Effect of electromagnetic field and mechanical milling in the synthesis of metal matrix Nano composite

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Abstract

Ceramic nanometric SiC particles (n-SiCp) were reinforced in 7075 aluminium matrix to synthesize the metal matrix nano composites (MMNCs). The inclusion as well as uniform distribution of nano particles in aluminium matrix is a great challenge. To accomplish this, a new hybrid stir casting technique was used to fabricate the MMNCs. The uniform distribution of the reinforcement depends on good wettability of reinforcement with the metal matrix. Hence, to improve the wettability, 1 wt % micro Mg particles were mechanically milled with two different additions of n-SiCp with weight fractions 1% and 1.5 % and injected into the matrix melt with the assistance of argon gas. As-casted materials were peak aged for 12 hours at 135º C. Tensile tests, low speed impact test and hardness tests were used to investigate mechanical behaviour and found that composite reinforced with 1% SiC exhibited better mechanical properties. The mechanical properties of nano-composites are characterized by employing optical microscopy, scanning electron microscopy and X-ray diffractometer. This method remarkably facilitated a uniform dispersion of nano-SiC within the aluminium matrix as well as a refinement of grain size.

1. Introduction

The search for new and advanced materials has been extensively carrying out for many years and will continue forever due to technological improvement and advances. The space, aviation and automobile industries always have a requisite of material which possesses improved physical and mechanical properties including superior strength to weight ratio, high specific modulus, and low coefficient of thermal expansion, excellent wear and corrosion resistance [1, 2]. The amalgam of all these properties is not available in a conventional monolithic alloy. But, all these aforementioned properties are also present together in aluminium metal matrix composites (AlMMC). Now, the research is being carried out for enhancing these properties as optimum as possible. Zinc based aluminium 7XXX series alloys have great interest due to having combination of high strength with good toughness and corrosion resistance. Aluminium 7075 alloy is the baseline with balanced properties required for aerospace applications. Therefore, Al 7075 alloy is used as a matrix for the synthesis of composite. Generally, micro-reinforcement particles such as SiC, Al2O3, Mgo and B4C etc are used to improve hardness, ultimate tensile strength, refractoriness and compressive strength of the composite. Conversely, the ductility of MMC gradually deteriorates with increasing reinforcement particle concentration. This problem can be overcome by using nano-sized ceramic particles to improve the ductility of MMC, while maintaining high strength and toughness, high temperature creep resistance and better fatigue [3].

2. Literature Review

S.A. Sajjadi et al fabricated a metal matrix composite in which micro and nano sized Al_2O_3 particles are reinforced in A356 aluminium alloy. The injection of heat treated micro and nano Al_2O_3 particles into the molten matrix alloy was carried out by the assistance of inert gas pressure and steering the melt at different speeds. Hardness, compressive strength and porosity were investigated in the samples and concluded that the amount of hardness, compressive strength and porosity increased as weight percentage of reinforcement [1]. SiC particles reinforced AlSiC7Mg2 matrix composite materials were fabricated by using gravity and squeeze casting techniques and followed by T6 heat treatment. The developed composite was extruded for uniform distribution of SiC particles and equiaxed the matrix structure. This study concluded the increment in tensile strength as well as decrement in impact strength values was observed by increasing the content of SiC particles [2]. The fabrication of metal matrix nano composite is extremely difficult due to agglomeration and segregation of nano particles. A new ultrasonic processing was used to uniform dispersion of nano SiC, B_4C and CNT particles into A 356 aluminium matrix melt. After testing the samples for mechanical properties, the enhancement in the values of tensile strength and hardness was observed due to the addition and good distribution of nano particles [3]. Stir casting method was used to reinforce 1.5, 2.5 and 5 vol% nano particles MgO into A 356 aluminium matrix melt. Fabrication was performed at various casting temperatures, viz 800, 850 and 900 ºC, to evaluate the density, microstructure and mechanical properties of the composites. The results revealed that the composite comprising 1.5 vol% reinforcement particle fabricated at 850 ºC have homogeneous microstructure as well as improved hardness and compressive strength [4]. Metal matrix nano composites (MMNC) were fabricated by use of inexpensive ultrasonic nonlinear effects on A356 aluminium

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alloy melt for mixing and uniform dispersion of nano SiC particles into the melt. The effect of various weight percentages, viz 0.5, 1 and 2% of nano sized SiC was analyzed in order to improve the mechanical properties of composites and concluded that the mechanical properties have been improved significantly even with a low weight fractions of nano sized SiC [5]. The various problems accompanied with casting have been reduced by the application of electromagnetic field. In the presence of low frequency electromagnetic field, a substantial reduction of grain size and macro-segregation of 7075 aluminium alloying elements was achieved [6]. The melt infiltration technique was used to produce SiC-B_4C-Al composite. For this purpose, SiC and pre-treated B_4C powder mixtures were pressureless infiltrated with 7075 Al alloy at relatively low temperatures under an inert gas atmosphere [7]. Al206/5vol. % Al_2O_3 cast composites were fabricated by the injection of reinforcing particles into molten Al alloy in the form of milled particulates of alumina with Al and Mg powders. Results showed that injection of milled reinforcement powders leads to considerable improvement in incorporation and distribution of Al_2O_3 particles in the Al206 matrix alloy leading to the improvement in tensile properties of the composites [8]. Electromagnetic and mechanical process techniques were simultaneous used to produce metal matrix composite with variation in the size of reinforcement particles. The tensile strength of the composites was tested with and without heat treatment with T6. Optimal designing of coil for electromagnetic stirring were obtained in order to study thixoforming of metal matrix composite [9]. Metal matrix composite was produced by either hand or mechanical stirring in which over 4 wt.% of 80 µm size Al_2O_3 particles were successfully introduced in pure aluminium or in A1-Si-Cu alloy melts, to which 4.5 wt.% magnesium was freshly added just prior to the addition of a-alumina particles. It was impossible to add more than 0.05% Al_2O_3 particles in the melts of the same alloys in the absence of the magnesium in the aluminium alloy melt [10]. Poor mechanical properties such as tensile strength and hardness of nanometric scale SiC particulate-reinforced Al 7075 composites synthesized via powder metallurgy process were examined by Ahmed et al [11]. Stir casting process followed by hot extrusion was used to fabricate three composites in which B_4C, SiC and Al_2O_3 (0-20%) particles reinforced in pure aluminium. Fracture surface analysis of three composites revealed that B_4C reinforced Al composite exhibits better interfacial bonding compared to the others [12]. Molten metal mixing technique was used to fabricate SiC (15% vol) particulate-reinforced A 356 composite. Magnesium aluminate (spinel), $MgAl_2O_4$, was observed as an interfacial reaction product after material processing. Thermodynamic analysis revealed that the presence of oxygen in various forms such as SiO_2, Al_2O_3 and MgO in the system during processing was responsible to supply oxygen for the formation $MgAl_2O_4$ [13]. Aluminium alloy AA1050/ 7 vol% SiC cast composite was fabricated using disintegrated metal deposition (DMD) technique followed by extrusion process. The formation of about 2.5 µm thick layer of Al_4C_3 compound was a reason of stronger interfacial bonding results increase in average yield strength, ultimate tensile strength, work hardening and work-to-fracture of the composite [14]. The AA7075 alloys reinforced with SiC and without SiC particles were fabricated by a pressureless infiltration method and analyzed by their microstructures and tensile properties. Spontaneous infiltration was owing to the combined effect of both Mg and Zn, lead to an enhancement of wetting between the molten alloy and the reinforcement. The improvement in strength of composite may be attributed to good bond strength through good wetting [15]. Al 7075/ SiC composites are formed with three nominal sizes, 5, 13 and 60 µm of reinforcement using co-spray deposition process. The ageing conditions such as peak aged, under aged and over aged are studied based on micro hardness measurement. However, the composite reinforced with 60 µm particles had reduced 0.2% proof stress and tensile strength in the underaged and peak aged condition, and a greater 0.2% proof stress in the overaged condition compared to the monolithic alloy. All the composites had lower ductility than the unreinforced material, with the material containing 5 µm SiC being the most ductile and that reinforced with 60 µm SiC having very low ductility [18]. Al–Zn–Mg alloy reinforced with SiC particles (average size 40 µm) composites were fabricated by liquid metal processing or stir casting technique. The mechanical properties were studied by altering the matrix strength with different heat treatments. The results are shown that the composites exhibited enhanced modulus value and strengthening was observed to be dependent on the damage that occurred during straining [19]. Al 2024/ SiC composites were fabricated by using spray forming, PM hot pressing, thixoforming and compocasting techniques. Two major interfacial reaction product hexagonal-platelet shaped Al_4C_3 and Si were found in the formation of composite. Based on DTA and SEM analysis, almost no interfacial reaction occurred in the spray formed composite, while significant amounts of interfacial reactions were observed to occur in PM hot pressed, thixoformed, and compocast composites [21]. Al 2024/ B_4C nano composites were produced by mechanical milling and hot extrusion and tested by tribological and mechanical properties such as tensile, compressive strength and hardness. It is concluded that the mechanical milling decreases the size of aluminum matrix grains to less than 100 nm [22]. Al 356 matrix composite reinforced with 1.5, 2.5 and 5 vol% nanoparticle MgO were fabricated via stir casting method. Hardness and compression test were carried out to identify mechanical properties [23].

The abovementioned literature review shows that no experimental work has been reported so far about effect of addition of nano sized SiC particles on the microstructure of 7075 Al alloy fabricated by hybrid stir casting process. Ball milling process is used to prepare the reinforcement material for improving the wettability and distribution of nano-sized particles within 7075 aluminium alloy and to hamper agglomeration of particles. The objectives of the present investigation are to fabricate and analyze the microstructure of 7075 Al alloy, Al 7075/1 wt% n-SiC_P (40-60 nm) and Al 7075/1 wt% n-SiC_P (40-60 nm) composites and to study their characterization by SEM, XRD, EDX techniques. So that the interfacial reactions can be identified and evaluate the reason of formation of Al_4C_3.

2. Experimental procedure

2.1. Preparation of reinforcement material

Nano-powder of SiC (with purity 99.99%, spherical shape, and average diameter 40 nm) and Mg powder (purity 99%, average particle size of 40–60 µm) were used as raw reinforcement material. Adequate mixing of nano-SiC and (1 wt. %) micro-Mg powder was performed in a planetary ball mill machine. To prevent agglomeration among the powder particles, alcohol (3 wt. %) was added with the mixture during ball milling. The milling speed and time were maintained at 80 rpm and 18 hrs respectively, with an intervening period of 20 min for every 1 h, in order to prevent over-heating. To remove the alcohol, the prepared composite reinforcement powder was sintered at 400º C for 2 hrs.

2.2. Experimentation

Al 7075 alloy was selected as the matrix material and its chemical composition are shown in Table 1. The proper amount (970-1000 g) of aluminium alloy ingots was correctly cleaned by using the abrasive paper and washed with acetone to eliminate the surface impurities and positioned into a graphite crucible in induction furnace.

Table: 1. Chemical Composition of Al 7075 Alloy

Element	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
Wt. %	0.09	0.2	1.4	0.07	2.3	0.2	5.7	0.03	90.01

Al 7075 alloy matrix was heated over liquid temperature (635º C) and melted completely (over 700º C), and held at that temperature for 15 mins. After oxidation, oxide films by contact with atmosphere were removed. Nano metric SiC powder was preheated up to 400º C in the electric furnace. A K-type thermocouple and a high frequency stainless steel stirrer system were placed on the top of electromagnetic coils. The stirrer was located at the depth of 2/3 of the height of the molten metal from the bottom of the crucible. Experimental set-up and schematic of designed equipment used in this study has been shown in Figure 1 and 2.

The liquid matrix was stirred under the electromagnetic field developed by 10 A current and simultaneously mechanically stirred during the addition of preheated reinforcement particles into the liquid matrix. The reinforcement particles were injected into the melt by using a stainless steel tube under the pressure of inert argon gas. The melt was stirred at the speed of approximately 400-500 rpm. Then, the mechanical stirrer was turned off after that molten mixture was stirred continuously under the action of rotational electromagnetic field up to 30 A current for 60 seconds and then current gradually reduced to 5 A. The melt solidified under the electromagnetic field of 5 A current to avoid shear stresses in the final product and Figure 3 shows the prepared materials. The sample specimens were produced for testing of mechanical properties and the specimens were peak aged for 12 hours at a temperature of 135º C before conducting the experiments. Figure 4 shows the samples of tensile strength testing and impact strength testing of prepared materials.

To observe the microstructure clearly, the specimen from each composite was ground, polished, dipped into etchants (0.5% HF solution) and finally washed with picric acid solution. ZEISS EVO 50 EP scanning electronic microscope (SEM), D/max-2500 PC X-ray diffractometer (XRD) and Inca Energy 350 energy dispersive spectrum (EDS) were used to observe the microstructure and analyze the unknown crystalline elements present in the composites while mixing reinforcement with Al alloy matrix.

The mechanical tests were performed at room temperature for each material. Tensile testing specimens were prepared according to ASTM: B557M-10 standard in which diameter and gauge length of specimen were 6 mm and 30 mm respectively [8]. Tensile tests were conducted on a servo-hydraulic computerized Instron machine at a cross head speed of 0. 5 mm/s

The Brinell method was used to determine the hardness of specimen after grinding of samples and they were polished down to 1µm. Hardness tests were made with a load of 150 kgf and an indenter diameter of 2.5 mm. The Brinell hardness was obtained by dividing the load to the surface area of indentation.

The Charpy impact test of the as-cast composites samples was conducted on impact testing machine. The mass of hammer was 227 Kg and striking velocity was 3.6 m/s. Standard square impact test sample measuring 55mm x 10 mm x 10 mm with notch depth of 2 mm and a notch tip radius of 0.02 mm at angle of 45° was used.

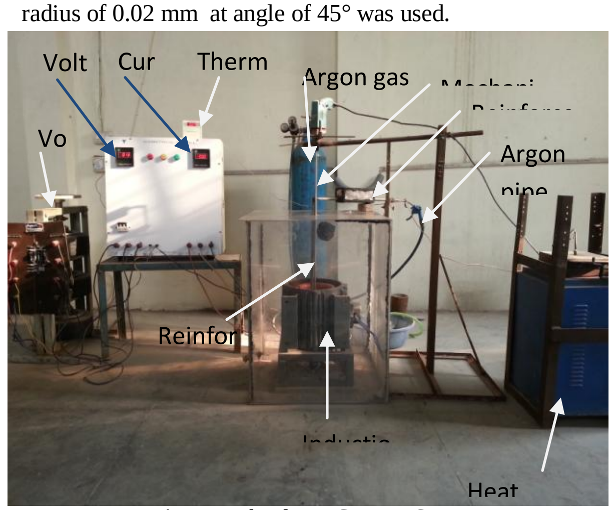

Fig: 1. Hybrid stir-Casting Set-up

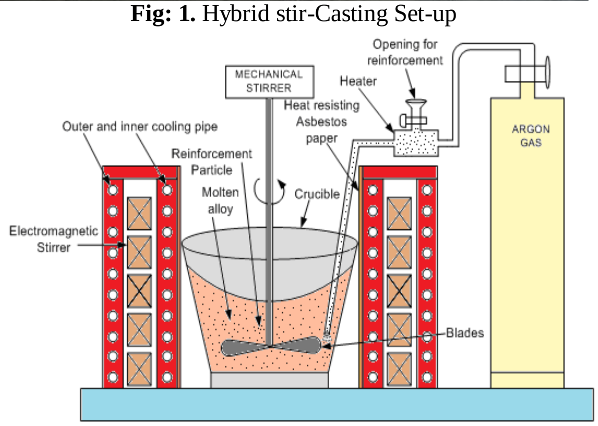

Fig: 2. Schematic Diagram of Hybrid stir-Casting

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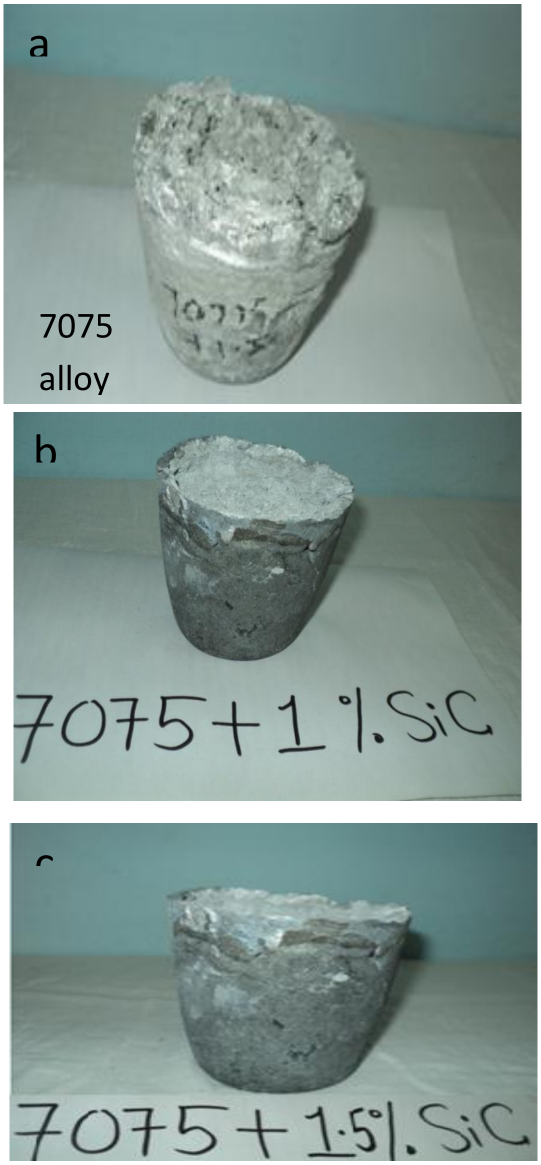
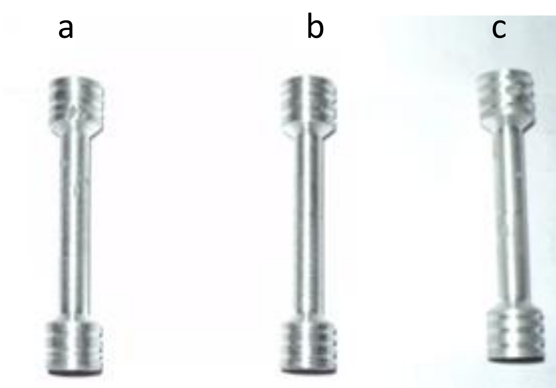


Fig: 3. Fabricated workpiece (a) Al 7075 alloy (b) 1 wt% SiC/7075 Al nano composite (c) 1.5 wt% SiC/7075 Al nano composite



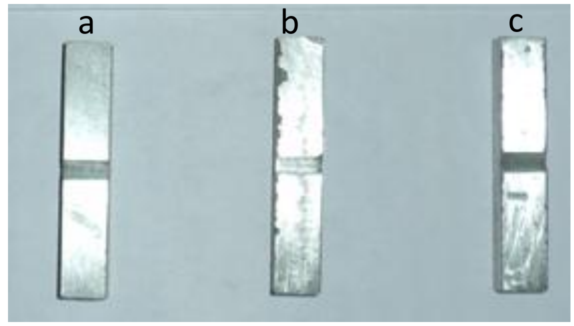


Fig: 4. Prepared samples for characterization (a) Al 7075 alloy (b) 1 wt% SiC/7075 Al nano composite (c) 1.5

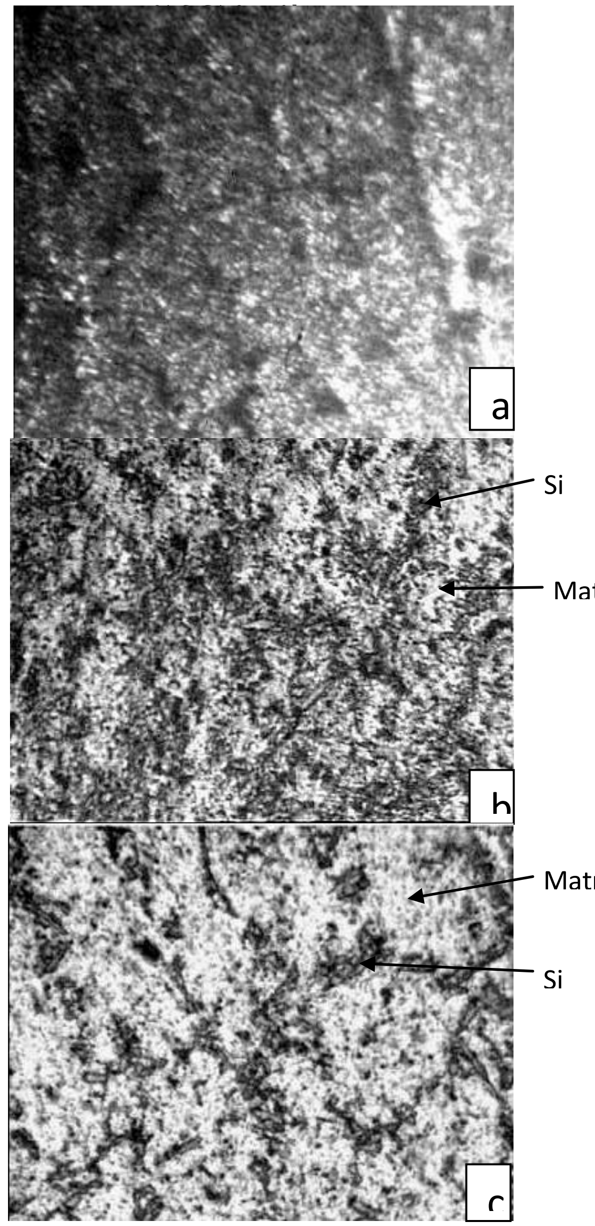


Fig: 5. Optical microstructure (a) 7075 Al alloy (b) 1 wt% SiC/7075 Al nano composite (c) 1.5 wt% SiC/7075 Al nano composite

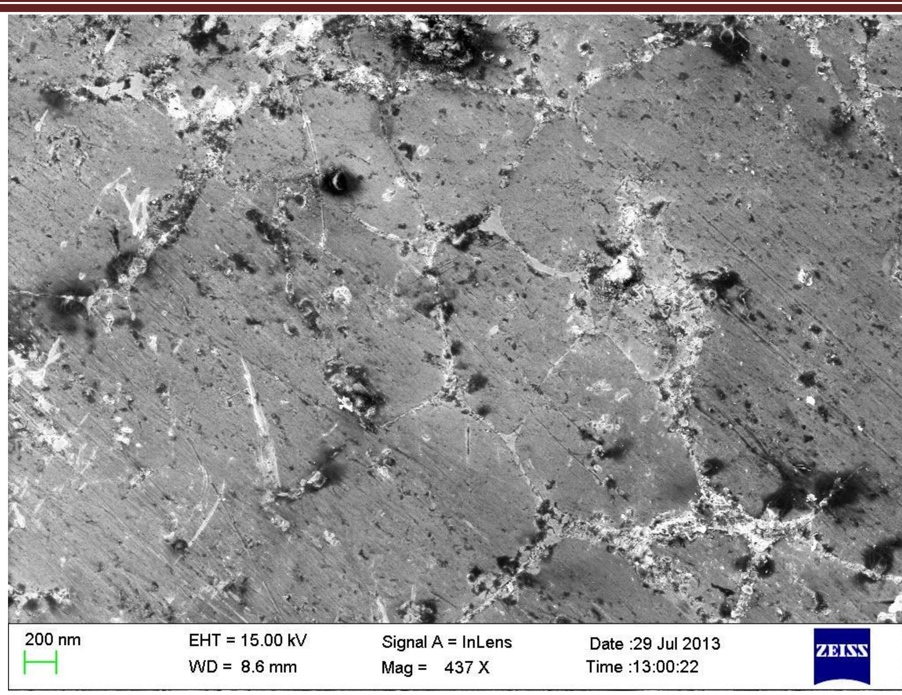


Fig: 6. SEM micrograph of 1 wt% SiC/7075 Al nano composite

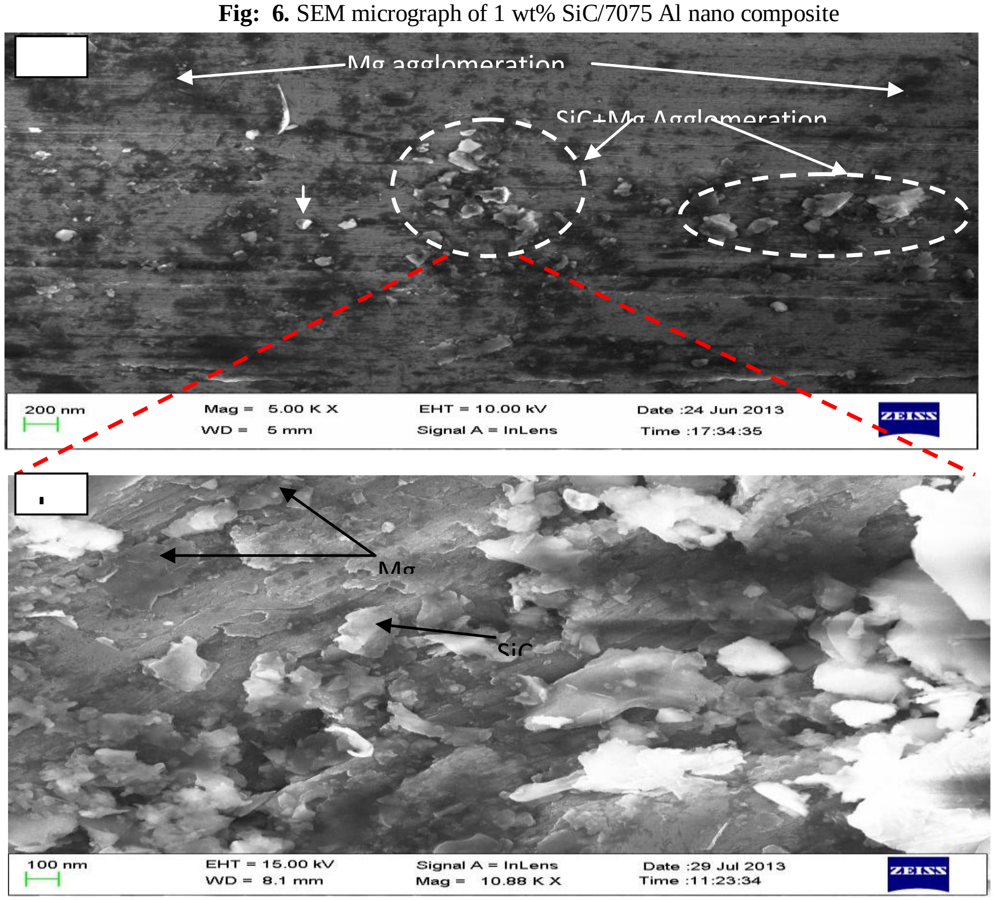


Fig: 7(a). SEM micrograph of 1.5 wt% SiC/7075 Al nano composite (b) Magnified view of SEM micrograph

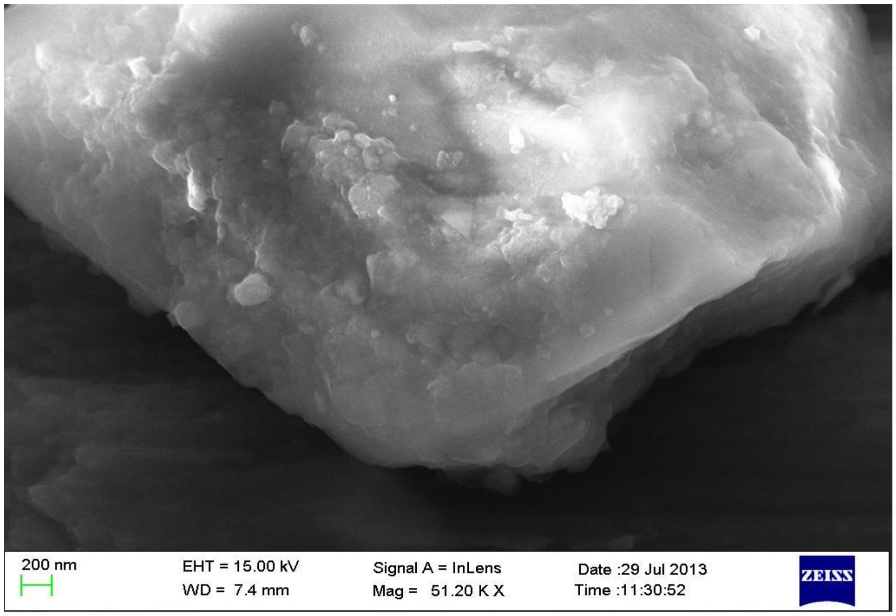


Fig: 8. SEM micrograph of 1.5 wt% SiC/7075 Al nano composite

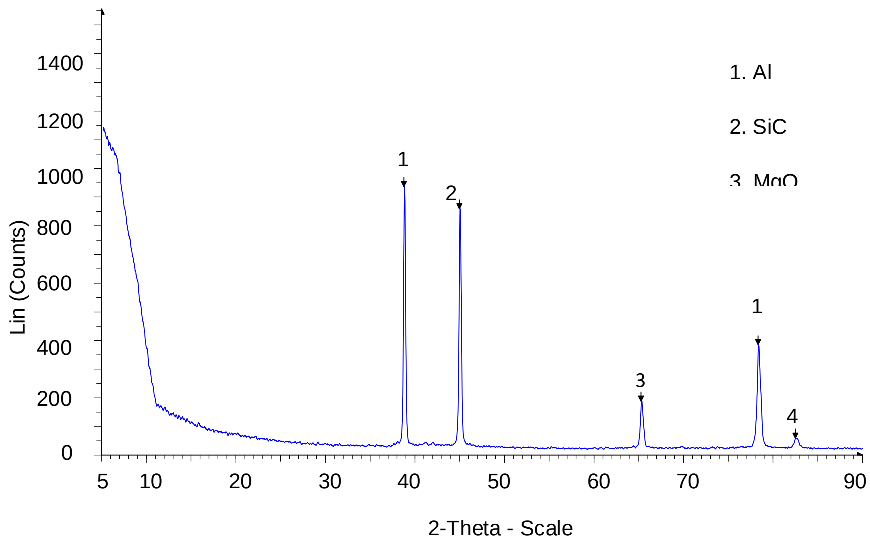


Fig: 9 XRD of 1 wt% SiC/7075 Al nano composite

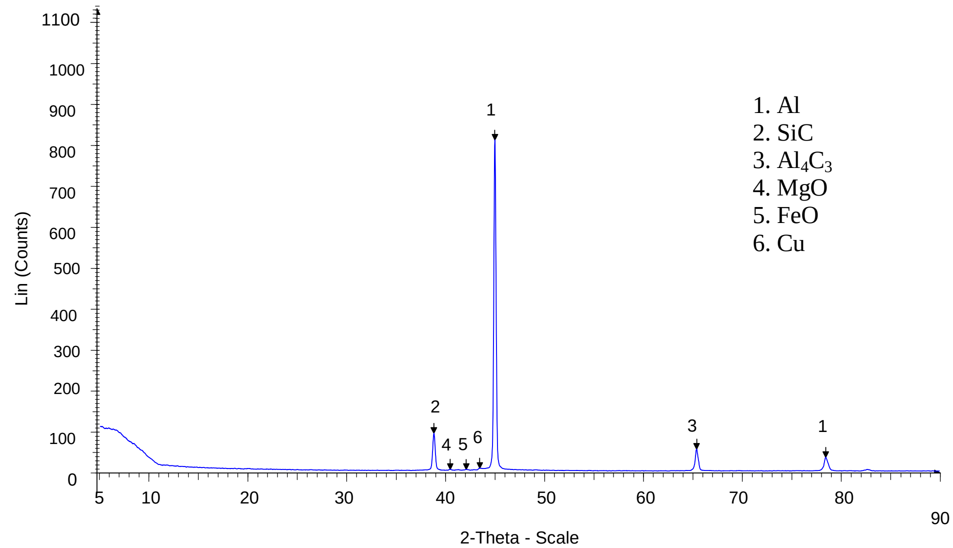
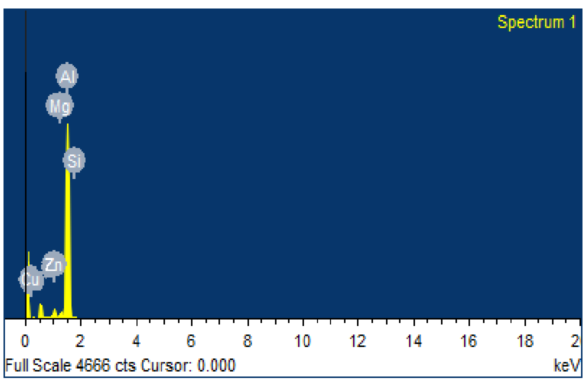
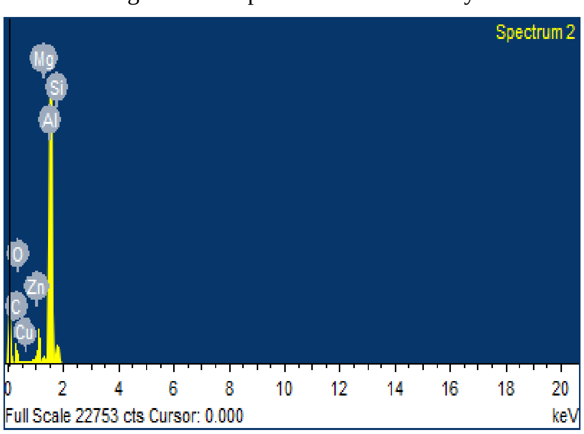


Fig: 10. XRD 1.5 wt% SiC/7075 Al nano composite



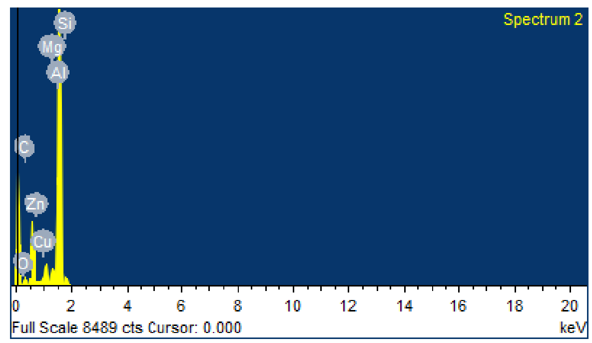
Element	Mg	Al	Si	Cu	Zn
Wt%	2.78	90.05	0.13	2.15	4.89
At%	3.08	93.59	0.13	1.1	2.10

Fig 11 EDAX profile of 7075 Al alloy



Element	C	O	Mg	Al	Si	Cu	Zn
Wt%	8.51	2.81	4.66	70.83	9.57	1.79	1.83
At%	18.05	5.80	3.41	63.02	8.48	0.53	0.71

Fig: 12. EDAX profile of 1 wt% SiC/7075 Al nano composite



Element	C	O	Mg	Al	Si	Cu	Zn
Wt%	16.77	4.2	4.68	60.16	10.23	1.77	2.10
At%	22.19	8.80	3.97	54.37	8.71	0.91	1.15

Fig: 13. EDAX profile of 1.5 wt% SiC/7075 Al nano composite

3. Characterization of Fabricated Nano Composite

3.1. Microstructural Analysis

Samples microstructures were examined under an optical microscopy and scanning electron microscopy as shown in Fig 5, 6 and 7. The agglomeration could be observed in the microstructures of composite specimens containing 1.5 wt% SiC nano particles (Fig 5 C and 7). The non uniform microstructure caused by agglomeration of SiC particles had an adverse effect on mechanical properties of composite. The agglomerations might be possible due to the large difference in densities of n-SiC_p and Al alloy melt, consequently poor wettability of n-SiC_p. As shown in Figure 7, the segregation of only Mg element is observed along with the nano-SiC particles among all alloying elements of Al 7075 alloy. One reason of it could be the lightness of Mg atom. According to the periodic table, Mg is the lightest element among all elements present in Al 7075 Alloy. Hence, Mg would be easily flow and fill the gaps created at the grain boundaries and interfaces cause segregation. It is also proposed by A. Ahmed et al. [11] that the interfaces of matrix/ reinforcement act like a good sink for the solute atoms during the cooling processes. The good distribution of SiC particles along with the grain boundaries as well as no formation of porosity can be observed in the composite sample figures 5 (b) and 6. Hence, agglomeration of nano SiC particles was the result of increasing the content of reinforcement which reduces the viscosity and wettability of the system.

3.2. XRD analysis

XRD analysis are conducted on Bruker ASX D- 8 X-ray diffractometer, which has a copper target operating at 1.8 kW and graphite-curved single crystal {0002} monochromator to select the CuK radiation at the goniometer receiving slit section. The diffraction angle (2θ) is maintained between 10 and 120° during the entire XRD analysis. The tendency of oxide formation of Mg is higher than of Al at any temperature [11]. Introducing the composite powder in the melt, free oxygen on SiC particles reacts with Mg, leading to the formation of MgO. Due to the formation of silica and MgO, the wettability of reinforcement has been improved. XRD graph (Figure 9) of Al/1 wt% n-SiC_p composite shows that there is no precipitation of any reactive phase except MgO. The highest and second highest peaks indicate the presence of Al and SiC particles in XRD of 1% SiC composite while fourth peak indicates the existence of undesirable Fe or Cr element that may come from the stainless steel stirrer during the stirring of molten alloy at high temperature. Nano-SiC particles were heat-treated at 700ºC in air for 1 hour in order to increase their reactivity with Al melt by increasing their surface energy. The increment in the surface energy is obtained by removing moisture, gas and other contaminants as well as by forming of a thin layer of SiO_2 on the surface of Sic particles [12]. The following reactions [10, 12, 13] could take place in this experiment:

$$SiC + O_2 = SiO_2 + C \quad [a]$$

$$2Mg + O_2 = 2MgO \quad [b]$$

$$SiO_2 + \frac{4}{3}Al = \frac{2}{3}Al_2O_3 + Si \quad [c]$$

$$3Mg + Al_2O_3 = 3MgO + 2Al \quad [d]$$

$$2Mg + SiO_2 = 2MgO + Si \quad [e]$$

$$2Mg + SiC = Mg_2Si + C \quad [f]$$

$$4Al + 3SiC = Al_4C_3 + 3Si \quad [g]$$

An undesirable interfacial reactive compound Al_4C_3 was observed in the sample of Al 7075/1.5 wt% n-SiC_p composite which is indicated by third peak in the XRD graph (Figure 10). It is observed during the fabrication that holding time of 1.5% SiC composite at liquidus temperature was about 20 minutes while it was 15 minutes for 1% SiC composite. SiC becomes thermodynamically unstable above liquidus temperature of Al melt under atmospheric pressure; interfacial reactions may occur. Therefore, extra holding time at liquidus temperature is the cause of formation of reactive phase Al_4C_3, which degrades the SiC particles and result in weakening of the composite [7, 14].

3.3. EDX Analysis

The chemical compositions of the different phases present in casted samples are investigated by spot and line-scan analysis on energy dispersive X-ray (EDX) detector, attached to the SEM. EDX analysis of matrix 7075 Al alloy has shown in Fig. 11 which revealed Al, Mg, Si, Cu, Zn element concentration 90.05% 2.78%, 0.13%, 2.15% and 4.89% respectively, represents the equilibrium precipitate.

Figure 12 is EDX analysis of 1 wt% SiC/7075 Al nano composite, showing increment of Mg and Si elements concentration to 4.66% and 9.57% due to the addition of Mg and SiC powder while decrement of Al, Cu and Zn elements to 70.83%, 1.79% and 1.83%. This EDX analysis also indicates the absence of formation of Al_4C_3 phase.

Figure 13 is EDX analysis of 1.5 wt% SiC/7075 Al nano composite, showing increment of Si element concentration to 10.23% due to the addition of more SiC powder and concentration of Mg element is the almost same while decrement of Al and Cu elements to 60.16% and 1.77%. This EDX analysis also indicates the formation of Al_4C_3 phase.

3.4. Mechanical properties

The strength of 7xxx Al matrix composites were nearly the same or lower than that of unreinforced material [15] by the fabrication of mechanical string alone but in this study, it is observed higher, if matrix melt stirred and solidified simultaneously under the influence of electromagnetic field. Figure 14 reveals that the maximum value (714 MPa) of ultimate tensile strength (UTS) of 1 wt% SiC/7075 Al nano composite which is 17.36% greater than the matrix alloy. Lee et al [16] and Doel et al [18] have observed 16.80% and 4.03% increment in UTS by using pressureless infiltration method and spray deposition method respectively. Kumar et al [19] observed continuous decrement in UTS by using stir casting method. Hence, in present study, the increment in the UTS is only caused by modifying the fabrication process in the form of hybrid stir casting. In present observation, it is impossible to insert nano SiC particles into the melt without any assistance because of formation of oxide layer on the top surface of melt due to having great affinity of aluminium melt with the oxygen. The nano particles are injected into the melt through the steel tube with the assistance of argon gas pressure. A new problem, clustering of nano-SiC particles is formed in the melt because sufficient shear force would not be available to break these clustering. The agglomerated nano particles was dispersed into the melt by using mechanical stirrer for only two minutes and then melt is electromagnetically stirred during solidification. During solidification of the melt, the electromagnetic stirring produces strong shear stresses which will throw away the newly formed dendrites adjacent the solidification front into the bulk liquid pool of higher temperature by convection. In high temperature zone, some dendrites are remelted while others quasi-melted and are sent back to the solidifying region. These quasimelted dendrites behave extra nucleation spot upon which again grain growth will occur, thereby resulting in grain refinement, in the final composite material. Thus the application of electromagnetic field can refine the microstructures of aluminium alloy and lead to the formation of an equiaxed grain structure [16] which enhances the strength of composites. The tensile strength of

7xxx matrix composites fabricated by various methods is shown in Figure 15. As per the Figure 15, tensile strength in composites fabricated by powder metallurgy, stir casting methods, pressureless infiltration method were nearly the same, lower and higher respectively than that of unreinforced materials, while composite fabricated by hybrid stir casting method showed higher strength than the matrix material.

A significant reduction was tested in the tensile strength of the 1.5% wt n-SiC_p/Al 7075 composite as shown in Figure 14. The tensile strength reduction of the composite was caused by occurring the reaction of Al melt with SiC particles as well as segregation of SiC particles at the grain boundaries and interfaces of composite (Figure 8). XRD and EDAX results obtained from 1.5 wt% n-SiC composite sample (Figures 10 and 13) indentified interfacial reaction product brittle hexagonal Al_4C_3 crystal which is formed as per reaction (g). This interfacial product degrades the mechanical properties (strength) of reinforcing particles (SiC) or reduces interfacial adhesion or interfacial strength of the composite [13, 17, 21].

Table: 2. comparison of mechanical properties of Particulate-Reinforced Al 7075 composites at peak aged condition (135ºC/12 h)

Material	**Processing route**	**Particle Size**	**UTS (MPa)**	**Elongation to tensile strength**	**Hardness**	**Toughness (Joules)**	**Ref.**
Al 7075 7075/9% SiC 7075/18% SiC	Stir Casting	----	561 492 442	11.7% 2.7% 1.7%			19
Al 7075 7075/15% SiC 7075/15% SiC 7075/15% SiC	Spray Deposition	 5µm 13µm 60µm	619 630 645 504	0.068 0.066 0.035 0.006			18
Al 7075 7075/10%SiC	Pressureless Infiltration method	20 µm	604 726	10.6% 3.7%			15
Al 7075 7075/1% n-SiC 7075/5% n-SiC	Powder Metallurgy	50nm	710 690 700	15% 6% 4%	73 HRB 44 HRB 37 HRB		11
Al 7075 7075/15 vol% SiC	Hot Extrusion	14 µm	600 550	15% 5%			20
Al 7075 7075/1wt%SiC 7075/1.5wt%SiC	Hybrid Casting	 40 nm 40 nm	590 714 581	15% 8.9% 2%	72 HRB 123 HRB 145 HRB	17 12 4	Present Study

Figure 14 depicted that tensile ductility of the composites decreases with an increase in weight fraction of nano SiC particles, which results in the increment of clustering of particles which initiate localized damage as shown in Figure 7. The ductility of composite reinforced with 1wt.% SiC particles is 8.9% while it is greatly reduced to 2% for composite reinforced with 1.5wt.% SiC particles due to the formation of intermetallic compound Al_4C_3 and clustering of nano SiC particles which crack during straining. Since clustered SiC_p are stiffer than the matrix and resist more loads by restricting plastic deformation. Hence, they act as stress concentrator and are main cause to initiate cracks and interface failure in matrix [11]. Such clusters can be considered the regions of potential damage that exist prior to loading. In general, clustering is more likely to occur in composites reinforced with fine particulates [18].

Hardness of SiC particles is much more than of 7075 Al alloy. The hardness of 1.5 wt. % SiC/7075 Al composite is increased to 145 HRB by the formation of hard Al_4C_3 compound. Hardness of nano-reinforced composites increases as a result of increasing the content of nano SiC particles which is attributed to dispersion strengthening. Because the increase of SiC particles to Al matrix increases the number of barrier across dislocations movement as a result hardness increases [22]. Table 2 shows the comparison of mechanical properties of particulates-reinforced Al 7075 composites with the present study.

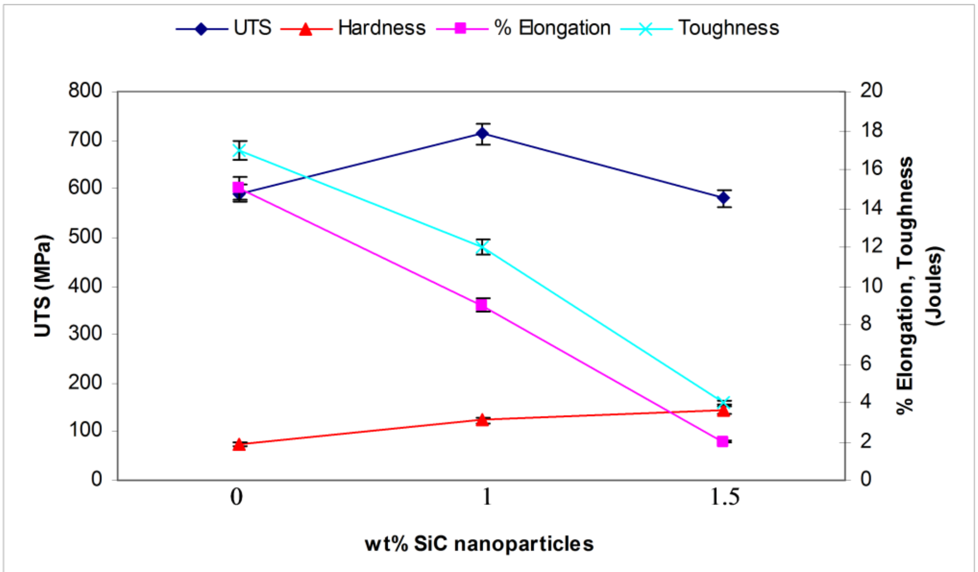


Fig: 14. Mechanical properties of 1 wt% SiC/7075 Al nano composite SiC reinforcement

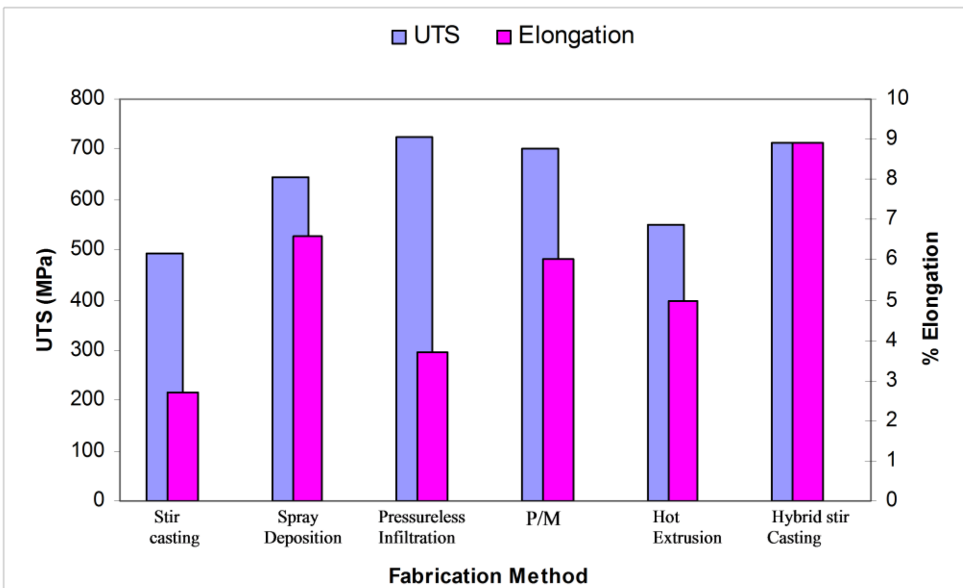


Fig: 15. Tensile strength and elongation in 7075 Al matrix composites fabricated by various methods

As shown in figure 14, the composites which contain higher amount of SiC particles have poor toughness. This could be possible because rigid SiC inclusion acts as a barrier to the mobility of dislocations. Therefore, by increasing the content of SiC, the rate of work hardening increases and this would lead to a decrease in toughness value. Besides this, the density of dislocations increases because of mismatch between thermal expansion coefficient of reinforcement particles and matrix [23]. The formation of interfacial product Al_4C_3 degrades the interfacial strength of nano composite. Hence, the nano composite reinforced with 1.5 wt.% SiC particles absorbs very less energy, i.e. 4 Joule during fracture as compared to 12 Joule absorbed by nano composite reinforced with 1 wt.% SiC particles.

SEM observations of ductile fractured surface of composites exhibit a dimpled appearance and show the existence of voids at the matrix/ reinforcement interface in the direction of applied load as well as in the regions of agglomeration of SiC particles. Precipitate at the matrix/reinforcement observed in the sample of 1 wt% SiC/7075 Al nano composite (Fig 16) may be credited void nucleation, which drive debonding between the matrix and reinforcement. At 1.5% SiC reinforcement (Fig 17), more brittle natured agglomeration of SiC particles is observed. When composite is strained, the stress flows around the clustered region, giving rise to enhance debonding.

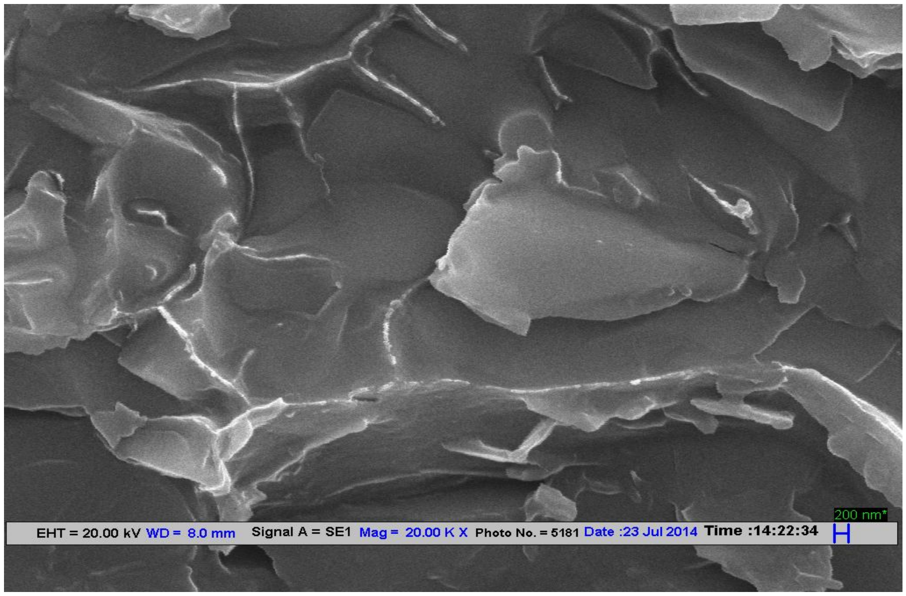


Fig: 16. SEM fractograph of tensile samples of1 wt% SiC/7075 Al nano composite

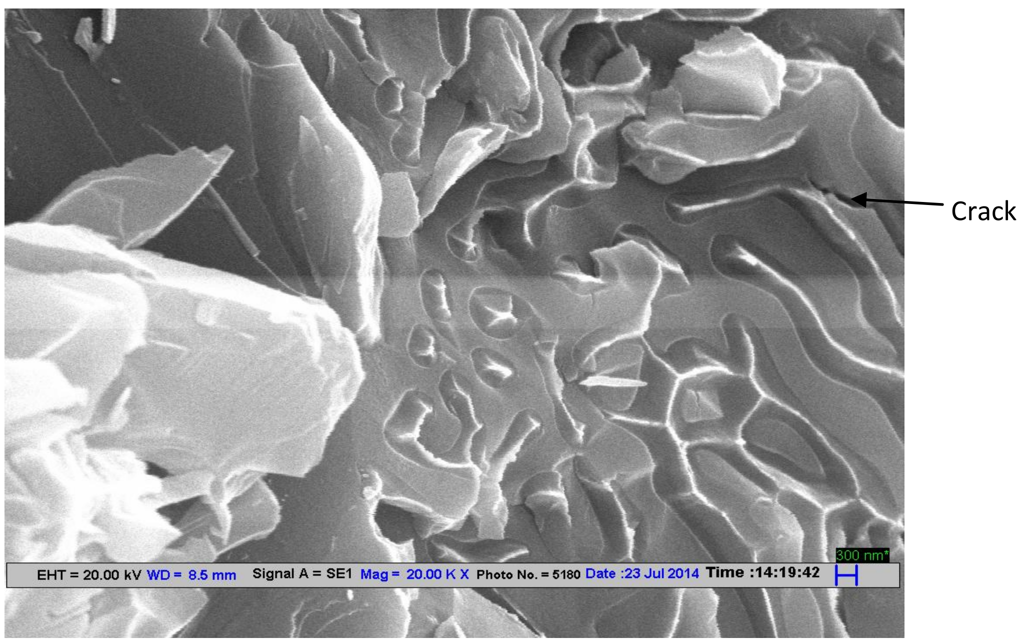


Fig: 17. Fig 12 SEM fractograph of tensile samples of1.5 wt% SiC/7075 Al nano composite

4. Conclusions

The abovementioned experimental findings directed to the following conclusions.

1. 7075 Al alloy reinforced with nano-sized SiC was successfully fabricated via hybrid stir casting method. Reinforced particles were reasonably distributed in the matrix in order to improve the mechanical properties of the composites.
2. Mechanical milling of SiC nano particles with high reactive Mg powder was beneficial for improving the wettability of the reinforcement with the melt of matrix.
3. Short time mechanical stirring was helpful for providing extra shear force to break the agglomeration and disperse the nano particles in the melt. Besides, the stirring under electromagnetic field was helpful to refine the grain size for improving the strength of the composite.
4. Agglomeration and interfacial reactions Al_4C_3 was observed in SEM and XRD of 1.5 wt% SiC composite

which reduces the UTS and impact strength of the composites.

5. The SEM fractographs of tensile samples of composites at different weight fractions of reinforcement reveals that the specimen of 1 wt% SiC/7075 Al nano composite are fractured in a entirely ductile way comprising of well-developed dimples over the entire surface, but the dimples get scattered on surface of the latter. The ductile to brittle transition observed in the fracture surface of the sample of 1.5 wt% SiC/7075 Al nano composite because formation of brittle reactive product and cracks are visible adjacent to the reactive product. Hence, it is well authenticated that initialization of fracture occurs near the reactive phase due to weak bonding between the reactive phase and matrix material.

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