

## Effects of TiC, B<sub>4</sub>C and Al<sub>2</sub>O<sub>3</sub> Nanoceramic Reinforcement Particles on Friction Stir Welding of AA7075

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**Abstract** - The most optimal combinations of both physical and mechanical properties are produced by carefully choosing the matrix and reinforcement in a metal matrix composite (MMC). Due to their superior strength and corrosion resistance, precipitation-hardened aluminum alloy 7075 is mainly used in aerospace applications. In this study, Aluminium alloy 7075 metal matrix composites have been fabricated (three samples) by reinforced with nano ceramic particles at different weight ratios (1.0, 1.0 and 1.5 wt. %) of Titanium carbide (TiC), (0.5, 0.0 and 0.0 wt.%) of boron carbide (B<sub>4</sub>C) and (0.5, 0.8 and 0.5 wt. %) of Aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) using friction stir casting process. Also, for those samples, friction stir welding process has been carried out. Microstructural analysis has been done by optical microstructures (OM). Specimens for impact strength (based on ASTM E23 standards) have been prepared for the welded joints of aforesaid samples. The significant improvement of hardness (78 Hv) has been observed in weld sample-1, which has the combination of 1.0 wt.% of TiC, 0.5 wt.% of Al<sub>2</sub>O<sub>3</sub> and 0.50 weight percent B<sub>4</sub>C. But, the Impact strength of the Sample 1 is significantly decreased instead of increasing compare to samples 2 and 3. Finally, based up on the micro structural results, it was noted that significant improvement of fine grain structure by the reinforcement effect of nano ceramic particles with base alloy.

**Keywords:** Metal matrix composites (MMC), friction stir welding (FSW), Titanium carbide, Boron carbide and Alumina

### 1.0 Introduction

It is becoming an increasingly relevant issue of discussion for many countries due to the rising concern over greenhouse gas emissions, reducing carbon dioxide emissions, and reducing fuel consumption in the automotive and aircraft industries. Numerous industries, such as the automotive and aerospace sectors, are looking at ways to lighten the overall weight of their products. Low density materials like aluminum and magnesium have taken the place of ferrous materials and high strength steels. These materials exhibit promising results to replace steel in both aerospace and automotive vehicles to lower overall weight due to their low density and excellent mechanical strength. Because of the lighter weight, less fuel is used, which lessens the environmental impact of carbon dioxide emissions. Metal matrix composites (MMCs) are widely employed because of their high specific strength,

high stiffness, resistance to wear and creep, and use in structural, transportation, electrical, and thermal applications [1-4]. Traditional fusion welding procedures provide several challenges, such as solidification shrinkage and porosity caused by the aluminium matrix's high thermal expansion and conductivity, as well as the ceramic reinforcement's high melting temperature and viscosity. Friction stir welding (FSW) is an emerging solid-state process that uses friction between a non-consumable rotating steel tool and the metal substrate to melt and weld them together, which is alternate fusion welding. FSW has several process attributes including geometry of tool pin, downward pressure, tool tip tilt angle, welding speed, and rotation speed [5-10]. Due to their superior strength and corrosion resistance, precipitation-hardened aluminum alloy 7075 is mainly used in aerospace applications.

Composite nanoparticles are advanced materials that have recently gotten a lot of attention

because of their logical and inventive value[16]. They are used in a variety of applications, including high-action and specificity impetuses, metal semiconductor intersections, optical sensors, and modifiers of polymeric films for bundling. The piece and nuclear request of the totals, regardless of size, are essential variables in determining their characteristics and functions, but the nanoscale system offers them with underneath and electronic levels of possibility that are unavailable to mass materials. The designing of custom-made composite nanostructures is the most important stage in fostering innovative nanotechnologies. For all intents and purposes, every possible physicochemical peculiarity has been used to achieve this aim, allowing for the creation of an enormous number of conventions, each with its own set of benefits and drawbacks. Two original copies are devoted to the components of unique planning techniques.

When compared to unreinforced alloys, AMCs that have been reinforced with ceramic particles such as aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), silicon carbide (SiC), boron carbide (B<sub>4</sub>C), titanium carbide (TiC), and titanium diboride (TiB<sub>2</sub>) have excellent physical properties in terms of strength, stiffness, wear resistance, and corrosion resistance[11-15]. MMCs are difficult to join using conventional fusion welding techniques because the aluminium matrix has a high thermal expansion coefficient, a high melting temperature, and the ceramic

reinforcement has a high viscosity. These factors together cause solidification shrinkage and porosity. Additionally, because the thermal expansion coefficients of the hard ceramic reinforcement and the aluminium matrix differ, distinct thermal stresses are produced during welding. Limited investigation has been conducted on nano B<sub>4</sub>C reinforced aluminum matrix composites because of the high cost of B<sub>4</sub>C powder. But B<sub>4</sub>C is an attractive reinforcement material for several reasons: It is chemically and thermally stable. B<sub>4</sub>C has lower densities, higher hardness and better bonding properties than Al<sub>2</sub>O<sub>3</sub>.

In this study, AA7075 was strengthened with nano ceramic particles such as aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), boron carbide (B<sub>4</sub>C), titanium carbide (TiC), and titanium diboride (TiB<sub>2</sub>) at various weight percentages to improve the mechanical properties of the alloy. Also, reinforced castings have been joined by Friction Stir Welding to analyze the weld strength of joints.

**2.0 Materials and Experimental Methodology**

**2.1 Materials**

Al-7075 has been used as the basis alloy for the current experiment, with ceramic nanoparticles made of titanium carbide (TiC) and boron carbide (B<sub>4</sub>C) acting as reinforcement particles to improve the base alloy's mechanical properties. The composition of base alloy was shown below.

**Table 1: Chemical composition of Al -7075 alloy (mass%)**

Al	Zn	Mg	Cu	Si	Fe	Mn	Ti	Cr
90-91	5.6-6.1	2.1-2.5	1.2-1.6	0.5	0.5	0.5	0.5	0.5

**Experimental Methodology**

The experiment is split into two stages: the first stage includes stir casting to create Al-MMCs with various reinforcement compositions. The second phase includes testing and characterization after the FSW of the stir cast samples.

**2.2 Casting fabrication**

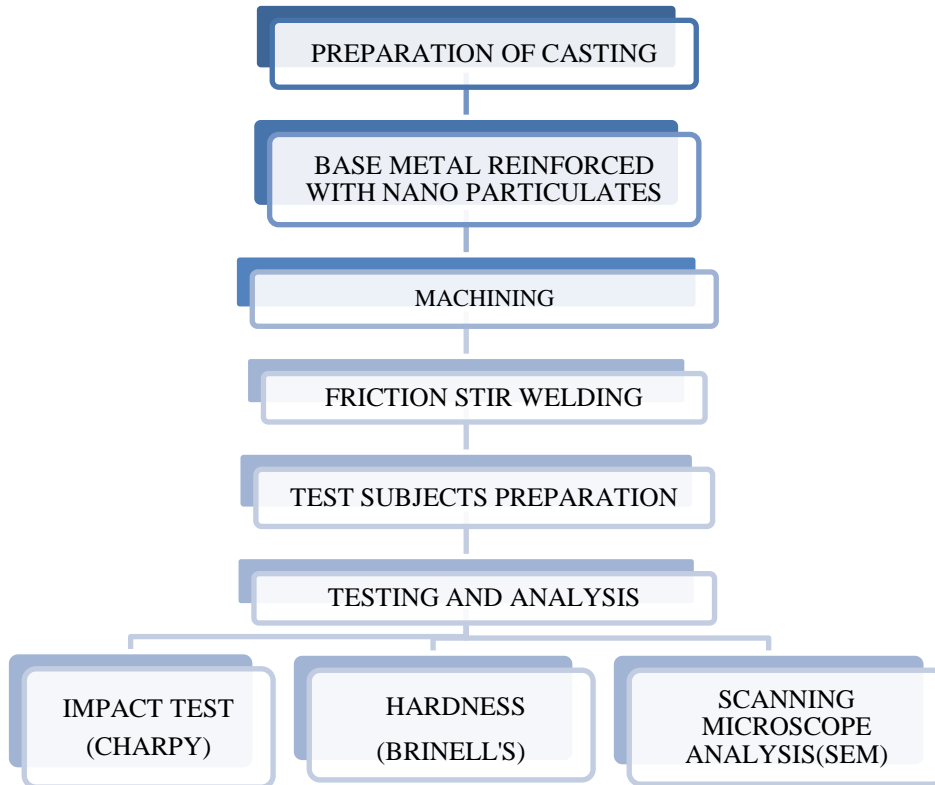
A new computerized stir casting system, which has an electric induction furnace attached with a pouring arrangement at its bottom, has been used for the fabrication of base alloy strengthened with nano scale particles. Primarily, one kilogram of Al-7075 base alloy has been charged in crucible of stir

casting setup which is coated with graphite. The temperature of the furnace has been raised to 900 °C to melt the Al-7075 base alloy. After melting, the slag which has formed on surface of the molten metal was removed cautiously. The graphite coated stirrer has been used homogenous mixing of ceramic particles in base metal. Graphite coating to the blades of the stirrer is important to avoid the relocation of ferrous ions from the stirrer into molten metal. After melting the preheated nano particles of Titanium carbide (TiC) and Boron Carbide (B<sub>4</sub>C) at different weight percentages are added to the base metal. With a

proper stirring(at 400 rev/min speed), the melt (at 900°C) reinforced with nano particles was poured in to the preheated (300 °C) permanent steel

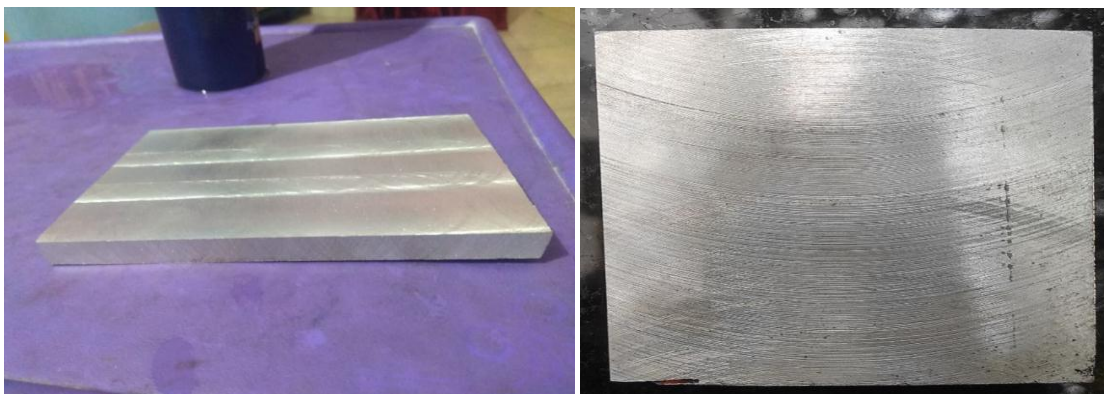
rectangular mould (300 x 150 x 10 mm size)and allowed to solidify .

**Flow chart for stir casting**



**PROCESS PARAMETERS:**

- Stirrer speed:400RPM
- Stirring temperature:900°C
- Preheat temperature of nano powders:300-400° C



**Fig1: fabricated Pieces**

TABLE-2 Ratios of Nano Powders in Casting

	Temperature (° C)	TiC (Wt. %)	Al <sub>2</sub> O <sub>3</sub> (Wt. %)	B <sub>4</sub> C (Wt. %)
Sample 1	700	1.0	0.5	0.5
Sample 2	750	1.0	0.8	0.0
Sample 3	780	1.5	0.5	0.0

The cast samples of 100 x 100 x 8 mm in size were cut from the casting and machined by milling machine to get the required thickness of the plate for friction stir welding to analyze the weld strength of the base metal. After machining of the casting samples, they are welded together using friction stir welding. The cast samples of dimensions 10 × 10 × 8mm in size were cut from casting and their surfaces for structural investigations were ground with 120–1200 grit silicon carbide abrasive papers and polished using emery polishing papers of grades 1/0 to 4 /0. Finally, polishing was carried out using an alumina solution by means of a polishing machine. Tucker's reagent (15ml hydrofluoric acid + 15ml nitric acid + 45ml hydrochloric acid + 25ml distilled water) is used to etch the polished cross-sectional samples. A microscopic examination was carried out using a metascope metallurgical microscope.

### 2.3 Friction Stir Welding

The many facets of the process must be examined in order to comprehend the FSW mechanism. In order to soften the material and allow it to be

welded together, the procedure needs an immense amount of heat. The friction between the revolving tool and the material being welded generates heat. The heat produced by the rotating tool causes the metal to plasticize, forming a connection between the two parts. Frictional heat is produced between the wear-resistant tool and the work components during the FSW process, which causes a softened area close to the FSW tool [5-8]

Tapered pin with threads tool is selected for welding the samples. One of the key advantages of using a tapered pin with thread tool for friction stir welding is its ability to withstand high temperatures. Another advantage of a tapered pin with thread tool for friction stir welding is that it may generate strong welds with little to no distortion of the base material.

To evaluate the tensile strength properties of the experimental castings joined by Friction Stir Welding (FSW) process, the rectangular specimens were prepared according to ASTM: B557-15 standard using the CNC wire cutting machine.

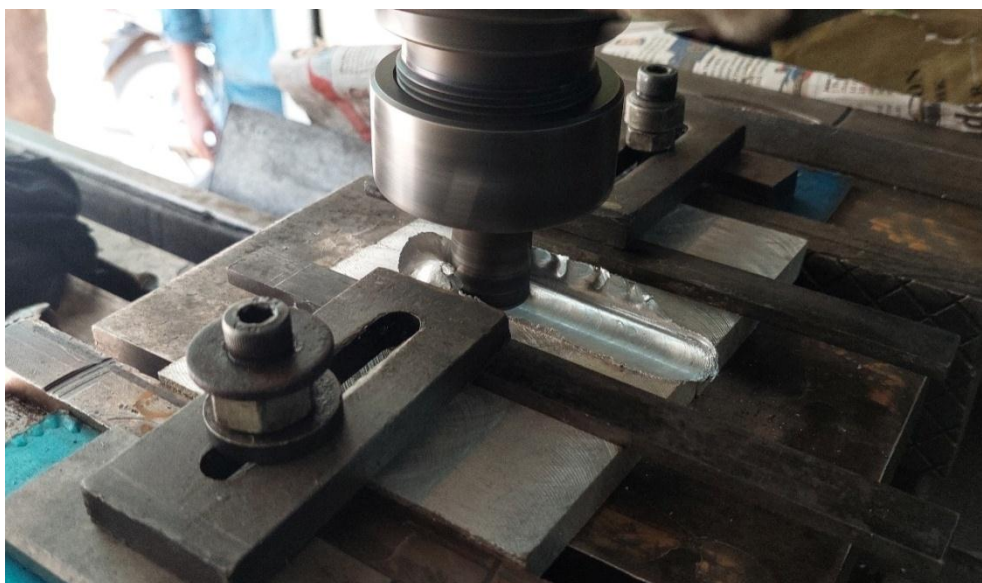




Fig2 FSW process using vertical milling machin

### 3.0 Results and Discussions

#### 3.1 Effect of nano ceramic particles (TiC and B<sub>4</sub>C) on Al-7075 base alloy

The microstructures of the commercial Al-7075 base alloy with the addition of different wt.% of nano ceramic particles (TiC, Al<sub>2</sub>O<sub>3</sub> and B<sub>4</sub>C) at 700 °C are shown in Figure 3. Figure 3(a) shows the microstructures of the Al-7075 alloy with the addition of nano particles (1.0 wt. % of TiC, 0.5 wt.% of Al<sub>2</sub>O<sub>3</sub> and 0.5 wt.% of B<sub>4</sub>C), reveals the fine grain structures. Here, TiC and B<sub>4</sub>C act as nucleation sites to enhance equiaxed grain structure instead of columnar grain structure. Also Al<sub>2</sub>O<sub>3</sub> has been caused to increase hardness and

tensile strength. . Figure 3(b) shows the microstructures of the Al-7075 alloy with the addition of nano particles (1.0wt. % of TiC, 0.8 wt.% of Al<sub>2</sub>O<sub>3</sub> and 0.0 wt.% of B<sub>4</sub>C). Figure 3(c) shows the microstructures of the Al-7075 alloy with the addition of nano particles (1.5wt. % of TiC, 0.5 wt.% of Al<sub>2</sub>O<sub>3</sub> and 0.0 wt.% of B<sub>4</sub>C) and From figure 3(b) and 3(c), it was observed that the formation equiaxed grain structure has been decreased due to the lack of heterogeneous nucleation sites like B<sub>4</sub>C) with compare to Figure 2(a).

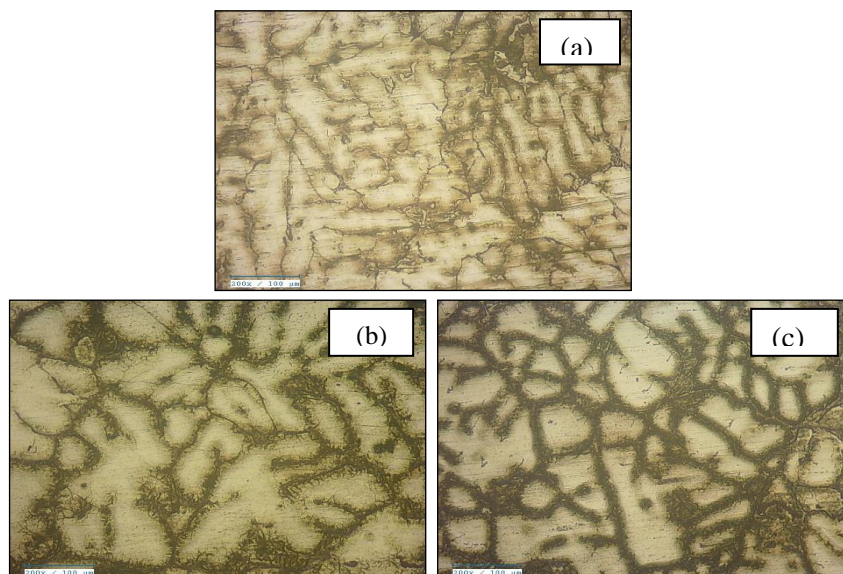


Figure 3: Optical microstructure images of (a) Sample – 1, (b) Sample -2 and(c) Sample-3

**3.2 Mechanical properties of friction stir casting Al-7075 alloy**

The hardness and impact strength of the alloy AA7075 die castings with the addition of the nano particles with different wt.% of TiC , Al<sub>2</sub>O<sub>3</sub> and B<sub>4</sub>C are shown in the Figure 5(b). The hardness observed at the weld zone was higher than other zones for all the samples. It shows that Al-MMCs have been strengthened as a result of the FSW process. This is because FSW's friction action helps to distribute the reinforcing particles evenly throughout the Al matrix. It was observed that the sample 1 has highest hardness value (78HV)

compare to sample 2 and 3, because optimized combination of nano particles (1.0 wt. % of TiC, 0.5 wt.% of Al<sub>2</sub>O<sub>3</sub> and 0.5 wt.% of B<sub>4</sub>C) have been incorporated in sample 1. But in sample 2 and 3 only TiC and Al<sub>2</sub>O<sub>3</sub> nano particles are incorporated. Finally it was observed that addition of nano particles to base alloy improves the hardness values. Nevertheless, the impact strength values are subsequently decreasing with increasing weight percentages of different nano particles (TiC, Al<sub>2</sub>O<sub>3</sub> and B<sub>4</sub>C) to base alloy as shown in Fig.5(a). The values of hardness measured from 3 samples are shown in table 3

**Table 3: Hardness of 3 samples**

	TiC (Wt. %)	Al <sub>2</sub> O <sub>3</sub> (Wt. %)	B <sub>4</sub> C (Wt. %)	Hardness values(Hv)
Sample 1	1.0	0.5	0.5	78
Sample 2	1.0	0.8	0.0	68
Sample 3	1.5	0.5	0.0	74

**Impact test:** To assess the resistance of AMCC to breaking by flexural shocks on weld zone, the Charpy impact test is used. Specimens for impact

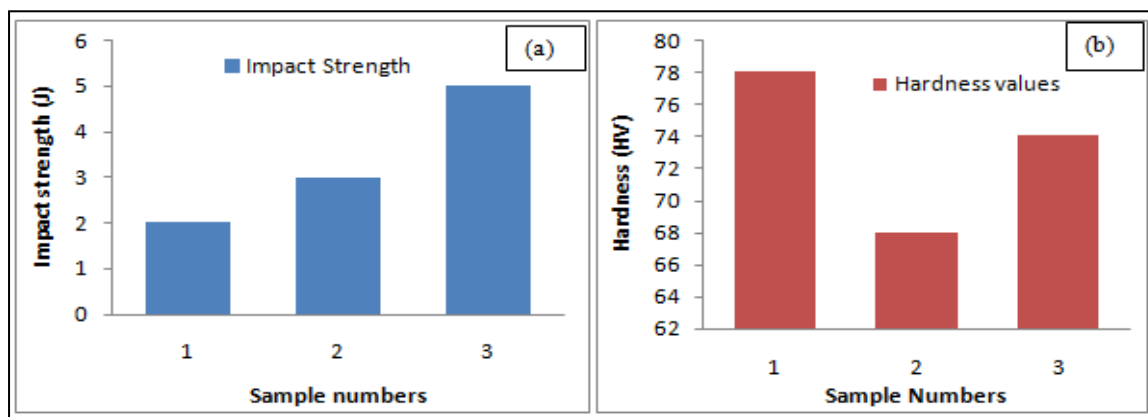
strength (based on ASTM E23 standards) have been prepared for the welded joints. The values obtained from Impact test are shown in table 4.

**Table 4: Impact strength of 3 samples**

	TiC (Wt. %)	Al <sub>2</sub> O <sub>3</sub> (Wt. %)	B <sub>4</sub> C (Wt. %)	Impact result(J)
Sample 1	1.0	0.5	0.5	3
Sample 2	1.0	0.8	0.0	4
Sample 3	1.5	0.5	0.0	5



**Fig : 4 Impact test specimens**



### Conclusions

Researchers have looked into how nanoparticles affect the microstructure and mechanical characteristics of friction stir welded joints. The results of the experimental work lead to the following conclusions.

(1) A significant grain refinement has been observed due to reinforcement effect of nano particles mainly TiC and B<sub>4</sub>C; these particles act as a inter metallic particles to enhance the heterogeneous nucleation. Mainly fine grain structure has been noticed in sample – 1, which is reinforces at 1.0 wt.% of TiC, 0.5 wt% of Al<sub>2</sub>O<sub>3</sub> and 0.5wt% B<sub>4</sub>C.

(2) The mechanical properties of the AA7075 mainly hardness has been significantly enhanced by reinforcement of nano particles, mainly in sample-1 such as 78 Hv (at weight percentages of 1.0 wt.% of TiC, 0.5 wt% of Al<sub>2</sub>O<sub>3</sub> and 0.5wt% B<sub>4</sub>C) due homogenous mixture of nano particles in composite.

(3) It was noticed that significant improvement in mechanical properties with fine grain refinement in sample 1. But, the Impact strength of the Sample 1 is significantly decreased instead of increasing compare to samples 2 and 3.

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