Development and Characterization of Nanoparticle Metal Matrix Composites: (Al 2024-SiC NP)

Muhammad Arshad Chaudhry¹, Liaqat Ali², Khalid Mahmood Ghauri², Javed Iqbal²

¹Ph.D Research Scholar, Department of Metallurgical and Materials Engineering, University of Engineering & Technology, Lahore, Pakistan ²Professor Dr. Department of Metallurgical and Materials Engineering, University of Engineering & Technology, Lahore, Pakistan

ABSTRACT

Composite materials get an importance in value as an advance materials such as automotive, aerospace, aircraft, defense, medical, marine, sports, recreation and various engineering applications due to their high strength-to-weight ratio, good cast ability and better tribological properties. Al-base 2024 alloy reinforced with SiC micron and nano particles were developed using stir casting technique due to low cast, ease in fabrication, recyclablility and isotropic characteristics. The development of Aluminum metal matrix nano composites (AMMNCs) is most considered material for high temperature applications because of their excellent mechanical properties, increase performance and weight saving for more reduction of fuel consumption. The results indicate that Al-SiC composite has improved physical and mechanical properties such as tensile strength, charpy impact strength, brinell hardness, density and porosity percentage. Samples with micron particles and nano particles were developed to compare the properties of both. Microstructures of the samples were studied by means of X-Ray Diffraction and Scanning Electron Microscopy. The elemental composition was also analyzed through Energy Dispersive Spectroscopy. It was found that composites of Al-SiC have better and improved physical properties in nano dimensions.

Keywords: Al-SiC development, stir casting, characterization of reinforced samples, optical micrograph, XRD, SEM and EDS

Correspondence to Author:
Muhammad Arshad Chaudhry
Ph.D Research Scholar, Department of Metallurgical and Materials Engineering, University of Engineering & Technology, Lahore, Pakistan
muhammad.arshad@tech.uol.edu.pk

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1. Introduction

Stir casting is the type of vortex heating with stirring method in which the raw material gets homogeneously mixed with each other at controlled temperature rate [1]. It is well known that MMCs being light weight, hard and abrasion resistant are widely used for high temperature and speed parts such as pistons, axles, high speed wheels and so on [2]. Al alloys having light weight, good stiffness, corrosion resistance and improved mechanical properties etc [3].

Decrease in the reinforcement particle size from micron to nano sized increases the tendency of particles clustering and agglomeration but having good strength. Homogenous particle distribution improves mechanical properties [4]. A MMC is an engineered material by combining the metal (matrix) and ceramic hard particles (reinforcement) in order to obtain required properties [5].

Normally, Al and its alloys solidify in columnar structure having large grain size with less mechanical properties. The addition of Cu in Al alloy, there is a substantial improvement in mechanical properties and microstructure [6]. Stir casting method has some limitations of poor wettability which enhances the tendency of agglomeration of reinforcement material. The wettability of SiC and Al2O3 may be improved by adding Si or Mg [7].

Al alloys are used for engineering applications at moderate temperature [8]. Al alloys are mostly attractive due to their low density, good thermal & electrical properties and having good damping capacity [9]. In the production of composite with desired properties, important factors like nature of metal matrix and choice, the kind of reinforced particulates and the process involve, must be standardized [10].

Current researches reveal that the dispersing of nanoparitcles into the Al matrix improve the hardness, yield and UTS substantially whereas the ductility is retained. It was observed that yield strength of A356 alloy having 50% improvement with 2.0 wt% nano particle [11].

Al alloys reinforced with Al2O3 have been used in automobile, aerospace, aircraft etc. due to their high strength- to-weight ratio, good cast ability and better tribological properties [12]. Al alloy reinforced with particulates composites are achieving great importance due to their low cost, isotropic in nature and useful for secondary processing [13]. Al Metal Matrix Nano Composites (AMMNCs) reinforced by nano scale particulates are widely used in industry such as automotive and aerospace [14].

The objective of the present study was to investigate the influence of the stir casting process parameters like heating temperature with holding time for uniform distribution of SiC particles and obtain mechanical properties such as TS, ductility, impact and hardness behavior [15]. Cast Al alloy matrices have higher specific strength, specific modulus and good wear resistance [16].

The dispersion of SiC into Al matrix is constrained due to more %age of Si. It is noted that viscosity of the molten metal increases because of the addition of nano SiC particles [17]. MMC is produced using Stir Casting by selecting metal matrix of required grade and the dispersion of the reinforcement material. In order to form a vortex, stirring is carried out vigorously in which reinforcing materials are inserted from the vortex side. The reinforcement particles along with all impurities drag to form the vortex. The air is entrapped by the vortex into the melt. Due to increased viscosity of the slurry, it is difficult to remove the air from the melt [18].

Al is widely used because of its easy availability, high strength to weight ratio, easy machinability, durability, ductility and malleability [19]. Composite materials have more potential for replacing of widely used steel and Al. They have many times better performance [20]. During the last three decades, Al based composite has been creating an interest in materials science and engineering sector for
the development of high performance components in the fields of automobile, medical, aerospace, defense, marine, sports and recreation [21].

Stir casting method is used to achieve a suitable dispersion. It has some advantages such as simple, flexible, economical and applicable to large quantity production [22]. Stir Casting is one of the most economical, simple casting routes for the production of AMMCs [23]. Al Metal Matrix Composites (AMMCs) are produced by dispersing SiC, Al 203 and B4C having micron or nano sized into Al alloy matrix. [24].

Al matrix composites reinforced with SiC have structural and non-structural applications both at room and high temperatures. [25]. Aluminum MMC exhibits better mechanical properties than unreinforced Al alloys. Al is only second to steel, when it comes to automobile body frame, with 5xxx and 6xxx series on the lead [26]. Al alloys are preferred engineering materials in automobile and aviation industries for various high-performance components [27].

There is a dire need of modern development of advanced engineering materials for various engineering applications. [28]. It is desirable that the composite material be economical for the mass production [29]. Al metal matrix composites have specific use due to low cost, ease in fabrication, recyclability and isotropic characteristics [30].

Al and its alloys have preferable dispersing of SiC due to its high melting point (2300 °C), high stiffness (480 GPa), good thermal stability, high hardness (9.7 Mohs), great resistance to chemical attack at room temperature, low density (3.21 gm/cm³) and low thermal coefficient of expansion (4.7 x 10⁻⁶ K⁻¹). That's why, SiC has proved competitive reinforcing material with wider applications in industries [31]. The Metal matrices have a useful combination of properties such as high strength, ductility and high temperature resistance but sometimes have low stiffness, whereas ceramics are stiff and strong though brittle [32].

Al Metal Matrix Nano Composites (AMMNCs) have gained considered importance because of dispersion of nano particles in the host matrix to achieve superior mechanical properties [33]. It is well known fact that Liquid phase process has capability to develop producing of intricate profiles having light weight [34].

Stir casting method is most suitable for large quantity production of composite [35]. By using casting method, the cost of composite production is about 1/3 to 1/2 and for high volume production, it falls to 1/10 [36]. The Particle distribution in the melt depends upon the viscosity of the slurry, particle wetting, particle settling rate, effective mixing, agglomeration breakup and minimum gas entrapment [37].

In order to obtain better properties, hybrid MMCs have more than one type, shape and size of reinforcement are utilized. Hybrid MMCs possess better and improved properties being, combined advantages of their constituent reinforcements [38]. The development of Al alloy / Al2O3 reinforced (MMNCs) is important for such applications in aerospace, jet engine exit vanes, blade sleeves of helicopters, parts of space shuttle, piston and cylinder liners, brake drums and discs [39].

The development of Aluminium Metal Matrix Nano Composites (AMMNCs) is most considered material for high temperature applications, due to their excellent mechanical properties, increased performance and weight saving for more reduction of fuel consumption [40]. Al and its alloys in the form of MMCs are widely used in aircraft, aerospace, automobiles and various other fields [41].

2. Research Methodology

2.1 Materials

Al alloy Al 2024 and reinforced micron and nano SiC particles of size 50 um and 50 nm were used. The chemical composition of each
is shown in table 1 and table 2

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elements</strong></td>
</tr>
<tr>
<td><strong>Wt %</strong></td>
</tr>
</tbody>
</table>

Table 2 The Silicon Carbide Beta (imported from NanoAmor, USA) has the following characteristics

<table>
<thead>
<tr>
<th></th>
<th>1. Average particle size</th>
<th>45-55 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Purity</td>
<td>97.50%</td>
</tr>
<tr>
<td>3</td>
<td>Stock #</td>
<td>4620 KE</td>
</tr>
<tr>
<td>4</td>
<td>Composition</td>
<td>Si&lt;0.15% C&lt;0.15% C&lt;0.75% O&lt;1.25%</td>
</tr>
<tr>
<td>5</td>
<td>Color</td>
<td>Grayish White</td>
</tr>
<tr>
<td>6</td>
<td>Density, Bulk</td>
<td>0.068 g/cc</td>
</tr>
<tr>
<td>7</td>
<td>Density, True</td>
<td>3.22 g/cc</td>
</tr>
<tr>
<td>8</td>
<td>Morphology</td>
<td>Spherical</td>
</tr>
<tr>
<td>9</td>
<td>Hazardous</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>X-Ray Diffraction Pattern</td>
<td>Depicted</td>
</tr>
</tbody>
</table>

Figure 1

Silicon carbide, SiC
Stock number: 4620KE
~85% β + ~15% amorphous
JCPDS card number(β): 29-1129
Radiation: Cu Kα
Crystallographic system(β): cubic
Space group(β): F 43m (216)

Figure 2 (a) Stir Casting Experimental Rig [Top Loaded Electric Resistance Furnace with Mechanical Stirrer Assembly]. (b) Power Control Panel. (c) Mechanical Stirrer Assembly with lifting / lowering Mechanism with Variable Speed Electrical Motor (1HP). (d) Electric Resistance Furnace with Stainless Steel Crucible and Stainless Steel Stirrer Rod. (e) Crucible Lid. (f) Sample Mold Die

3. Objectives
- The Literature survey has shown that Aluminum Metal Matrix Nano Composites (AMMNCs) have created a lot of interest for researchers as they have full potential of confidence to explore further improvements
enhancements in the specified physical / mechanical properties and other requisite economical parameters of nano composites of various MMNCs in the tremendously expanded engineering sectors such as automotive, aerospace, strategic defense, biomedical, electronics etc, for engineering applications.

- To develop indigenous manufacture method of stir casting for casting samples of Al alloy matrix nano composite in order to investigate enhanced hardness and physical / mechanical properties for longer life of the components / engineering systems.
- To characterize / analyze the nano composite test results in order to find the optimized reinforcement with an appropriate percentage of nano particles having homogeneity in microstructures and increased mechanical properties like tensile strength, impact strength and hardness etc.
- Under optimized condition, efforts would be made to reduce porosity and improve homogenization of particulates in the Al matrix.
- In view of growing increasing demand of Al alloy matrix nano composites due to reduced weight of components / engineering systems with the aim to enhance the fuel efficiency of the systems being economical.
- After having achievement on the above mentioned parameters, the sectors of strategic defense, aerospace, automotive and industrial infrastructure etc will definitely be benefited in the long run.
- Moreover, the present research study / work will be an attempted endeavor for a positive contribution towards the development and characterization of AMMNCs in the good name of the country and UET Lahore.

4. Problem Statement

- Since MMC materials may have to develop by many different techniques. The main focus should be on the selection of suitable process, type, reinforcement %age fraction and distribution of the reinforcement particles into the metal matrix with the aim to obtain highly enhanced properties.
- The problem might be addressed to evolve a development process for the proper dispersion of reinforcement of components for Al-SiC System with optimized physical and mechanical properties.
- In case of stir casting, process parameters such as preheat of metal matrix, preheat of reinforcement particles, speed of rotation, stirring speed, stirring temperature, stirring time, mold temperature and pouring temperature etc, play a vital role on properties of Al based MMC. If the process parameters are well controlled, improved properties of MMC could be achieved.
- During fabrication of Al-SiC MMC by stir casting, there exist the potential for the formation of Al4C3 by the dissolution of SiC, for instance, the stir casting route is more suitable for low volume fraction (< 20% ).
- Uniform distribution of reinforcement particles may be achieved by re-stirring process.
- Oxidation treatment for SiC particles in Al-SiC MMC [4 Al+3 SiC = Al4C3 +3 Si] prevents the chemical reaction between Al & SiC product Al4C3 which is detrimental for reducing reinforcement and interfacial strength and increasing corrosion susceptibility.
- Low wettability between the metal matrix and the reinforcement particles may be improved by the addition of Mg 1wt% which increases the interfacial bonding strength.

5. Experimental Work

5.1 Melting

Preheated the Al Alloy at 450 °C for 3-4 hours and SiC micron particles (APS 50 µm) at 800-900 °C for 2 hours before melting. Charged 1500gm of Al alloy into the stainless steel crucible and melted in an electric resistance furnace by heating upto 700 °C. Cleaned the melt from the slag by overheating of the melt.
50 °C above the liquidus temperature. Maintained furnace temperature at 800 °C and degas the melt by using hexachloroethane (C₂Cl₆) solid degasser. Allowed melt to cool to 700 °C. Added preheated SiC micron particles at 700 °C to the melt and performed stirring at 300 rpm for 20 minutes. Added Mg 1 wt% as wetting agent in the melt to increase the wettability between the matrix and reinforcement. Reheated the composite slurry and maintained at a temperature of 750-760 °C. Performed mechanical stirring for 10 minutes at 400 rpm. The same melting procedure was used for nano composites.

In present research study, the composites were developed / produced by 2 step stir casting technique. Al 2024 was used as metal matrix and SiC as reinforcement particle of size APS 50 um and 50 nm. Cast the micron composites with 0.0 wt%, 0.5 wt%, 1.0 wt%, 1.5 wt% and 2.0 wt% and nano composites with 0.0 wt%, 0.3wt%, 0.6 wt%, 0.9 wt%, 1.2 wt%, 1.5 wt% & 1.8 wt% SiC as reinforcement.

### 5.2 Sample Casting
Preheated steel mold die (En 31) at 550 °C for 20 minutes. Casted test sample bars of dia 20 mm and length 180 mm

### 5.3 Machining of Test Samples
Machined the test samples as per standard to perform Tensile Strength Test, Brinell Hardness Test, Charpy Impact Test, Density Measurement, Metallographic Test etc.

### 5.4 Heat Treatment of Machined Samples
Heat treated the machined test samples at 530 °C for 3 hours. Quenched the test samples in water at room temperature. Aged at 180 °C for 5 hours and then air cooled at room temperature.

### 5.5 Sample Preparation for Testing
Prepared heat treated specimens for (i) Metallography, (ii) Tensile Strength Test (iii) Charpy Impact Strength Test, (iv) Brinell Hardness Test, (v) Density Measurement Test (vi). For Micrograpy, samples were prepared using conventional grinding emery papers and polishing (diamond paste method).

### 6. Characterization of Test Samples

#### 6.1 Tensile Strength Test
Tensile strength test was performed on Monsanto Tensometer (UK) both for micron and nano composites and its sample as shown in figure 3.

![Figure 3](image)

#### 6.2 Percentage Elongation Test
It was performed along with tensile test on Tensometor.

#### 6.3 Charpy Impact Strength Test
Performed Charpy Impact Strength test on Charpy Impact Testing Machine (Shamidsu, Japan) as per specimen both for micron level and nano level and its sample as shown in figure-4

![Figure 4](image)

#### 6.4 Brinell Hardness Test
Performed hardness test on Brinell Hardness Tester (Shamidsu, Japan) as per specimen both for micron level and nano level and its sample as shown in figure-5

![Figure 5](image)
6.5 Density Measurement Test

Performed Density Measurement Test by Archimedes Principle as per standard formula both for micron level and nano level as shown in Figure 6

\[ \text{Density} = \left( \frac{\text{wt in air}}{\text{wt in air} - \text{wt in water}} \right) \times \text{density of water} \]

6.6 Percentage Porosity

It was calculated as per formula:

\[
\frac{\text{theo.density-experimental density}}{\text{theo.density} \times 100}
\]

along with density measurement test.

6.7 Metallographic Test

Performed the Metallographic Test of finished samples both for micron level and nano level on Metallurgical Microscope (Metkon) at higher magnification as shown in figure-7

7. Results and Discussions (Micron Level)

7.1 Tensile Strength Test

Tensile Strength Tests were carried out on a Tensometer for samples of micron composites. It reveals that tensile strength increases with the increase in wt% of SiCµp. It is maximum at 2.0 wt% SiCµp with value of 279 MPa as shown in figure-8

![Figure 8](image)

The tensile strength of Al-based alloy is 240 MPa and this value increases to a maximum of 279 MPa for 2.0 wt% SiCµp which is about 16 % improvement.

Similar trend has been observed by different researchers [10, 14, 17 and 18]

7.2 Percentage Elongation

The %age elongation is the measure of ductility. It decreases with the increase in wt% of SiC as shown in figure-9

![Figure 9](image)

The composite materials exhibit lower elongation due to hard and brittle SiC particles. Similar trend has been observed by different researchers [14, 17 and 18].

7.3 Charpy Impact Strength Test
Impact resistance is the measure of toughness. Impact strength firstly increases by increasing the wt% SiCµp. It has maximum value of 1.17 at 1.0 wt% of SiCµp. Thereafter ductility of Al matrix decreases with increase of wt% of SiCµp. The impact strength reduces at higher wt% of SiCµp which shows the variation in toughness of samples for different wt% of SiCµp as shown in figure-10.

Similar trend has been observed by different researchers [18 and 19]

7.4 Brinell Hardness Test
It increase with increase in wt% of SiCµp and SiCnp in the composites as shown in figure-11

Similar trend has been observed by different researchers [17, 18 and 19]

As the wt% of SiC is very small, there is no appreciable increase in hardness with increase in wt% of SiC. It reveals that maximum hardness value is 97.9 BHN at 2.0 wt% SiCµp. It implies that hardness increases with the increase in wt% SiC particles. The Brinell Hardness number of Al based alloy is 85.7 and this value increases to a maximum of 97.9 BHN for 2.0 wt% SiC which is about 23% improvement.

7.5 Density Measurement
Density of composite increases with increase in wt% SiC as shown in figure-10. It has maximum value of 2.81 g/cc at 2.0 wt% SiCµp which is about 3 % improvement as shown in figure-12

Similar trend has been observed by different researchers (18 and 19)

7.6 Percentage Porosity
The percentage porosity decreases with increase of wt% SiC particles. It implies that the microstructure of composite becomes sound with increase of wt% SiC for micron level and nano level as shown in figure-13

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considerably decreased with increase in wt% SiC and casting was performed in two stirring step.

7.1.1 Tensile Strength Test (Nano Level)
Tensile Strength Tests were performed on a Tensometer for samples of composites prepared. It reveals that tensile strength increases with the increase in wt% of SiCnp. It is maximum at 1.8 wt% SiCnp due to hard phase of SiC as shown in fig-14. It exhibits an improvement of about 22% compared to base Al alloy unreinforced. It is believed that the great enhancement in tensile strength in nano composites is due to good distribution of the nano SiC particles and low degree of porosity.

Fig-14 Schematic diagram of Tensile Strength Test Results

7.1.2 Percentage Elongation
The %age elongation is the measure of ductility. It decreases with the increase in wt% of SiCnp as shown in figure-15.
It is observed that the incorporation of 0 to 1.8 wt% resulted 50% decrease in ductility / elongation of the matrix. The composites which exhibit lower elongation is due to hard and brittle particles.

Fig-15 Schematic diagram of Graph showing Test Results

7.1.3 Charpy Impact Strength Test
Impact resistance is the measure of toughness. Impact strength decreases by increasing the wt% SiCnp because as the wt% of SiCnp particles increases, the ductility of Al matrix decreases and the hardness value increases. The impact strength reduces at higher wt% of SiCnp as shown in figure-16 which shows the variation in toughness of samples for different wt% of SiCnp and has maximum value of 1.24 at 0.9 wt% SiCnp.
It reveals that there is an improvement of 65% at 0.9 wt% SiCnp than base Al alloy. It implies that the increase in reinforcement above optimum level (0.9wt% SiCnp) drastically reduces the toughness of the material.

Fig-16 Schematic diagram of Charpy Impact strength Test Results

7.1.4 Brinell Hardness Test
It increase with increase in wt% of SiCnp in the composites as shown in the figure-17
As the wt% of SiCnp is very small, there is no appreciable increase in hardness with increase in wt% of SiCnp. It reveals that maximum hardness value is 110 BHN at 1.8% wt% SiCnp.

It implies that hardness increases with the increase in amount of wt% SiCnp. The hardness of the Al MMNCs improved significantly to 29% at 1.8 wt% SiCnp compared to base Al alloy. The higher hardness of the nano composites is attributed to the fact that SiCnp acts as obstacles to the motion dislocation being reduced grain size.

### 7.1.5 Density Measurement

Density of Composite increases with increase in wt% SiCnp as shown in figure-18.

It indicates that there is an improvement of about 4% compared to the base Al alloy.

### 7.1.6 Percentage Porosity

The percentage porosity decreases with increase of wt% SiCnp. It implies that the microstructure of composites becomes sound with increase of wt% SiCnp as shown in figure-19.

Variation of percentage porosity with increase in SiC Nano particle, as the casting was performed in two stirring steps.

### 7.1.7 Microstructural Analysis

The enhanced properties of the metal matrix nano composites depend on distribution of the reinforcing particles and interface bonding between metal matrix and the dispersed particles. The microstructures shown in figure-20 at 100X magnification in the optical microscope reveals uniform distribution of SiCnp reinforced nano particles in the matrix. As the wt% of SiCnp increases in the matrix, the SiC nano particles increases and the inter particle space decreases. It is obvious that there is no agglomeration of SiC nano particles in the matrix. The distribution of SiC nano particles across the casting samples reveals that the method of two stirring steps is successful.

It is noted that the uniform dispersion of nano particles provide some heterogenous nucleation sites during solidification, resulting in
a more refined microstructure.

The micrographs of AMMNCs are depicted as under:

**Micrographs of Micron Composites**

![Micrograph of SiC 0 wt% (Base Al Alloy)](image1)

![Micrograph of SiC 0.5 wt%](image2)

![Micrograph of SiC 1.0 wt%](image3)

![Micrograph of SiC 1.5 wt%](image4)

![Micrograph of SiC 2.0 wt%](image5)

**Micrographs of Nano Composites**

![Micrograph of 0.3 wt% SiCnp](image6)

![Micrograph of 0.6 wt% SiCnp](image7)

![Micrograph of 0.9 wt% SiCnp](image8)

![Micrograph of 1.2 wt% SiCnp](image9)

**Figure 20**

Fig-20 Micron Micrographs of (a) 0.0 SiC wt% (b) 0.5 SiC wt% (c) 1.0 SiC wt% (d) 1.5 SiC wt% (e) 2.0 SiC wt%
8. 1 X-Ray Diffraction (XRD) Analysis

XRD Analysis was performed to analyze the crystal structure and crystallite of different compositions micron and nano particles and also to locate the existence of different elements in the SiC particles. X-Ray diffractograms were obtained using Cu Kα radiation. The SiC powder was packed on a sample holder of size 20 mm x 20 mm with 2 mm deep samples were scanned at a speed of 2° / min (2θ) in the limit of 10-80°.

Measurement was made at an applied voltage of 40 KV and current of 40 mA. Figure-22 indicate graphs from XRD analysis of SiC micron particles and figure 23 indicate graphs from XRD analysis of SiC nano particles. The intense peak of SiC micron particles and nano particles and corresponding FWHM values is mentioned at each.

According to Sherrer formula, the average crystallite size was found as 50 µm and 50 nm

\[
\beta = 0.9 \lambda / t \cos \theta
\]

where \( \beta \) = FWHM value (Full Width at Half Maximum); \( \lambda \) = wave length of x ray for Cu is 1.54 Å; \( t \) = grain size; \( \theta \) = bragg angle

XRD scattering techniques are actually non destructive analytical techniques which shows information about the crystal structure, chemical composition, physical properties of material and thin films.

X-Ray Diffraction crystallography is a method to find the arrangement of atoms within a crystal, wherein a beam of X-Rays strikes a crystal causing to spread into many specific directions. After getting the angle and intensities of the diffracted beams, a 3D picture of electrons within the crystal is obtained.

It is based on observing the scattered and intensity of X-Ray beam hitting a sample as a function of incident and scattered angle, polarization and wave length or energy. A crystallographer can made a three dimensional picture of the density of electrons with the crystal. The intense peaks at (2θ) and corresponding FWHM values have been indicated at each X-Ray spectrum.

XRD spectrum of Al 2024 with 0.0 wt%, 0.5 wt%, 1.0 wt%, 1.5 wt% and 2.0 wt% micron particles and 0.0 wt%, 0.3 wt%, 0.6 wt%, 0.9 wt%, 1.2 wt%, 1.5 wt%, and 1.8 wt% for nano particles is exhibited in figure22 and figure 23 respectively.

**XRD Patterns of Micron Composites**

![XRD Pattern](image)

Intense peak value 44.628 (2θ) - FWHM value 1.612 (2θ)

![XRD Pattern](image)

Intense peak value 44.618 (2θ) - FWHM value 1.431 (2θ)
Intense peak value 38.320 (2θ) - FWHM value 1.432 (2θ)

Intense peak value 65.231 (2θ) - FWHM value 2.032 (2θ)

Intense peak value 38.610 (2θ) - FWHM value 1.425 (2θ)

Intense peak value 38.540 (2θ) - FWHM value 1.432 (2θ)

Intense peak value 39.359 (2θ) - FWHM value 1.429 (2θ)

Intense peak value 38.652 (2θ) - FWHM value 1.428 (2θ)

Intense peak value 44.780 (2θ) - FWHM value 1.432 (2θ)

Intense peak value 35.625 (2θ) - FWHM value 1.540 (2θ)

Figure 22
Fig-22 XRD images a) SiC 0.0 wt% b) SiC 0.5 wt% c) SiC 1.0 wt% d) SiC 1.5 wt% e) SiC 2.0 wt%.

XRD Patterns of Nano Composites
Intense peak value 38.869 (2θ) - FWHM value 1.430 (2θ)

Intense peak value 44.693 (2θ) - FWHM value 1.430 (2θ)

Figure 23
Fig-23 XRD images a) SiC 0.0 wt% b) SiC 0.3 wt% c) SiC 0.6 wt% d) SiC 0.9 wt% e) SiC 1.2 wt% f) SiC 1.5 wt% g) SiC 1.8 wt%

8.2 Scanning Electron Micrography (SEM) Analysis
The enhanced properties of the metal matrix micron and nano composites depend on distribution of the reinforcing particles and interface bonding between metal matrix and the dispersed particles. The optical micrograph and SEM images of AMMCs reinforced with varying %age of micron SiC are exhibited in figures 24. The optical micrograph and SEM images of AMMNCs reinforced with varying %age of nano SiC are exhibited in figures 25. The SEM images indicate that there is uniform distribution of particles in the Al matrix and small agglomerates of the powders and voids also be seen at higher magnification.

The overall microscopic analysis shows that there is good bonding between the matrix and the particles interface indicating uniform distribution of particles because of controlled stirring and grain boundaries are seen distinctly.

SEM Micrographs of Micron Composites

Fig-24 SEM images a) SiC 0.0 wt% b) SiC 0.5 wt% c) SiC 1.0 wt% d) SiC 1.5 wt% e) SiC 2.0 wt%
8.3 Energy Dispersive Spectroscopy (EDS) Analysis

SEM and EDS with elemental composition was carried out to study the particle distributions patterns and to identify the elements present in the solidified composites. Samples for microstructural study were cut and prepared from as-cast bulk AMMCs and AMMNCs. The specimens for SEM were prepared first by polishing with 240, 400, 800 and 1200 grit emery sheets and then by mechanical polishing and diamond paste using in polishing machine. SEM and EDS was conducted on VEGAS TESCON.

EDS analysis was used to obtain the qualitative and quantitave composition of the micron and nano composites. EDS spectra in figure 26 & 27 confirms the presence of expected elements in required amounts. It is evident that SiC and C peaks correspond to composition of micron and nano particles as shown in figure 26 & 27.

EDS Spectra of Micron Composites
Figure 26  Fig-26 EDS spectra a) SiC 0.0 wt% b) SiC 0.5 wt% c) SiC 1.0 wt% d) SiC 1.5 wt% e) SiC 2.0 wt%

EDS Spectra of Nano Composites

<table>
<thead>
<tr>
<th>Element</th>
<th>Line Type</th>
<th>Apparent Concentration %</th>
<th>MPA</th>
<th>EVA Signal Standard Label</th>
<th>Factory Standard</th>
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<td>C</td>
<td>6 protons</td>
<td>0.0129</td>
<td>204</td>
<td>0.03039</td>
<td>204</td>
<td>204</td>
</tr>
<tr>
<td>Al</td>
<td>6 protons</td>
<td>0.0129</td>
<td>204</td>
<td>0.03039</td>
<td>204</td>
<td>204</td>
</tr>
<tr>
<td>Mn</td>
<td>6 protons</td>
<td>0.0129</td>
<td>204</td>
<td>0.03039</td>
<td>204</td>
<td>204</td>
</tr>
<tr>
<td>Fe</td>
<td>6 protons</td>
<td>0.0129</td>
<td>204</td>
<td>0.03039</td>
<td>204</td>
<td>204</td>
</tr>
<tr>
<td>Cu</td>
<td>6 protons</td>
<td>0.0129</td>
<td>204</td>
<td>0.03039</td>
<td>204</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>600</td>
<td></td>
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</tbody>
</table>

IJNI: http://escipub.com/international-journal-of-nanoparticle-research/
The tensile strength of composite samples increases with increase in wt% of SiCμp which is maximum at 279 MPa for 2.0 wt% of SiC. Thereafter it is decreased because of Hard and Brittle SiC particles. The increase in strength of the material is owing to the restriction to the material flow between the layers due to obstruction by the reinforced SiC particles in the matrix. The decreases in the ductility is due to the resistance to the plastic flow of layers by the SiC particles.

Similarly, it increases with increase in wt% of SiCnp which is maximum at 298 MPa for 1.8 wt% SiC. The ductility decreases with the increase of wt% of SiC. Percentage elongation decreases with the increase in wt% of SiCμp and SiCnp because of addition of brittle and hard particles of SiC. The ability of a metal to deform plastically and to absorb energy in the process before fracture is termed as toughness. The impact toughness of a metal is determined by measuring the energy absorbed in the fracture of the specimen. The impact values are slightly increases with increasing the processing temperature and SiC content. The decrease of impact values at lower temperature and high SiC content in the Al-SiC composites can be attributed to the presence of brittle and hard SiCp which may act as stress concentration areas.

Charpy impact strength increases initially to 1.17 at 1.0 wt% of SiCμp and then decreases with the increase of hard and brittle SiC particles. Similarly, it increases initially to 1.24 at 0.9 wt% of SiCnp and then decreases with the increase of wt% of SiC.

Brinell Hardness increases with increase in wt% of SiCμp which is maximum at 97.9 BHN with varying wt% of SiCnp (0.0, 0.3, 0.6, 0.9, 1.2, 1.5 & 1.8 wt%). The physical and mechanical tests were performed. The experimental study reveals the following conclusions:

9. Conclusions

The Al 2024-SiCp composites were developed produced by stir casting technique with varying wt% of SiCμp (0.0, 0.5, 1.0, 1.5 & 2.0 wt%). Similarly, the nano scale samples were also developed by using stir casting technique.
for 2.0 wt%. It is due to harder and brittle SiC particle.
Similarly, it increases with increase in wt% of SiCp, which is maximum at 110 BHN for 1.2 wt%.
Density measurement shows that the density of the sample increases with increase in wt% of SiCp, which is maximum at 2.83 g/cc for 2.0 wt%. It is because of high density of SiC particles.
Similarly, it is maximum at 2.83 g/cc at 1.8 wt% SiCnp.
Percentage porosity decreases with increase of wt% of SiCp and SiCnp. It is due to casting of composites in semisolid state.
Porosity formation in cast metal matrix composites has been shown to be influenced by a number of parameters. These include gas entrapment during stirring, air bubbles entering the slurry either independently or as air envelopes around the reinforced particles, water wipers on the surface of the particles, hydrogen evolution and solidification shrinkage. The entrapped air inside the agglomerated particles coupled with the hindered metal flow into them also contributes to the formation of porosity. It also reveals that the composites manufactured by injection of SiC powder in the composites rather than untreated SiC particles have lower porosity contents.
Optical micrograph shows reasonably uniform distribution of SiCp and SiCnp. Homogenous dispersion of SiC particles in the Al metal matrix shows an increasing trend in the samples produced by stir casting technique.
Micrographs of Micron and Nano Composites show that homogeneous dispersion of SiC μp and SiC np in the Al metal matrix an increasing trend in the samples produced by stir casting technique.
XRD spectra of Al with micron particles of SiC with 0.0 wt%, 0.5 wt%, 1.0 wt%, 1.5 wt% and 2.0 wt% and nano particles of SiC with 0.0 wt%, 0.3 wt%, 0.6 wt%, 0.9 wt%, 1.2 wt%, 1.5 wt% and 1.8 wt% shows that the crystal structure, chemical composition and physical properties of material are as per microstructure, the uniform distribution and strong interfacial bonding strength.
SEM images of Micron and Nano composites indicate the uniform distribution of particles and interface bonding between metal matrix & dispersed particles.
EDS spectra confirms and identify the elements present in the solidified composites. It is obvious that Al, SiC and C peaks correspond to composition of micron and nano particles.

10. Further Research Work
Development with more percentage of SiCnp samples and their characterization may be attempted in future.

11. Conflict of Interest
The authors declare that they have no conflict of interest.

12. References


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