Microstructure Study and Mechanical Testing of Al 6061-Si_3n_4 Metal Matrix Composites

T. Vijaya Kumar, M. Indu, A. Sai Gopal, A. Vamsi Krishna, D. Venkat Reddy

ABSTRACT: ***In these days exceptional properties are needed for wide range of applications like aerospace, medical, and automobile to improve strength, corrosive resistance and weight reduction. For these purposes composites have been developed. Metal matrix composite (MMC) is one of them, and aluminium composites have been using in various fields because of its less weight, thermal and electrical conduction and corrosive resistance. Here we are introducing silicon nitride (Si_3N_4) as reinforcement which is a ceramic in aluminium 6061 which is effectively used in many applications these days. Our composite has been made using Stir casting method for proper dispersion. Mechanical testing methods like Brinell's, Charpy impact tests are carried out to identify properties of composite and microstructure is also been figured out through SEM. Properties of both 5% and 15% Si_3N_4 powder composition of MMC are compared with each other and discussions are made.***

KEY WORDS: metal matrix composite, stir casting, microstructure, SEM.

I. INTRODUCTION:

MMC's (Metal Matrix Composite) are composites with at least two constituent parts, in which one should be metal that is matrix, the other one can be a different metal or another material, such as a ceramic or organic compound named as reinforcement shown in Fig: 1. MMC's attain this much strength, hardness and toughness because of arresting or deviating forces acting on it, as the forces get obstructed by the denser particulate reinforcements. Especially reinforcements in aluminium improve the wear, creep, stiffness, strength and fatigue properties compared to the all other engineering materials [1].

Stir Casting is widely used to prepare metal matrix composites which are known for its discontinues distribution of reinforcement throughout the metal matrix. Sufficient procedures are needed to get good wettability and to reduce agglomeration up to an extent [2]. Hardness test for a material is carried to find the resistance against the penetration which might be indentation, wear scratch, abrasion. Hardness test and tensile test both measure the resistance of plastic deformation and the values also occur parallel. Hardness test is selected because of it is simple and relatively non-destructive. Brinell's hardness test is conducted to find the level surface penetration which is generally performed hardness test for composites [3]. Charpy Impact Test is done to find the energy absorption while sudden load is placed on parts.

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Composition and properties of Al 6061 and Si_3N_4 are shown in Table: 1(a), (b) and Table: 2 respectively.

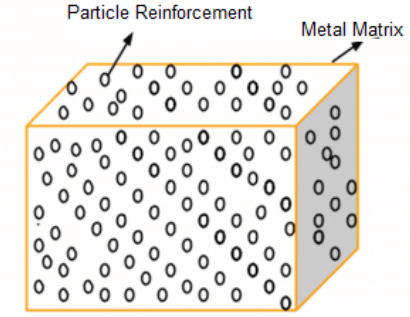


Fig: 1-Pictorial representation of Metal Matrix Composite

II. MATERIALS AND METHODOLOGY:

Aluminium 6061 is named for its good mechanical properties like heat treatable and weld-ability and has been used in various automobile components like pistons, brakes etc. This is categorised in medium strength metal alloy [4]. Some of the properties and composition of alloy are shown in Table: 1 (a), (b).

Table: 1 (a) - Composition of Aluminium 6061.

Element	Composition %
Si	0.4-0.8
Fe	0.7
Cu	0.15-0.4
Mn	0.8-1.2
Mg	0.8-1.2
Cr	0.04-0.35
Zn	0.25
Ti	0.15
Al	Balance

Table: 1 (b) - Properties of Aluminium 6061.

Properties	**Aluminium 6061**
Density (ρ)	2.70 g/cm3
Young's modulus (E)	68.9 GPa
Tensile strength (σt)	124–290 MPa
Elongation (ε) at break	12–25%
Melting temperature (Tm)	585°C
Brinell's hardness for pure Al and for Al 6061	15 BHN, 25 BHN

Ceramics are inorganic non-metallic solids; they are hard, corrosion-resistant and brittle, strong in compression, weak in shearing and tension. Silicon nitride is ideal engineering ceramic which has high strength, wear resistance, low coefficient of friction, corrosive resistance and resistance to thermal shocks [14]. This has 25% of porosity so that this can't be sintered to maximum density by high pressure and temperature [5]. We have considered particle size of

reinforcement as approximately 10μm. Particle size also place major role in variation of hardness and tensile strength, compressive strength, Ductility. And even microstructure also varies with particle size of reinforcement [6]. Major properties of Silicon nitride powder properties are mentioned in Table: 2.

Table: 2- Properties of Silicon nitride Powder.

Si_3N_4 Properties	**SI/Metric**
Mechanical Properties	
Density	3.27gm/cc
Elastic modulus	310Gpa
Poisson's ratio	0.24
Hardness	1450Kgf/mm^2
Fracture toughness	5.7Mpa $m^{1/2}$
Melting point	1900^oC

III. EXPERIMENTATION:

STIR CASTING:

Stir casting is widely accepted and used as a low-cost method for fabrication of MMC's. Discontinues distribution of particulate reinforcement throughout the molten metal matrix is done by mechanical stirring in which we get a well dispersed medium [7]. Casting is done in cylindrical furnace and mixing of reinforcement with metal matrix is done by 2-step mixing method which enhances the hardness and impact strength [8]. Stirring is done at regulated opted speed of 350RPM for 5minutes so that it ensures the distribution of particulate powder in metal matrix.

Reinforcement powder is needed to be heated before mixing because it helps in dispersion of particulate materials in metal matrix. Pre-heating of reinforcement enhances wet-ability between molten aluminium alloy and reinforced powder by maintaining temperature of the melt, removing surface impurities and gases that associated with powder agglomeration [9]. The proportions of metal matrix and reinforcement are tabulated as shown in Table: 3.

Table: 3-Composition of Reinforcement added in Metal Matrix, Al 6061

S. No	Al 6061 (grams)	Percentage Composition of Si_3N_4	Reinforcement (grams)
1	750	5%	37.5
2	750	15%	112.5

Fig: 2 (a) - Al 6061- 5% of Si3N4 Specimen

Fig: 2 (b) - Al 6061- 15% of Si_3N_4 Specimen

Procedure:

Initially Aluminium 6061 metal block is cut in to small pieces and cleaned thoroughly to remove dust, grease etc so that slag can be reduced. These pieces are placed in pre-cleaned crucible and closed tightly with silica wool to reduce escaping of heat from furnace [10].

Then is made on for 2hours where temperature is kept at 800^{o}C for melting of metal. After identifying full molten metal we opened the crucible top plate to add preheated Si_3N_4 powder along with manual stirring. After adding, plate is again tightly closed and temperature of crucible is set to 750^{o}C to attain lose heat while mixing powder. Soon after attaining 750^{o}C at crucible stirrer is attached to motor for rotation and speed is of 300RPM. Stirring is done for 10minutes [11] at same speed and then the composite is made to flow into the die placed at bottom.

Die is in cylindrical shape with 4cm diameter and 25cm height. The composite is kept still in air until it gets cooled; it took 12hours to cool completely. This is carried out for both the specimens as shown in Fig: 2 (a), (b).

TESTING:

IV. BRINELL'S TEST:

Brinell's testing method consists of a spherical, 10mm diameter indenter made of hardened steel or carbide on which a maximum load of 3000kgf (kilogram force is equivalent to kilogram multiplied by acceleration of gravity which is 9.8m/s^2) can be applied. For soft materials load can be varied from 1500kgf to 500kgf which are predefined. The total load in applied for 10-20seconds for soft and 20-30seconds for hard steels, irons etc. Here for our composite as it is aluminium based composite 500kgf is chosen and dwell period is 10seconds [12].

Procedure:

Initially the indenter is made to touch the specimen using elevating screw then weights are added and then lever is turned on to pressurize the loads on specimen, after 10seconds load is removed by pulling lever and then turning the elevating screw moves the specimen away from indenter, specimen can be removed and afterwards the indentation diameter is measured using microscope which has scale inside it on the lens. Indentation is carried out as shown in Fig: 3. by using Eqn: 1, Brinell's hardness values for both the specimens were calculated.

Fig: 3 – Indentation on Specimen

$$BHN = \frac{2P}{\Pi D(D-\sqrt{D^2-d^2})} \quad \ldots\ldots \text{Eqn. (1),}$$

Where P = Load applied on the specimen,

D = Indenter diameter
d = Indentation diameter

Table: 4- Test values of Brinell's Hardness Testing

Sample No.	BHN (for 5%)	BHN (for 15%)
1	42.43	22.76
2	36.20	40.19
3	38.12	36.20
4	40.19	36.20
Average value	39.23	33.83

It has been found that Brinell's Hardness number for 5% silicon Nitride Al 6061 MMC is 39.23 and for 15% it is 33.83. From Table: 4, it is understood that hardness value reduces with increase in reinforcement percentage because of agglomeration that is the formation of clusters of reinforcement particulate powder with increase in the weight% [13].

V. CHARPY IMPACT TEST:

Charpy Impact test is for toughness and notch sensitivity and are determined by finding amount of energy absorbed by material during fracture, generally done for metals, ceramics, composites, polymers. Brittle materials absorb little quantity of energy and as well for ductile materials it needs more energy for fracture [16]. Test values are calculated by dividing the fracture energy with cross sectional area of the specimen. Before charpy impact test the specimens are prepared from cylinder shape to square rods (10mm X 10mm X 55mm) by milling. After 'U' notch is made using saw up to 2mm depth at centre of rod.

Procedure:

Initially specimen is to be made with 10mm X 10mm X 55mm dimension; notch should be made at exact centre. The pendulum is kept at maximum position and tested the impact without specimen to find the initial impact from scale provided, which might cause due to friction in machine. After then this specimen is placed in striking edge support so that the 'U' notch is towards testing machine. Charpy impact test values have been calculated by using Eqn. (2). Then same procedure is followed with keeping the specimen in striking edge support and readings are taken.

Charpy Impact: K/A $\ldots\ldots\ldots$ Eqn. (2) Area of cross-section (A)=1cm*0.8cm=0.8cm^2 Fracture energy (K) = K_1 - K_2, Where K_1 = Initial energy and K_2 = Final energy

Fig: 4-Specimens Prepared for Charpy Impact test

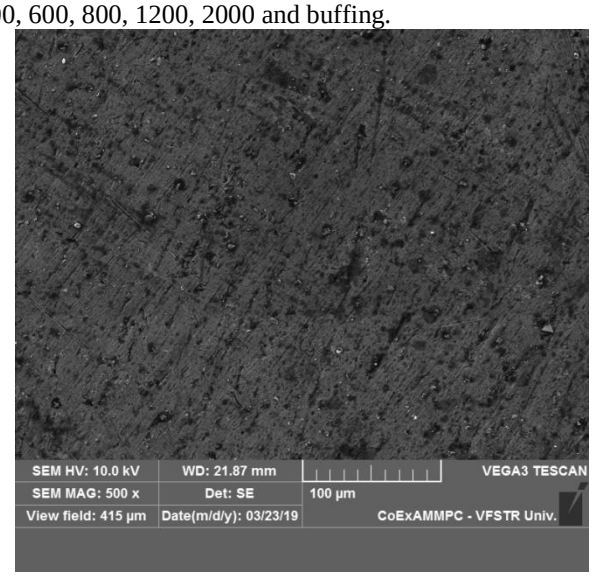
Table: 5 -Test Values of Charpy Impact Test.

S. No	%	Initial energy K_1	Final energy K_2	Fracture energy K	Impact (K/A) J/cm^2
1	5	2	22	20	16
2	%	2	14	12	9.6
1	5	2	20	18	14.4
2	%	2	16	14	11.2

Average for both compositions impact test results is same that is 12.8J/cm^2

VI. MICROSTRUCTURE:

Samples were examined using scanning electron microscope (SEM) to understand the distribution of silicon nitride powder in metal matrix. The SEM is done after polishing the surface of specimen with emery papers of grit size 180, 220, 400, 600, 800, 1200, 2000 and buffing.



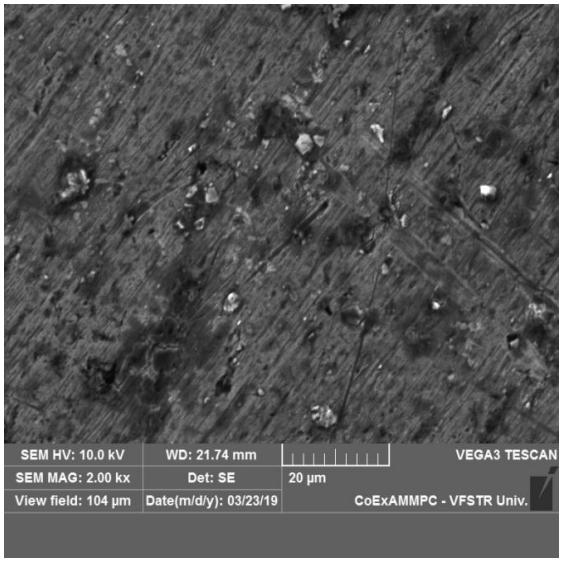
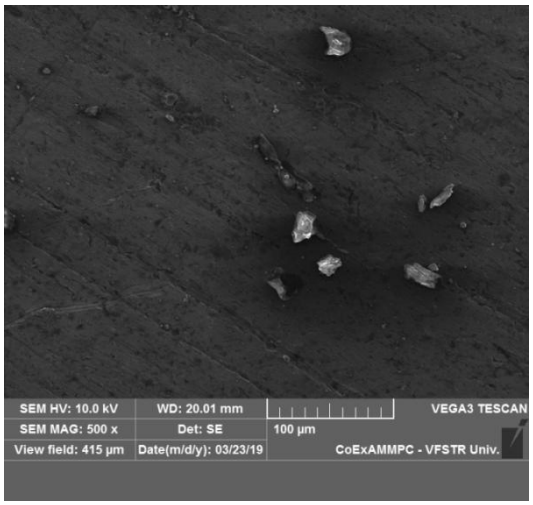


Fig: 6- 5wt% of Si_3N_4 powder in Al 6061 alloy from SEM



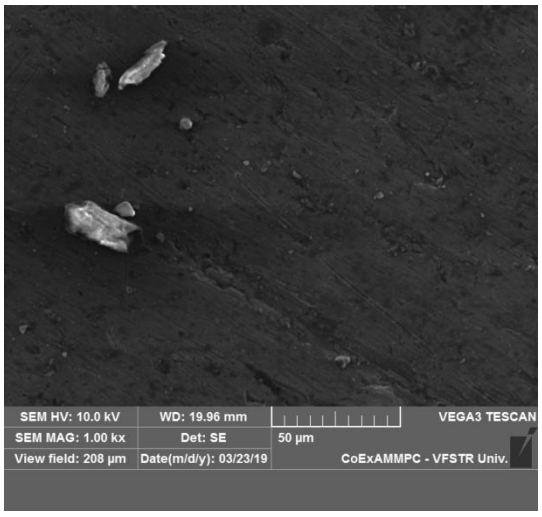


Fig: 7- 15wt% of Si3N4 powder in Al 6061 alloy from SEM

From the above Fig: 6, it is clearly understood that uniform distribution of silicon nitride powder is taken place in 5wt% silicon nitride Al6061 MMC and the dark spots represents the reinforcement particles all over the metal matrix [16]. But in Fig: 7, that is at 15wt% silicon nitride Al6061 MMC the cluster formation is seen in form of agglomeration which in turn results in decrease of hardness with respect to 5wt% MMC and this happens with every kind of reinforcement used with metal matrix if mixed in excess amounts[17-20].

VII. RESULTS AND CONCLUSION:

- ✓ Thus we successfully prepared Al 6061/Si_3N_4 composite using Stir casting.
- ✓ Uniform distribution of reinforcement with good dispersion has been observed.
- ✓ Brinell's test shows that hardness is improved at 5% but decreased at 15% which is due to cluster formation.
- ✓ Charpy Impact test results both compositions remained same.
- ✓ Finally Scanning Electron Microscope (SEM) Micrographs revealed the agglomeration of silicon nitride is more in 15wt% Si_3N_4 MMC than in that of 5wt%.

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