Fabrication of Aluminium Metal Matrix Composite by Friction Stir Processing - A Review

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Abstract: **Friction Stir Processing (FSP) is a new approach for successful fabrication of Aluminium Metal Matrix Composites (AMCs) with required properties of Nitinol (NiTi) Shape Memory Alloys (SMA). This reinforcement agent is used for heightening the mechanical properties of aluminium alloy with Shape Memory Effect but such fabrication was not possible without defects such as critical intermetallic formation between reinforced particles and matrix. So we present a creative strategy to fabricate Al7075-T6/NiTi composites by FSP. It has been found that the groove filling method results in a more homogenous distribution compared to the multi-holes filling method. In this innovative strategy, we are going to use the groove filling method with a new FSP tool design for the linear distribution of reinforcement particles in grooves. This FSP tool will be used with the help of a Vertical Milling Machine.**

Keywords: **Metal Matrix Composites, Friction Stir Processing, Shape Memory Alloys, Microstructure Defects, Homogeneous Distribution**

Introduction

Embedding particulate reinforcements in aluminium matrices to form Aluminium Matrix Composites (AMCs) is an attractive, alternative, and innovative process to enhance the mechanical properties of aluminium alloys. In the previous studies of **Heinz et al. (2000)** and **Williams and Starke (2003)**, the authors have shown that high-strength aluminium alloys, especially Al7075, are widely used in the aerospace industry due to their high strength-to-density ratio. [1]

Prakrathi Sampath, Vineeth Krishna Parangodath, Kota Rajendra Udupa, Udaya Bhat Kuruveri (2015) Friction Stir Processing is a novel solid-state mechanical technique in synthesizing MMNCs with a focus on surface and subsurface region and was developed with the concepts of friction Stir Welding. The surface properties of a material can be modified without changing the bulk properties of the base metal. FSP can alter surface properties according to the requirements. The working tool has 2 main parts- a rotating tool with a pin and shoulder. Rotating tool with a pin inserts into the material surface and moves. Functions of a rotating tool are (1) heating the specimen in the localized zone (2) moving and transporting the materials within the processing zone and (3) facilitating mixing up of base material and externally added material to produce a composite material within the processed zone. After completion of the process, a metal matrix composite with higher wear resistance and hardness is formed. [2]

Sharma et. al (2015) introduced reinforcement particles into the aluminium matrix to develop superior mechanical properties, such as tensile strength. [3]

Ramesh and Murugan the experimented with AA 7075-T651 plates. The thickness of the plate is 6.35 mm with a depth of the groove is 2.5 mm, 0.5 mm width, and 100 mm length along with the plate. The reinforcement particle used is Boron carbide powder with the diametric size of 5 micrometers and that is used to fill the grooves. They used one pass and multi passes up to 3 and found the maximum hardness of 64 BHN at rotation speed 575 rpm and travel speed 60 mm/min with 2 passes. A rise of 62% was found in the average hardness of the processed surface than that of the base metal AA 7075-T651. [4]

Sudhakar et. al after studying the processing of base material Al7075-O alloy with reinforcement material of Boron Carbide of the diametric size of 30 μm, at 960 rpm rotating speed and 60 mm/min traveling speed maximum hardness and tensile strength were achieved. [5]

Yongxian et. al done fabrication of AZ31 Mg matrix composite using reinforcements material such as carbon nanotubes of SiC. The process used is Direct Friction Stir Processing (DFSP) to generate a composite surface. In this method of DFSP, there is no such need for grooves to insert ceramic powder. DFSP method has increased the microhardness of the surface from 57.77 HV to 115.51 HV using a hollow tool and without a pin to modify the composite surface. DFSP is used on the AZ31 plate and found the thickness of the composite layer of 150 μm.

In the recent study, a new tool design is proposed. FSP tool with a pin is used to add SiC particles directly to the stirring zone through holes in the shoulder face. The FSP tool pin has proved to be advantageous in improving the mixing process of ceramic particles with base metal and increased the heat generated by friction. Different size particles are used to study the effects of particle size on the hardness of AA7075-T651 alloy. During the process, mechanical pressure is applied using a helical spring so that ceramic particles fall into the groove. [6]

Experimental Procedure

Aluminium AA7075-T6 plates of size 200 x 50 x 6.35 mm were used. The chemical composition of AA7075-T6 is given in Table 1. The tool is made of high chromium alloy steel, The FSP process parameters are identified as rotational speed (RS), traveling speed (TS), and particle size of NiTi and Al7075-T6 (PS).

The addition of NiTi particles and Al7075-T6 particles into the matrix alloy significantly increases the hardness and decreases elongation of the composites in comparison with those of the base alloy [7]. NiTi with two different particle sizes 19 and 3.5 μm. NiTi and Al7075 powders 19 μm and 3.5 μm have specifications shown in Table 2. Particles sizes are selected according to previous references [8].

A vertical milling machine was used to prepare the FSP plates, see Figure 2. The experimental parameters were selected as shown in Table 3. The specimens were prepared from the FSP samples.

The Tool design is shown in Figure 3. The hollow tool is used to fill it with NiTi and Al7075-T6 particles. The thickness of metal for the shoulder face is 5 mm. The generated heat equation below shows the thickness of the shoulder isn't an effective factor for shoulder thickness on the amount of generated heat.

$$q = \delta E \mu PN \, (r\omega - vx \sin\theta) \qquad\qquad (1)$$

Where:

δE	=	Slip ratio
μ	=	Coefficient of friction between the FSP tool and the surface of the material
PN	=	The pressure exerted by the tool on the material being processed
ω	=	Tool rotational speed
r	=	The distance between the tool axis and a tool surface fragment under consideration
vx	=	tool travel rate
Θ	=	angle between the tool axis and a fragment under consideration [8].

A thin disc of polystyrene foam has a thickness of 2 mm; it is placed inside the tool cavity to prevent the fall of the Al7075T6 and NiTi powder at the beginning of the process. At the beginning of the FSP process, the heat of the tool rises gradually to reach a high temperature near 80 percent of the melting temperature of the base metal (about 381.6 °C) [9]. At 240 °C temperature, the polystyrene disc will melt and evaporate [10], which allows the powder particles to pass through holes. After the disk evaporating, powder particles will extrude through holes due to the pressing of the piston due to releasing of compressed spring. A piston of steel is put in the cavity after filling the tool with 2 grams of NiTi and Al7075-T6 powder. It has been used to push the powder. A helical spring is used to supply a continuous force to press the Mixed Powder to extrude through the two holes, see Figure 3. A piece of aluminium foil is placed on the shoulder to close two holes before starting the process After starting the foil will tear by friction between the shoulder and workpiece surface and polystyrene will melt and evaporate due to the increased temperature of the tool when the tool shoulder starts to touch the workpiece.

The experiments were designed based on two level-three factors factorial technique. The developed and design matrix is shown in Table 4. Four samples were prepared as shown in Table 5. Four specimens were prepared for surface inspection. After mounting and preparing the specimens, they are inspected by Vickers hardness test. Microhardness is measured on the upper surface and thickness side of the processed surface.

Table 1: Chemical Composition of Al 7075-T6 Alloys

Element	Zn	Mg	Cu	Fe	Si	Mn	Cr	Al
Wt%	5.85	2.51	1.65	0.1	0.040	0.03	0.2	Bal

Table 2: NiTi and Al7075-T6 Powder Specifications

Median grain size (μm) of Al7075T6	(a) 3.5+-0.5 or (b) 19+-0.5
Median grain size (μm) of Nitinol	(b) 3.5+-0.5 or (b) 19+-0.5
Purity	97+-97.8

Table 3: Selected Parameter for FSP

Rotating Speed (rpm)	Traveling Speed (mm/min)	Particle Size (μm)
930	40	19
1460	60	3.5

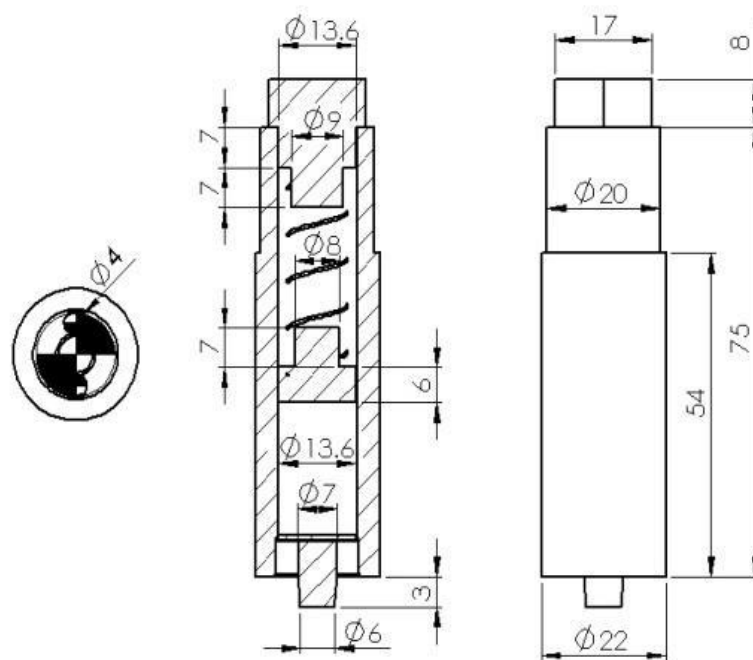Figure 1: Vertical Milling Machine Used for FSP

Figure 2: Sketch of Tool Design and its Dimensions
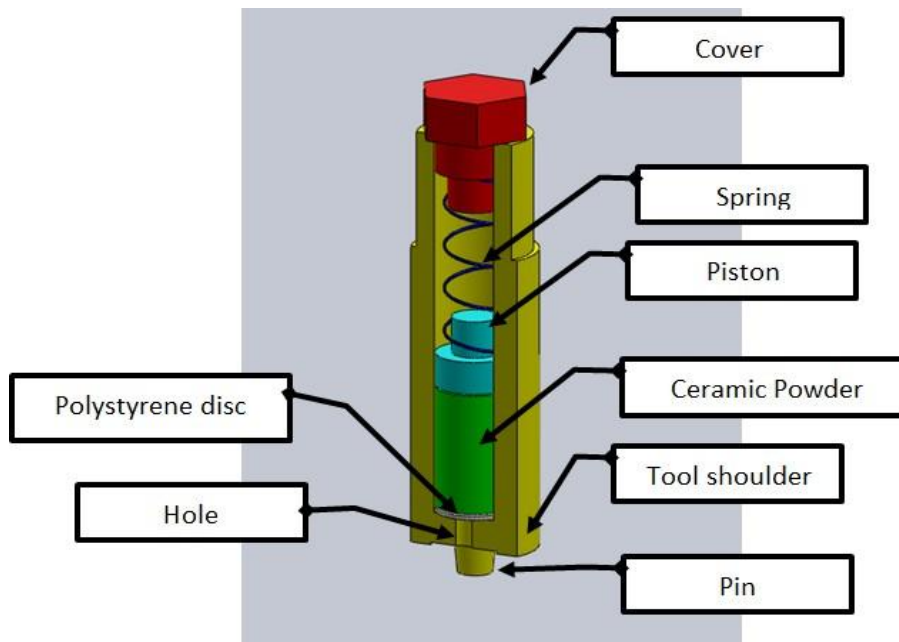
Figure 3: Section View for Tool Assembly

Table 4: Design Matrix and Estimated Values

Experimental Trial	Design Matrix		
	RS (rpm)	TS (mm/min)	PS (μm)
1	930	60	19
2	930	40	3.5
3	1460	60	3.5
4	1460	40	19

Results and Discussion

Microhardness is measured for the four surfaces. In table 5 microhardness for 4 specimens is presented. In figure 4 the hardness measurements are presented. The highest microhardness is of specimen S3 shown in Figure 5. Al7075-T6 softens and its hardness drops in the processed zone refer to Figure 6. After adding the NiTi and Al7075-T6 particles to the alloy surface, the hardness increases due to the insertion of the hard particles in the alloy. The increase in hardness was attributed to the presence of powders that have a high modulus of rigidity and for fine dispersion of NiTi and Al7075-T6 particles and fine grain size of the Aluminium matrix [12]. Pressing the NiTi and Al7075-T6 powder in the stirring zone improves the distribution and insertion in the base metal. The effects of traveling speed, rotating speed and SiC particles size on hardness were presented in Figure 7. By using the mathematical equations, graphs have been plotted between traveling speed vs Vickers hardness, Rotating speed vs Vickers hardness and particle size of particles vs Vickers hardness. From Figure 7 it has been observed that when the traveling speed increases hardness due to the reduction in heat input increases. when traveling speed is low the amount of heat input is high due to stirring and friction effects which will be in the same area for a long time. When traveling speed increase the heat input for the same area (as mentioned before) will be for a lesser time, therefore the growth of base metal grains will be less.

Table 5: Average Hardness of Specimen's Measurements

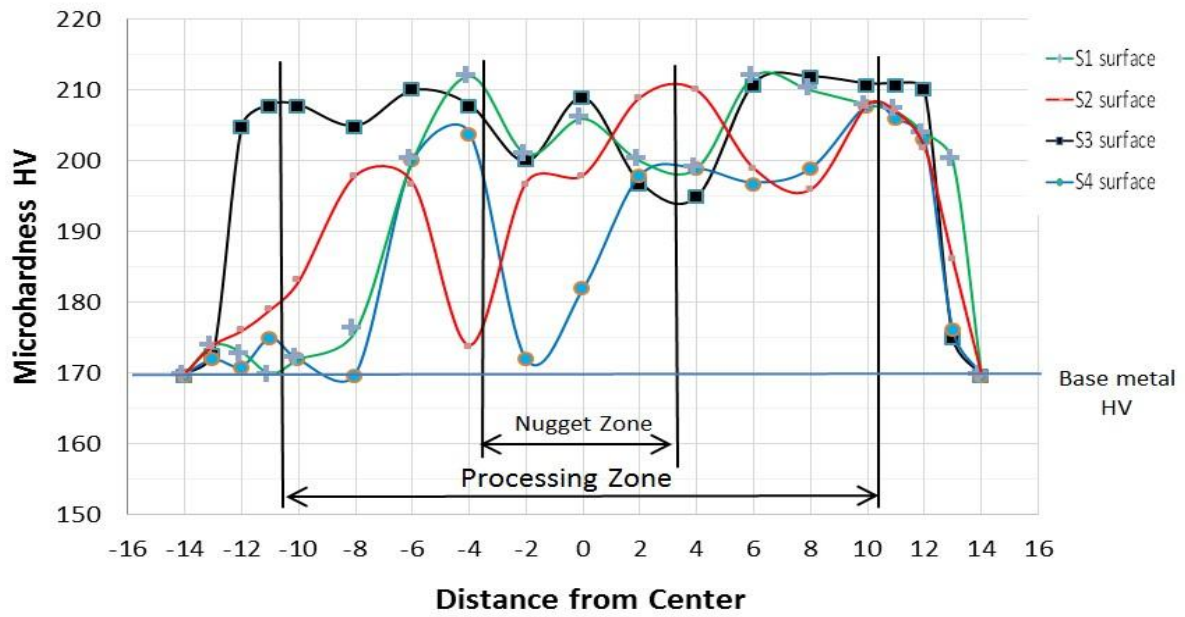| Specimens No.	Parameters			HV
	RS (rpm)	TS (mm/min)	PS (μm)	
S1	930	60	19	?
S2	930	40	3.5	?
S3	1460	60	3.5	?
S4	1460	40	19	?

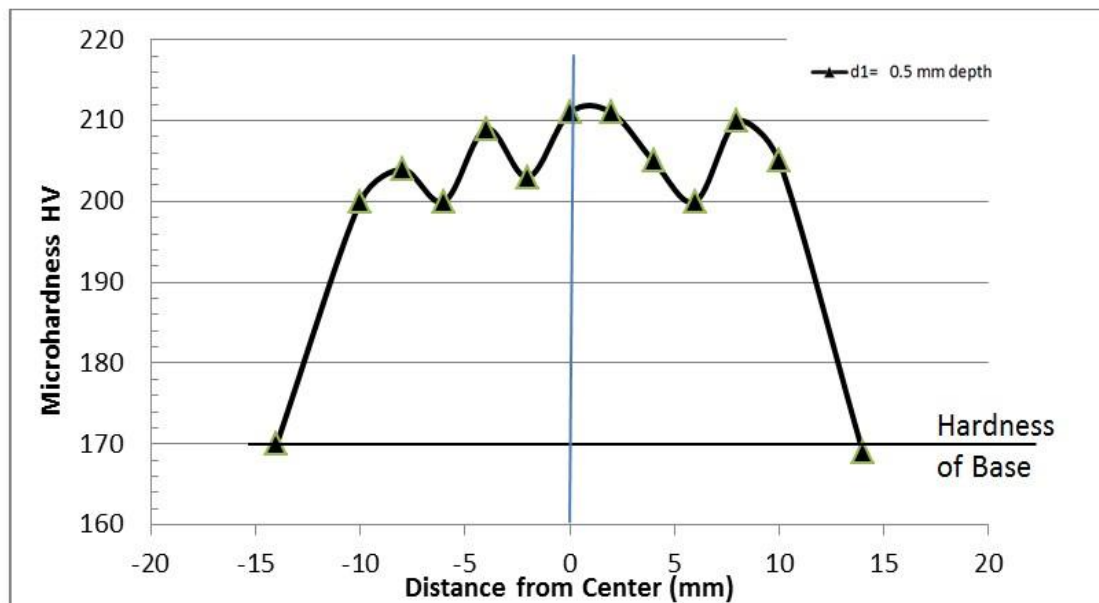Figure 4: Hardness Measurement for Processing Surface

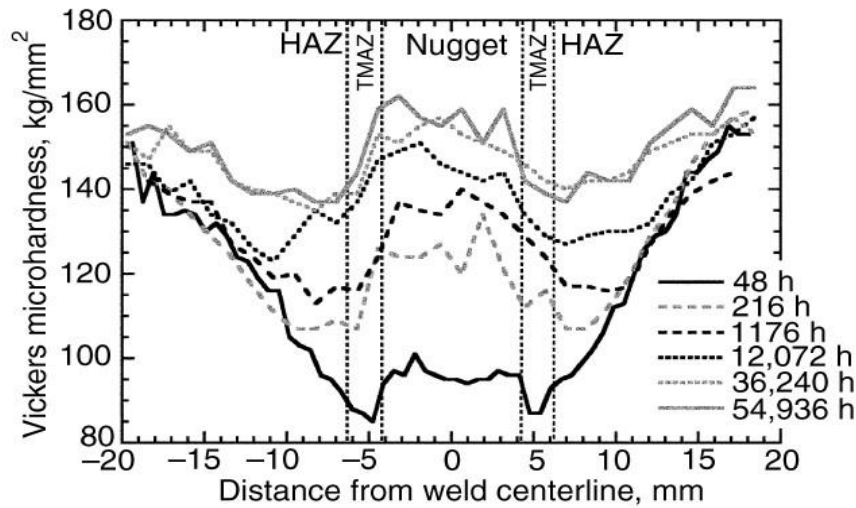Figure 5: Hardness Measurement for Specimen S3

Figure 6: Effect of FSP on the Hardness of Welded Joint of Al 7075-T651
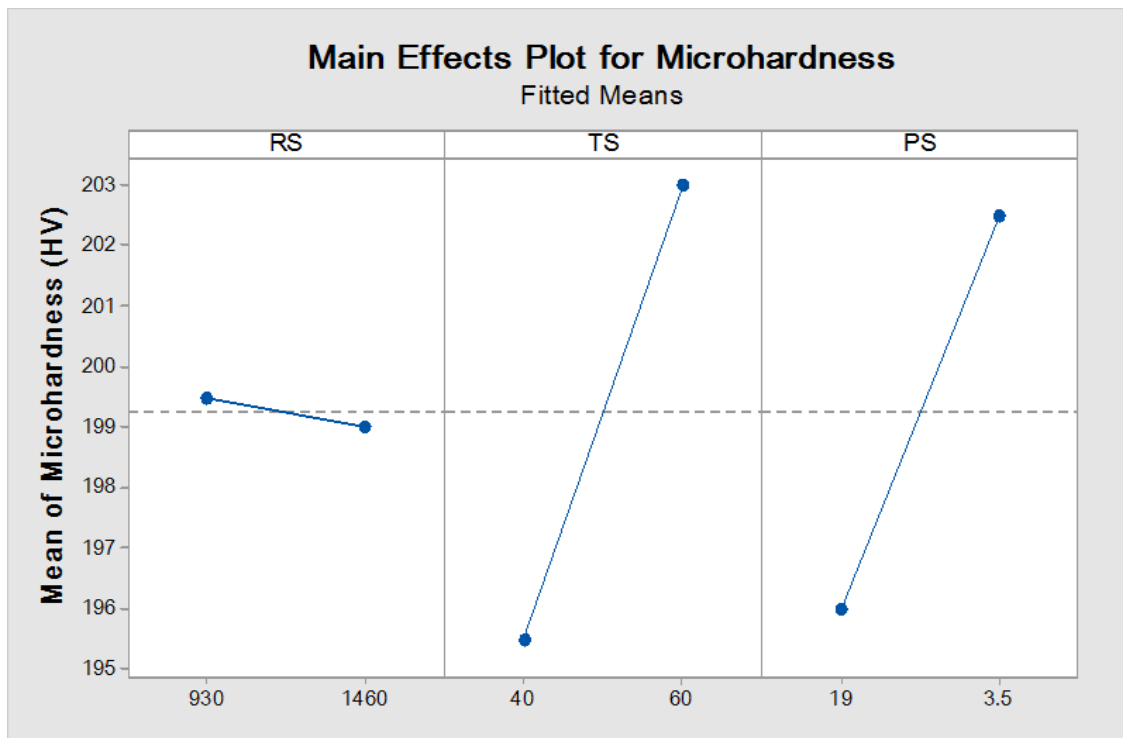after Different Hours (h) for Natural Aging [13]

Figure 7: Effect of Parameters of
Rotating Speed (RS), Traveling Speed (TS), and Particle Size (PS) on Hardness

Conclusions

From the recent study, it can be concluded that:

1. The microhardness value will be highest when the processing speed is 1,460 rpm and traveling speed is 60 mm/min respectively.
2. FSP using particle size 3.5 µm of NiTi and Al7075-T6 particles will show better microhardness results.
3. Surface hardness will increase drastically by using a new tool designed for FSP. Mechanical pressing of the powder succeeds in inserting the NiTi and Al7075-T6 particles into the processing zone.

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