62% higher compared to the base metal of Al7075-T651. Al7075-T651 was used as matrix and $B_4C$ particles as reinforcement. The improvement in hardness is due to uniformly distributed $B_4C$ particles. A groove of 0.5x2.5x100mm was made on the plate. The tool used was made up of high carbon chromium steel with cylindrical profile surface [9]. S. Gholami et al. reported that Al 7075 alloy sheet of dimensions 250x50x10 mm was used as material for friction stir processing. This material was solution treated and rapidly quenched at room temperature to get supersaturated solid solution. The material was cleaned with acetone. Friction stir processing was carried out at 1200 rpm rotational speed and 50 mm/min of traverse speed. H13 tool steel was used as material for tool with concave shoulder and tilt angle of $3^0$. Aging is done to the specimen and microstructure was investigated using optical microscopy, scanning electron microscopy and transmission electron microscopy. [6].

E.R I. Mahmud et al. Fabricated an Al 1050-H24 plate by incorporating SiC and $Al_2O_3$ powder into a groove of 3 mm width and 1.5 mm depth. A square probe shaped tool at a rotational speed of 1500 rpm and traverse speed of 1.66 mm/s was used to produce a hybrid composite [18]. A. A .Zadeh et.al Reported that the material used for friction stir processing was cast A356 plate of 10 mm thickness with SiC powder, having average particle size of 30µm and $MOS_2$ powder with 5µm average particle size as hybrid reinforcement. The tool was made up of hardened H-13 tool steel with columnar shape shoulder. The process parameters such as rotational speed and traverse speed were 1600 rpm and 50 mm/min respectively. The powder is filled in a groove of dimensions 3.5x0.6 mm [17]. H.R Akramifard et al. Performed friction stir processing on a pure Cu sheet with dimensions of 100x70x5 mm plate. SiC particles with average particle size of 25µm were filled in holes which were made on the Cu sheet as reinforcement. Rotational speed and traverse speed used were 1000 rpm and 50 mm/min respectively. The samples were prepared by an etching process [8]. H.B. Cui et al. Quoted that a 4.4 mm thick AISI 2.1 stainless steel plate was friction stir processing at rotational speeds of 500, 800, 1000 rpm with traverse speed of 100 mm/min and 1000 rpm with traverse speed of 50 mm/min. The tool material used was W-Re tool with columnar shaped pin of 3 mm diameter and 20 mm diameter shoulder [2].

## *3. Review and Discussion*

### *3.1 Microstructure*

H. G. Rana et al. Identified three zones were during micro structural observation, recrystallized fine grained microstructure was observed and accumulation of $B_4C$ was identified due to insufficient stirring. Fracture surface was also identified in the nugget zone, defects like porosity and worm holes were identified due to low rotational speed [1]. H.Eskandari.et al. Quoted from the SEM images it was found that $Al_2O_3$ and $TiB_2$ particles were distributed uniformly in the Al matrix and the bond interface between $Al_2O_3$ particles and matrix was good resulting in improved strength [3]. Ranjit Bauri et al. Investigated the solubility of Ni in Al is 0.05wt% and forms intermetallics like $Al_3Ni$. Here there was no intermetallics formation found by XRD. From the SEM images a uniform and a thick layer of the second phase has formed around the particles which is below the detection limit of XRD. TEM images shows fine and equiaxed grains [4]. R. Ramesh et al. Reported due to fine dispersion of $B_4C$ particles the hardness has increased 1.5 times that of the base metal [9]. S. Gholami et al Observed from the microstructure of the base material and friction stir processed Al7075 the grain size decreased from 50$\mu m$ to 500nm which was 10-12 times reduction of size from base metal to friction stir processed Al7075 and also equiaxed grains was found in the friction stir processed material. After aging coarser precipitates was observed in the grain boundary which has improved hardness [6]. E. R. I. Mahmud et al. investigated that the reinforced particles were distributed uniformly without any defects except small voids around the $Al_2O_3$ particles [18]. A. A. Zadeh et. al. Found from the SEM images the top surface was very smooth and defects like voids and cracks were not observed. SiC and $MOS_2$ particles were found to be dispersed uniformly over the entire surface. [17].H.R Akramifard et al. Reported that the microstructure was separated into three zones i.e. stir zone (SZ), Thermo mechanically affected zone (TMAZ) and Base metal (BM). From SEM images large equiaxed microstructure was observed in BM with grain size 120µm. Uniform distribution of SiC particles was observed in SZ due to multi pass friction stir processing [8]. H.B. Cui et al. quoted that coarse grains were found in the base metal ranging from 30-80µm. Three zones were identified such as SZ, TMAZ and BM. They found dislocations on advancing side with high density at low rotational speeds and rapid decrease of dislocations in SZ because of cooling rate [2].

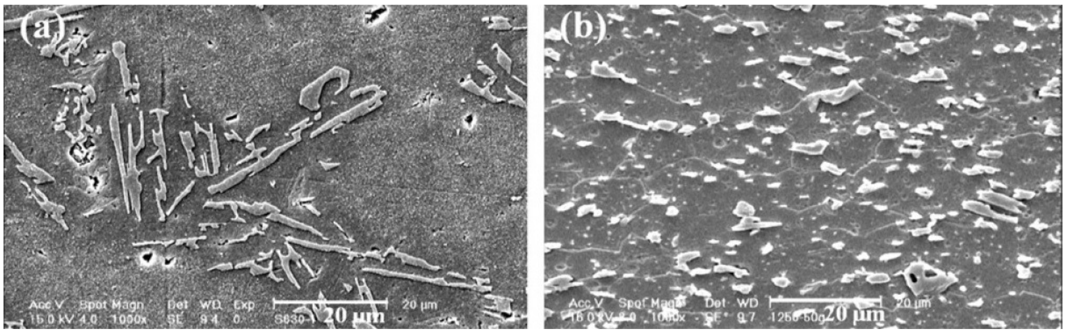


Fig. 2 SEM Images of Microstructure of (a) Cast A356, Interdendritic Distribution of Si particles, (b) FSPed A356, Si Particles Distribution

### *3.2 Microhardness*

H. G. Rana et al. observed an increase of 40-70% hardness compared to the parent metal using Vickers hardness tester at 300 gm load with 10 seconds of dwell time. They found that the hardness was reduced due to reduction in stirring times and increase in traverse speed [1].

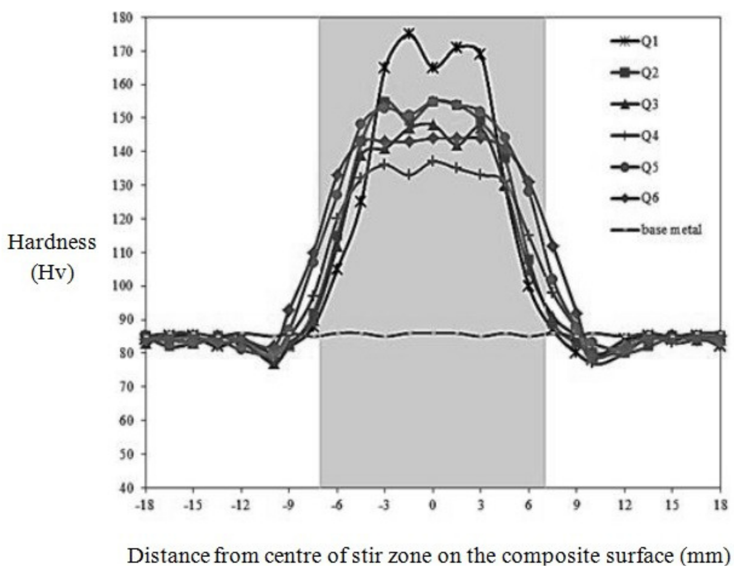


Fig. 3 Hardness Variation for Base Metal and Surface Aluminum Reinforced Composites.

H.Eskandari.et al. quoted that the hardness of base metal is about 85HV, after reinforcing $TiB_2$ and $Al_2O_3$ particles on surface hardness was found to be 175HV.with increase in tool rotational speed and decrease in traverse speed the hardness was reduced. Increasing the number of passes improved the hardness [3]. Ranjit Bauri et al. Quoted that the hardness of base metal was 81HV and improved to 91HV by friction stir processing. This increase is based on grain refinement and Ni particle distribution [4]. E. R. I. Mahmud et al. observed that the average hardness was decreased with a decrease in SiC and an increase in $Al_2O_3$ particles [18]. A. A .Zadeh et al. Found that the hardness of base metal was increased with the presence of SiC particles compared to composite having SiC there was a reduction in hardness due to $MOs_2$ particles [17]. H.R Akramifard et al. stated that the microstructure in SZ is much higher than that in BM [8]. H.B. Cui et al. Reported that the hardness in all SZ's was slightly higher than in base metal. In some places the hardness was 260HV which was due to severe plastic deformation during friction stir processing [2].

### *3.3 Effect of Tool Parameters*

Kurt et al. Reported that the distribution of Sic particles in AA1050 alloy was uniform with an increase in rotational and traverse speeds. Very high traverse speed resulted in a weak bond with the Al alloy substrate [11]. Asadi et al. observed that with increase in rotational speed there was increase in grain size and increase in traverse speed there was a reduction in grain size [19]. V. Sharma et al. reported some of the successful combinations of rotational and traverse speeds listed in table-1 [7].

Table-1 Successful Combinations of Rotational and Traverse Speeds.

| **Matrix/reinforcement** | **Rotational speed (rpm)** | **Traverse speed (mm/min.)** | **Reference** |
|---|---|---|---|
| (SiC+MoS2)/A356 | 1600 | 50 | Alidokht et al.(2011) |
| Sic/AZ91 | 900 | 63 | Asadi et al.(2010) |
| $Al_2o_3$/AZ31 | 800 | 45 | Azizieh et al.(2011) |
| Sic/Cu | 900 | 40 | Barmouz et al.(2011a) |
| Nano-clay/Polymer | 900 | 160 | Barmouz et al.(2011c) |
| Tic/Al | 1000 | 60 | Bauri et al.(2011) |
| Sic/AA5052 | 1120 | 80 | Dolatkhah et al.(2012) |
| (Sic + Al2O3)/AA1050 | 1500 | 100 | Mahmoud et al.(2009b) |
| $Al_2o_3$/AZ91 | 1600 | 31. 5 | Faraji et al.(2011) |
| SiO2/AZ91 | 1250 | 63 | Khayyamin et al.(2013) |
| Sic/AA1050 | 1000 | 15 | Kurt et al.(2011) |

## Conclusion

Friction stir processing has become a versatile technique for the production of surface composites. Due to large plastic strain in FSP it offers ease of particle distribution on the surface. Agglomeration of fine particles can be avoided by friction stir processing. There was a significant increase in the properties like Microhardness, Wear resistance, Grain refinement, Strength and Young's modulus. Defect free Hybrid composites comprising different reinforcements have been produced. The optimum tool parameters play a vital role in producing sound surface composites. Tools made of tungsten based alloys are recommended for producing defect free sound surface composites. High cost and low fracture toughness limit the usage of tungsten based alloys. Composites based on magnesium and aluminum alloys were produced by FSP so far.

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