Mechanical Properties of 7075 Aluminium Matrix Composites Reinforced by Nanometric Silicon Carbide Particulates

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Abstract

Aluminum Matrix composites (AMCs) are known as light weight and high-strength materials with their potential application in areas such as aerospace, automobile, defence, engineering and other industries. AMCs have the advantage to significantly reduce the overall weight of the vehicles and aircraft while maintaining their structural strength. Reinforcement of micron or nano-sized range particles with aluminium matrix yields improved mechanical and physical properties in composite materials. The strength of Al matrix composites will be improved about 20% with decreasing reinforcement particle size from micrometric scale to nanometric scale. In this study, Al7075 alloy and nano SiC composites have been fabricated by Electromagnetic stir casting process combined with mechanical stirring. Different weight % of nano SiC particles (0.5, 1, 1.5, and 2 wt%) were used for synthesis of composites. Certain test methods scanning electron microscopy (SEM) and X-Ray diffraction (XRD) are used to examine the microstructure along with the measurement of impact strength of the nano composite. SEM microstructure shows SiC particles are fairly infused into the matrix alloy with agglomeration and porosity at some places. X-Ray Diffraction (XRD) analysis acknowledged that no unknown crystalline elements are present in the composites while mixing reinforcement with Al alloy matrix. The results impact strength shows that impact strength decreases with respect to the base metal because of brittle nature of reinforcement.

1. Introduction

Industrial technology is growing at a very rapid rate and consequently there is an increasing demand for new materials [1]. Conventional metals and alloys have limitations in achieving good combination of strength, toughness, wear resistance, high temperature performance and corrosion resistance. Therefore, material researchers' have diverted their focus from monolithic to composite materials [2]. Aluminium alloys are promising materials in high technology fields owing to their excellent specific mechanical properties [and tribological properties. To overcome these problems, Abdizadel et.al.2009].However, they lack in poor elevated temperature aluminium matrix composites are developed in which hard Industrial technology is growing at a very rapid rate and consequently there is an increasing demand for new materials [1]. Conventional metals and alloys have limitations in achieving good combination of strength, toughness, wear resistance, high temperature performance and corrosion resistance. Therefore, material researchers' have diverted their focus from monolithic to composite materials [2]. Aluminium alloys are promising materials in high technology fields owing to their excellent specific mechanical properties [and tribological properties. To overcome these problems, Abdizadel et.al.2009].However, they lack in poor elevated temperature aluminium matrix composites are developed in which hard ceramic particles are dispersed in relatively ductile aluminium matrix .These composites materials have widespread applications in various areas of ground transportation(auto and rail),thermal management, aerospace, industrial, recreational and infrastructure industries because of their functional properties that include high structural efficiency, excellent wear resistance and attractive thermal and electrical characteristics [Hassan et.al.2005,Zhao et.al.2008].The size of particulate reinforcements in AMCs generally ranges from a few micrometers to several hundred micrometers [Ma et.al.1999].Nano structured Al based materials have received much attention in recent years from industry sectors such as automobile,defence and aerospace due to the increasing demand for light weight high strength materials.Grain size reduction of a material to the nanometric level(<100 nm) triggers some exceptional values to mechanical properties. Superior hardness and strength have been reported for nano grained metals when compared to micron sized counterparts while maintaining the ductility of the composites but the tendency of particle clustering and agglomeration increases[Fogagnolo et.al.2006]. Industrial technology is

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growing at a very rapid rate and consequently there is an increasing demand for new materials [1]. Conventional metals and alloys have limitations in achieving good combination of strength, toughness, wear resistance, high temperature performance and corrosion resistance. Therefore, material researchers' have diverted their focus from monolithic to composite materials [2]. Aluminium alloys are promising materials in high technology fields owing to their excellent specific mechanical properties [Abdizadel et.al.2009].However, they lack in poor elevated temperature and tribological properties. To overcome these problems, aluminium matrix composites are developed in which hard ceramic particles are dispersed in relatively ductile aluminium matrix .These composites materials have widespread applications in various areas of ground transportation(auto and rail),thermal management, aerospace, industrial, recreational and infrastructure industries because of their functional properties that include high structural efficiency, excellent wear resistance and attractive thermal and electrical characteristics [Hassan et.al.2005,Zhao et.al.2008].The size of particulate reinforcements in AMCs generally ranges from a few micrometers to several hundred micrometers [Ma et.al.1999].Nano structured Al based materials have received much attention in recent years from industry sectors such as automobile,defence and aerospace due to the increasing demand for light weight high strength materials.Grain size reduction of a material to the nanometric level(<100 nm) triggers some exceptional values to mechanical properties. Superior hardness and strength have been reported for nano grained metals when compared to micron sized counterparts while maintaining the ductility of the composites but the tendency of particle clustering and agglomeration increases[Fogagnolo et.al.2006]. Industrial technology is growing at a very rapid rate and consequently there is an increasing demand for new materials [1]. Conventional metals and alloys have limitations in achieving good combination of strength, toughness, wear resistance, high temperature performance and corrosion resistance. Therefore, material researchers' have diverted their focus from monolithic to composite materials [2]. Aluminium alloys are promising materials in high technology fields owing to their excellent specific mechanical properties [Abdizadel et.al.2009].However, they lack in poor elevated temperature and tribological properties. To overcome these problems, aluminium matrix composites are developed in which hard ceramic particles are dispersed in relatively ductile aluminium matrix .These composites materials have widespread applications in various areas of ground transportation(auto and rail),thermal management, aerospace, industrial, recreational and infrastructure industries because of their functional properties that include high structural efficiency, excellent wear resistance and attractive thermal and electrical characteristics [Hassan et.al.2005,Zhao et.al.2008].The size of particulate reinforcements in AMCs generally ranges from a few micrometers to several hundred micrometers [Ma et.al.1999].Nano structured Al based materials have received much attention in recent years from industry sectors such as automobile,defence and aerospace due to the increasing demand for light weight high strength materials.Grain size reduction of a material to the nanometric level(<100 nm) triggers some exceptional values to mechanical properties. Superior hardness and strength have been reported for nano grained metals when compared to micron sized counterparts while maintaining the ductility of the composites but the tendency of particle clustering and agglomeration increases[Fogagnolo et.al.2006].

Nanomeric scale reinforcements are better than micrometric scale because of their effectiveness in blocking the dislocation motions and because of their size, they are less prone to crack or damage during the composite's synthesis process [6].Currently, there are several fabrication techniques of AMCs including mechanical alloying using high energy milling [Razavi et.al.2009],vortex method [Habibnejad et.al.2010,Radi Y. et.al.2010], disintegrated melt deposition [Lu L. et.al.2003], powder metallurgy [Wang HY et.al.2004], ultrasonic casting [Mula S. et.al.2009,Lan J. et.al.2004] etc. But there are certain limitations in terms of the size and complexity of the components in solid state fabrication techniques. The liquid-state methods such as stir casting is generally accepted because of its simplicity, flexibility and applicability to large quantity production. Stir casting, suitable to disperse micron-sized particles, has been found to perform poorly when nano-particles are added to the metal matrix. The process restraints are: 1.Particle introduction in the melt; 2.Particle clustering; 3.Weak bond between matrix and reinforcement. Because of the increase in surface area together with the reduction in particle size, insert the particles in the melt and homogeneously disperse them is challenging. The increase of interfacial energy raises the free energy of the system, causing agglomerates to form in order to re-establish the stable state.

Electromagnetic stirring has the advantage of having no contact between the melt and the stirring system [Lim Sung-Chul et.al.1997].This is supposed to be the most suitable method of producing materials with thixotropic behaviour[Jung B.I. et. al.2001].It has already been established that electromagnetic stirring improves the microstructure of the composite [Nafisi S. et.al.2006] and intensinve melt stirring also improve the mechanical properties of the composites due to uniform distribution of the nano sized particles within the melt [Fan Z. et. al.2002].Moreover, several structural defects such as porosity, particle clustering, oxide inclusions and interfacial reactions also arises in this process[Zhou W. et.al.1997].

In the present study,nano SiC is used as a reinforcement into the Al7075 matrix to make nano metal matrix composites using Electromagnetic stir casting process combined with mechanical stirring. Then the experimental study was carried out on the microstructure of the prepared composite samples and the tensile strength and impact strength of nano-SiC reinforced Al7075 matrix composite were tested.

2. Experimental Work

2.1 Matrix: Al7075

For the development of composites, 7075 aluminium alloy was use as the matrix material because among all aluminium alloys Al7075 has got the highest strength and nano SiC powder of particle size 45-65 nm is used as a reinforcement material. The chemical composition of the alloy is shown in table 1.1

Table 1 Composition of Al7075 Alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
% Composition	0.09	0.2	1.4	0.07	2.3	0.2	5.7	0.03	Remainder

2.2 Reinforcement: Silicon Carbide

The product possesses high purity (99+ %), narrow range particle size distribution and large specific surface area. This product has chemical stability, high thermal conductivity, smaller thermal expansion coefficient and better abrasion resistance.

2.3 Fabrication of AL7075-SiC NMMC

An electromagnetic stirring (EMS) setup was used that consists of a stator of a 3-phase induction motor of power rating 15 HP, a control panel to measure the electric current and voltage of appropriate range, a 3-phase voltage variac to control the voltage and a muffle furnace of temperature range 40°C to 1200°C.A K-type thermocouple with a temperature recorder was used for measurement of the temp.0^0C to 2000^0C of the molten metal during EMS process.

First the alloy was melted in a crucible using the induction furnace and the temperature of the melt was raised to about 750°C i.e. above the liquidus temp. of the alloy so that the melt is totally melted. Simultaneously the nano reinforcement particles are treated in ball mill with Mg (1 wt%) for about 5-6 hrs so that they are fused together which helps in improving wettability of nano SiC particles with the Al7075 matrix. The purpose of Mg addition which is a highly reactive element is to increase the wettability of SiC particles with the metal matrix by forming a layer of $MgAl_2O_4$ at the interface of oxidized SiC thus protecting the SiC particles from reaction with Al and restricts the formation of Al_4C_3. The melt is then cooled down to a temp 450^0C between the liquidus and the solidus points and kept in a semi solid state.Semi-solid casting is an improved technology to overcome the disadvantages of traditional stir casting. The basic of semi-solid casting is to mix the reinforce particles into the semi-solid metal bulk, disperse these particles uniformly in the matrix by stirring to get well interface bonding, then put the molten metal into mould to get the near-shape product.

At this stage, the specific quantities of preheated nano-SiC particles(0.5,1,1.5 and 2wt%) mixed with Mg were added to the melt in the form of a packet made by aluminium foil and mixed by mechanical stirring. Continuous supply of argon gas is also maintained to prevent the oxidation of nano particles. Preheating of reinforcement particles are done to release all the moisture and trapped air between the particles which also improves wetting. The slurry is again heated and then placed in an electromagnetic field of EMS setup. Electromagnetic stirring of the melt was carried out for 2 min in the mushy zone under a temperature range of 450^0C to 590^0C. For electromagnetic stirring, the current was increased gradually from 0 to 25A in order to increase the strength of the electromagnetic field. After 2 min of electromagnetic stirring, the melt is allowed to solidify in the motor at low ampearage of 4A.

2.4 Characterization of AL7075-NANO SiC Composites

2.4.1 Metallurgical Characterization

Samples for the microstructural study were taken from the middle of the cross section from the casted samples. The specimens for metallography were prepared by first grinding through 240, 500, 800, 1000 and 1200 grit papers followed by polishing with Al_2O_3 powder and then etched with Keller's reagent. The microstructure was investigated by optical microscopy scanning electron microscopy (SEM), Energy Dispersive X-ray analysis (EDX) and X-ray diffraction (XRD).

Fig 1: Experimental Set-up

2.4.2 Mechanical Characterization

Tensile testing was done using computerized tensile testing machine. The gauge dia of tensile test specimens were 6mm and gauge length were 30mm according to ASTM B557M-10 standard. Impact testing was done for the measurement of impact strength of the composites.

3. Microstructure

The most important factor to achieve a homogeneous property of discontinuously reinforced composites material is the uniform dispersion of the reinforcement particles. Therefore the appearance of the microstructure could give an insight into the quality of the composite.

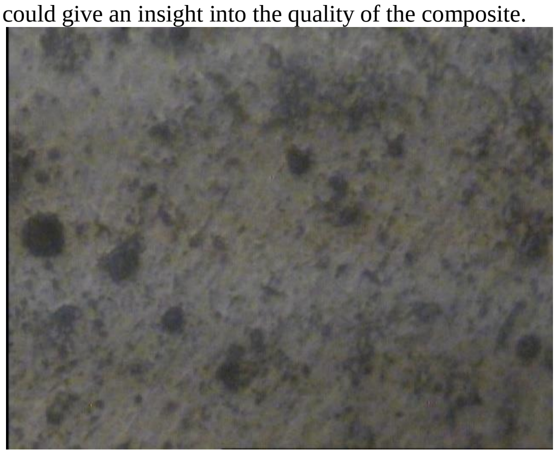

Fig 2: Optical Micro. [Al7075+0.5%nSiC]

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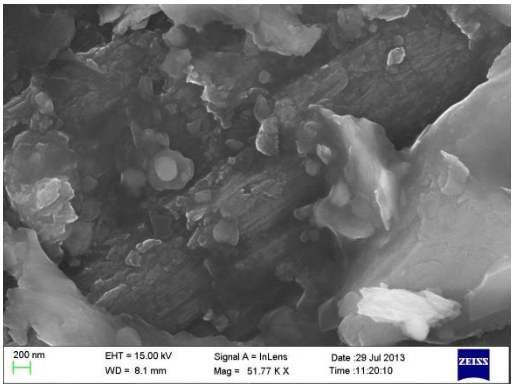

Fig 3: SEM image [Al7075+0.5%nSiC]

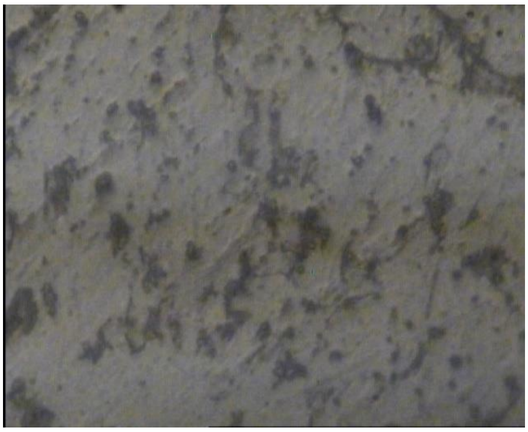

Fig 4: Optical Micro. [Al7075+1%nSiC]

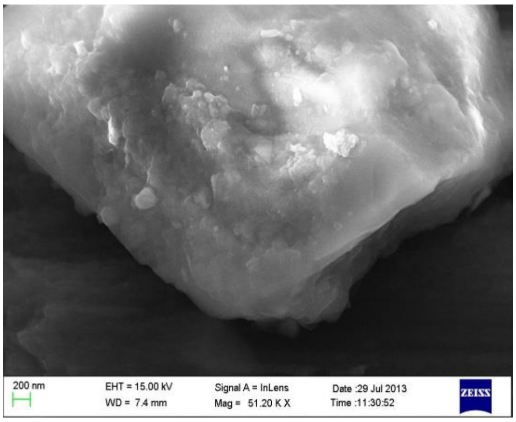

Fig 5: SEM image [Al7075+1%nSiC]

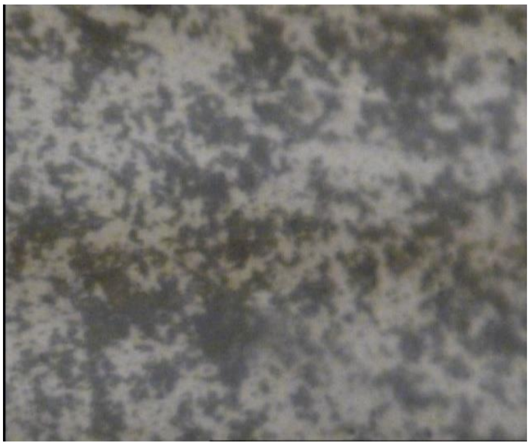

Fig 6: Optical Micro. [Al7075+1.5%nSiC]

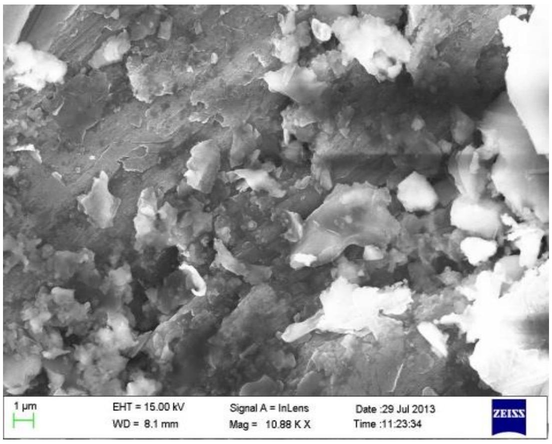

Fig 7: SEM image [Al7075+1.5%nSiC]

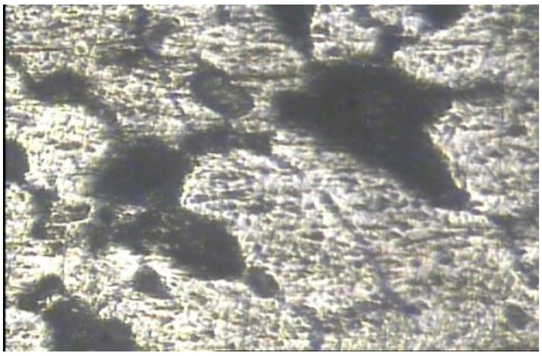

Fig.8: Optical Micro. [Al7075+2%nSiC]

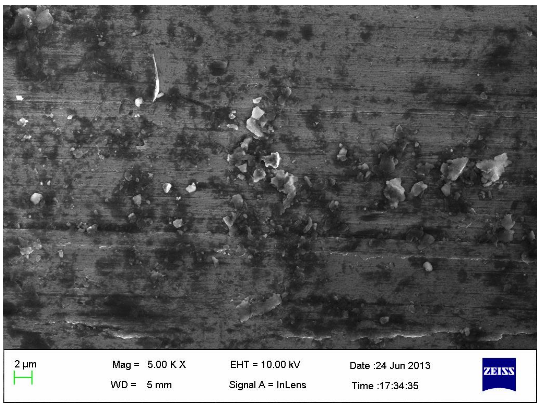

Fig 9: SEM image [Al7075+2%nSiC]

The microstructures observations revealed that the reinforcement particles are almost spherical in shape and their distribution is reasonably uniform throughout the matrices in a company with clustering of particles and porosity at some locations. The white spots characterize SiC particles whereas the black spots exposed the presence of porosity. Particles clustering may occur due to the insufficient stirring speed and stirring time, whereas the porosity may be attributed to the dissolved gases and air bubbles sucked into the melt while adding the argon gas and the ceramic powder to the melt via the vortex during the mechanical stirring.

Microstructures of the casted samples are obtained by optical microscopy and SEM. It is evident from the results that distribution of the nano SiC particles within the Al7075 matrix is reasonably uniform but there exists some defects in the form of porosity, crack and clustering of reinforcement particles which are undesirable. Depending on the proportion of added reinforcement the particle arrangement or crystalline structures have changed.

Microstructure shows the homogeneous distribution of SiC reinforced particles in matrix alloy. Homogeneous distribution of particles is desired in achieving good mechanical properties. Homogeneous distribution of particles in a molten alloy is achieved due to the high shear rate caused by stirring which also minimizes the particle settling. However, agglomeration of particles in some regions is clearly visible in all cases, this is due to the presence of porosity associated to it. Presence of entrapped air and moisture in the reinforcement particles results in the voids /porosity after casting.

4. XRD Test

X-Ray diffraction has been performed to measure the average spacing between atoms. By this analysis, the crystal structure of unknown materials was found and also the size, shape and internal stresses of small crystalline regions may be measured. Bragg's Equation ($n\lambda = 2d \sin\theta$) was used for all these analysis. This relation determines the cleavage face of crystal which appears due to the X-ray beam incident at certain angles on crystals. The metallographic specimens were prepared of different compositions and X-ray diffraction (XRD) was examined. The XRD was performed using Cu Kα radiation in copper medium with an angle ranging from 10^0 to 100^0 at gynometer speed 2^0/min.

It is expected that the contact between the reinforcing particles and Al melt would result in an interaction layer which improves wetting between the two constituents. The type of interaction layer depends on the elements present at the interface during processing. The interfacial reaction between the metal matrix and reinforcement in metal matrix composite is very important because strong interfacial bonding permits the transfer and distribution of the load from the matrix to the reinforcement. Therefore the nature of the interface is one of the important factors to consider when designing a MMC.

Addition of reactive element like Mg improves the wetting characteristics of metal ceramic systems through a reduction in solid –liquid interfacial energy and the surface tension of the liquid metal.The solid-liquid interfacial energy is changed through the presence of reaction products at the interface.The reactions of interace are: $Al + SiC = Al_4C_3 + Si$ (1)

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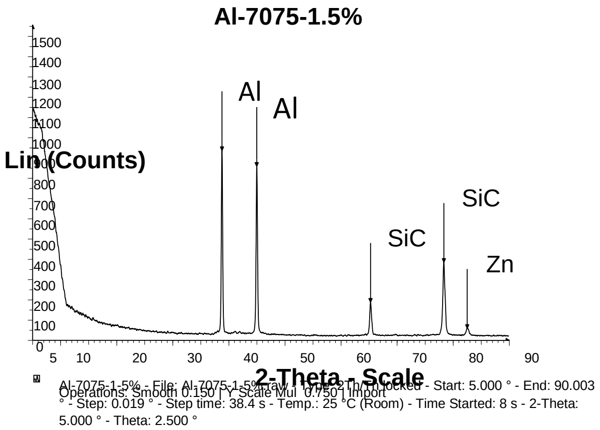

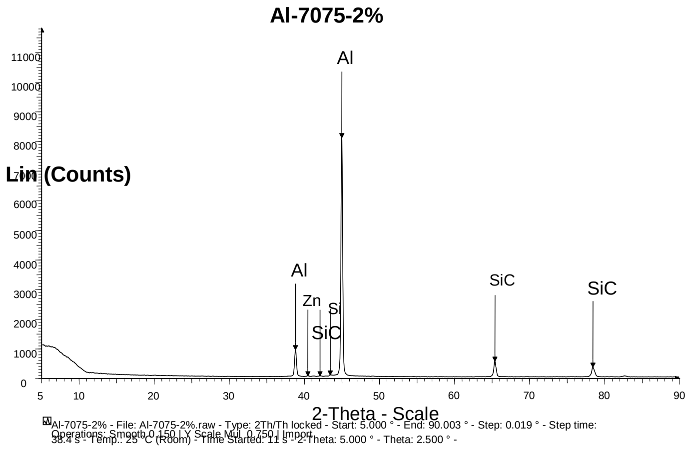

surface tension of the liquid metal.The solid-liquid interfacial energy is changed through the presence of reaction products at the interface.The reactions of interace are: $Al + SiC = Al_4C_3 + Si$ (1)

Heat treatment of ceramic particles before incorporation is used to improve the wettability of the ceramic particles by liquid Al which is improved through desorption of absorbed gases from the surface of ceramic particles.

The XRD pattern of the examined material revealed that no hard phases like Al4C3 and CuAl2 were present at interfaces between SiC and the matrix because the presence of such brittle intermetallic phases substancially affect the strength of the bond between the matrix and the reinforcement because of which load transfer process is affected that can cause the local stresses in the microstructure which leads to particle cracking that affects the mechanical properties of the composites.The XRD pattern confirmed the presence of Al matrix and SiC particulate in the composite.The highest peak shows aluminium and the other peaks are indicating the remaining materials in the composite material.

5. Measurement of Tensile Strength

The tensile testing was carried out on universal testing machine (Instron-UTM made in Taiwan) linked to a computer where data were stored and analysed by preparing the specimen of various compositions. The specimens were prepared according to ASTM standard as shown in fig. 10. The measured tensile properties for various volume fractions of SiC are summarized in table 1.2.

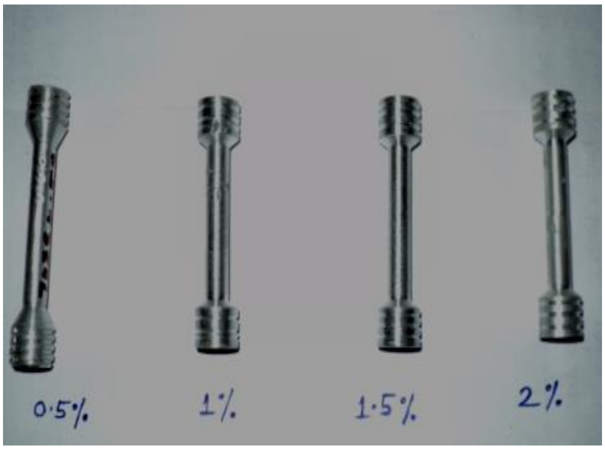

Fig.10 Tensile Test Specimen

Table 1.2 Variation Of Tensile Strength

Composition of material	Tensile strength(MPa)
Al7075	560
Al7075+0.5% nano SiC	584
Al7075+1% nano SiC	647
Al7075+1.5% nano SiC	618
Al7075+2% nano SiC	572

In the past study, Author was found that on increasing the volume fraction of SiC_p the tensile strength of composite increases [4]. In present study, on addition of SiC_p particles in Al7075 alloy, tensile strength increases up to the volume fraction of 1%. Further, increasing the weight fraction of SiC, tensile strength goes on decreasing and it is 572 MPa at 2% nano reinforcement. In a pure metal the dislocations are not severely hindered and therefore the material exhibits a low yield stress and a low hardness. By alloying the properties of the metal can be changed drastically. Dissolved impurities, precipitates and grain boundaries form obstacles for dislocation motion, which increase the critical shear stress and hence the strength and hardness. By correct reinforcement, followed by a proper heat treatment, the mechanical properties of the composites can be tailored so as to meet applications in practice.
The variations of tensile strength of samples of nano metal matrix composites are shown in fig.11.

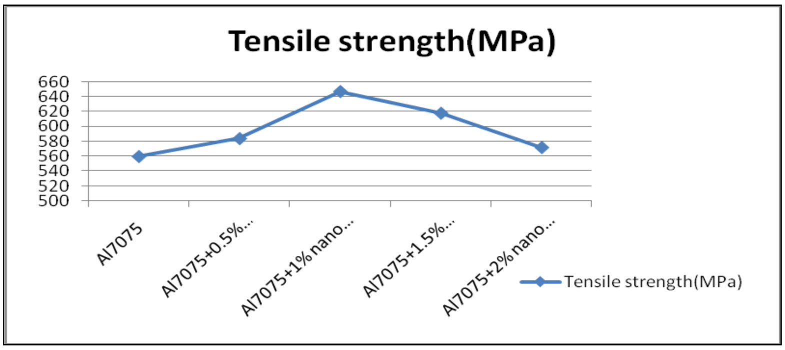

Fig.11 Variation of tensile strength

It is evident from the results that tensile strength increases as the weight fraction of reinforcement increases in the matrix material. However, with 1.5% and 2% reinforcement tensile strength decreases because higher content of SiC nano particles in the matrix would lead to more agglomeration of particles and the porosity in the composites.

6. Measurement of Impact Strength

The specimens of dimension 10 mm × 10 mm × 55 mm were prepared according to ASTM E-23 standard. A V-notch was made on it to improve the stress concentration. The impact test specimen shown in fig.12. The specimen was tested on charpy testing machine. The measured values of impact strength for different compositions of composites are shown in table 3.
It is clearly indicated from the table that as the weight fraction of nano reinforcement phase in the metal matrix increases, the impact energy of the composite, when compared to the unreinforced counterpart, actually decreases. Higher the percentage of particulate in the matrix lesser is the impact energy. This is actually due to the brittle nature of the reinforcing phase.

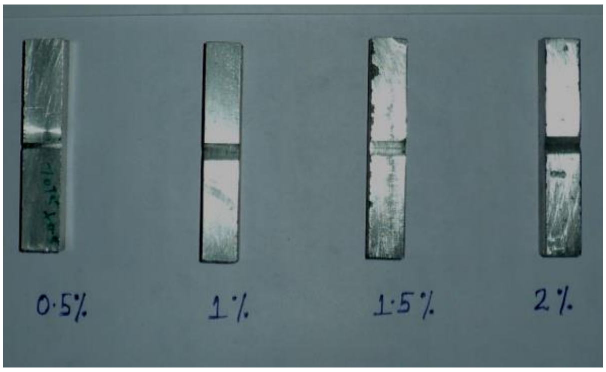

Fig.12 Charpy Test Specimen

Table 3 Impact Strength at different compositions

Composite	Impact Energy(J)
Al7075	12
Al7075+0.5% nano SiC	12
Al7075+1% nano SiC	11
Al7075+1.5% nano SiC	10
Al7075+2% nano SiC	9

7. Conclusions

Here we successfully fabricated the Al7075-nano SiC composites by Electromagnetic Stir Casting arrangement along with mechanical stirring with a fairly good amount of reinforcement incorporated within the matrix. Also we added Mg to improve the wettability of SiC particles by reducing its surface tension.We have drawn following conclusions based on the different experimental tests:

a) The EMS process combined with mechanical stirring can be used to produce Al7075 alloy/nano SiC particle composites in which the SiC particles are fairly distributed within the matrix alloy which is evident from the results of SEM and optical microscopy.

b) XRD diffraction results show that there is no formation of any other element during the mixing of reinforcements in metal matrix.

c) Tensile strength of the composites increases with increase in the %wt fraction of the reinforcement but decreases as it increases to a level of 1.5% due to particle agglomeration.

d) Impact strength of composite decreases with respect to the base metal.

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