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Characterization of the Aluminum Matrix Composite Reinforced with Silicon Nitride (AA8011/Si3N4) Synthesized by the Stir Casting Route

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Abstract: The result of different volume % of Silicon Nitride (Si3N4) in AA 8011 alloy fabricated through stir casting process & then tested for hardness, wear test. Energy Dispersive Spectroscopy (EDS), and Scanning Electron Microscopy (SEM) of these samples are done. It is found that the highest hardness and wear strength can be obtained with the addition of 80 µm particle size of Si3N4 with 6% of its total volume fraction. This increase in the properties is due to the increase in density caused by the addition of Si3N4 reinforcement particles. SEM study also shows that the distribution of Si3N4 with the matrix material. The maximum hardness is obtained at 40.7 HV in sample 04 having 6% of Silicon Nitride (Si3N4) and 94% of Aluminium Alloy 8011, Similarly, maximum wear is recorded in the sample having 6% of Silicon Nitride (Si3N4) and 94% of Aluminium Alloy 8011when the load is 4kg and RPM is 1800.
As compared to the AA8011 hardness of the composite with the addition of the silicon nitride increases, the wear and the coefficient of the friction decreases as compared to the AA8011, and the friction force remains almost same.
Keywords: EDM, Hardness Test, Wear Test, SEM, Composite.

I. INTRODUCTION

Composite is a mixture of two or more materials that are (mixed or bonded) but on a microscopic level. Generally, composite material is composed of matrix (polymers, metals or ceramics) and reinforcement (fibres, particles, flakes and fillers). The matrix holds the reinforcement to form the desired shape on the other hand the reinforcement improves the overall mechanical properties of the matrix. The final material which is composite exhibits better strength than each of the individual materials which is used for making composite.

Kelly [1] defines very clearly that the composite should not be regarded simply as a combination of two materials. Going further; the combination has its different properties. In terms of strength or resistance to heat or some other quality, it is better than either of the components alone or radically different from either of them.

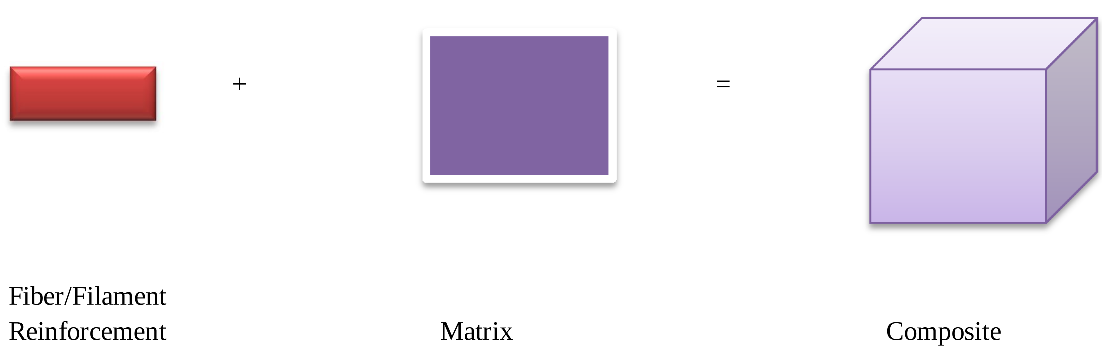

Figure 01 - Composition of Composites

Table 01 – properties of Reinforcement, Matrix & Composite

Properties of Reinforcement	Properties of Matrix	Properties of Composite
• High strength	• Good shear properties	• High strength
• High stiffness	• Low density	• High Stiffness
• Low Density		• Good Shear Properties
		• Low Density

II. CHARACTERISTICS OF THE COMPOSITES

Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the 'reinforcement ' or 'reinforcing material', whereas the continuous phase is term-led as the ‘matrix’. The properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may be spherical, cylindrical, or rectangular cross sanctioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of ·the interaction between the reinforcement and the matrix. Concentration, usually measured as volume or weight fraction, determines the contribution of a single constituent to the overall properties of the composites. It is not only the single most important parameter influencing the properties of the composites but also an easily controllable manufacturing variable used to alter its properties. The orientation of the reinforcement affects the isotropy of the system.

III. TESTING SETUP

In the present research, AA8011 is matrix material and Si3N4 is reinforcement material. AA 8011 is the form of sheets having 3mm as thickness and in the form of sheets and Si3N4 is the powder form having 80 micro size. AA8011 around 800 grams is measured for first casting. For the second casting 784 grams of AA8011 and Si3N4 16 grams were measured. For the third casting 768 grams of AA8011 and Si3N4 32 grams of are measured. For fourth casting 752 grams of AA8011 and Si3N4 48 grams is measured.

Table 02 – Weight Percentages of composite

Sample No.	Composition of Weight percentage of composite	
	AA8011	Si_3N_4
1	100%	0%
2	98%	2%
3	96%	4%
4	94%	6%

More than 6% of the reinforcement is not mixing well in the matrix material as it forms white powder with slag with fabrication technique as stir casting.

IV. SELECTION OF FABRICATION TECHNIQUE

The stir casting technique is considered the best technique for the fabrication of aluminium metal matrix composite. A stir casting machine in the General workshop in NIT Hamirpur is used in the present work to cast the samples.

V. STIR CASTING

Stir casting is a liquid-state method for the fabrication of composite materials, in which a dispersed phase is mixed with a molten matrix metal using mechanical stirring. The stir casting technique appears a promising technique for the production of metal matrix composite. In stir casting, we use the stirrer to agitate the molten metal matrix. The stirrer is generally made up of material which can withstand a higher melting temperature than matrix temperature.

Generally, a graphite stirrer is used in stir casting. The distribution of particles in molten metal is also affected by the velocity of the stirrer, the angle of the stirrer, vortices cone. The process parameters for stir stir-casting route are as under:

1) Stirring speed
2) Stirring time
3) Stirring temperature
4) Reinforcement pre-heat temperature
5) Pouring temperature

A. Silicon Nitride

Silicon Nitride has high thermal stability with strong optical nonlinearities for all-optical applications. It is white in colour having high-melting-point. It is very hard (8.5 on the mohs scale). Si3N4 is the most thermodynamically stable and commercially important of the silicon nitrides, and the term "silicon nitride" commonly refers to this specific composition. Silicon nitride is a chemical compound of the elements silicon and nitrogen.

Table 03– Properties of Silicon Nitride

Material Properties	Silicon Nitride
Young's Modulus (GPa)	270
Poisson Ratio	0.27
Thermal Conductivity (W/cm/C)	0.032
Specific Heat (J/gC)	0.71
Electrical Resistivity (Ωcm)	0.6
Diectric Constant	7.5
Density (g/cm3)	3.44
Coefficient of Thermal Expansion ($/^{O}C$)	2810x10-7

B. AA8011

In the present study, AA8011 was used as the matrix material. AA8011 has good strength, good fatigue strength and average machinability. It has superior stress corrosion resistance compared to other aluminium alloys. The melting point of AA8011 starts around 510 to 636 degrees celsius. It was acquired from M/S Ozair Tradelink Gujrat, India in the form of raw material reached via India Mart. The various alloying elements identified in AA8011 are Al, Zn, Mg, Fe, Si, Mn, Ti, Cr and Cu.

Table 04 – Properties of AA8011

Material Properties	AA8011
Tensile Strength (MPa)	110
Yield Strength (MPa)	140
Young's Modulus (GPa)	69
Specific Heat (J/gC)	0.9
Poisson Ratio	0.33
Thermal Conductivity (W/cm/C)	2.1
Density (g/cm3)	2.8
Melting Completion (liquid) (OC)	600

Table 05 – Properties of AA8011

Registered International designation	Composition in Weight percentage									
	Si	Cu	Fe	Mg	Mn	Zn	Cr	Ti	B	Li	Zr
8011	.70	.10	.65	.05	.20	.10	.05	.08	-	-	-

C. Hardness Test

The resistance of a material to indentation, deformation or penetration using such as abrasion, scratching, impact or wear is generally determined by hardness tests such as Rockwell, Brinell or Vickers. The hardness of the samples was measured by using a Mitutoyo HM 100 series micro hardness tester as shown in Fig 4.9. The hardness test was performed at NITTTR Chandigarh. The Vickers hardness tester was used for measuring the hardness of fabricated samples. A diamond indenter, in the form of a right pyramid with a square base at an angle of 136 between opposite faces, is forced into the material under load. A load of 1 kg was applied for 10 seconds and after that indenter was removed. The two diagonals of indentation left on the surface of the material after removal of the load were measured using a microscope and their mean calculated.

D. Wear Test

The pin-on-disc wear and friction tester is used to investigate the tribological properties of materials/coatings in sliding contact, such as wear and friction behaviour. A stationary pin and a revolving disc slide against one another. Normal load, rotating speed, and worn track diameter are the variables. Wear is calculated by first determining the linear measurement of the original dimensions (length, width and height of the original sample). The sample shall be fixed perpendicular to the flat EN 31 disc, such that the sample revolves around the disc centre. The sample is pressed against the disc at different loads. The two data sets of linear dimensions shall be converted into their respective volumes and subtracted to obtain the volume of specimen lost due to wear.

VI. MICROSTRUCTURAL ANALYSIS

SEM is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern and the position of the beam is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometre. The surfaces of the specimens were examined by SEM JEOL JSM-IT 100 shown in Fig. SEM was used to analyze the microstructure of surfaces. The EDS technique detects X-rays emitted from the sample during bombardment by an electron beam to characterize the elemental composition of the analyzed volume. EDS was used to analyze the composition of the specimens.

Figure 02 - SEM (Scanning electron microscope)

VII. RESULT AND DISCUSSION

The result of the present investigation entitled "CHARACTERIZATION OF THE ALUMINUM MATRIX COMPOSITE REINFORCED WITH SILICON NITRIDE (AA8011/SI_3N_4) SYNTHESIZED BY THE STIR CASTING ROUTE" are compiled and presented in different subsections:

A. Wear Test

The behaviour of material is determined while it detects a deformation, due to a change in temperature, frictional force or coefficient of friction by varying load, rpm and time. The wear properties can be evaluated from various graphs like wear-time, temperature time, coefficient of friction time, and frictional force time for different weight percentages of reinforcement in aluminium matrix composite.

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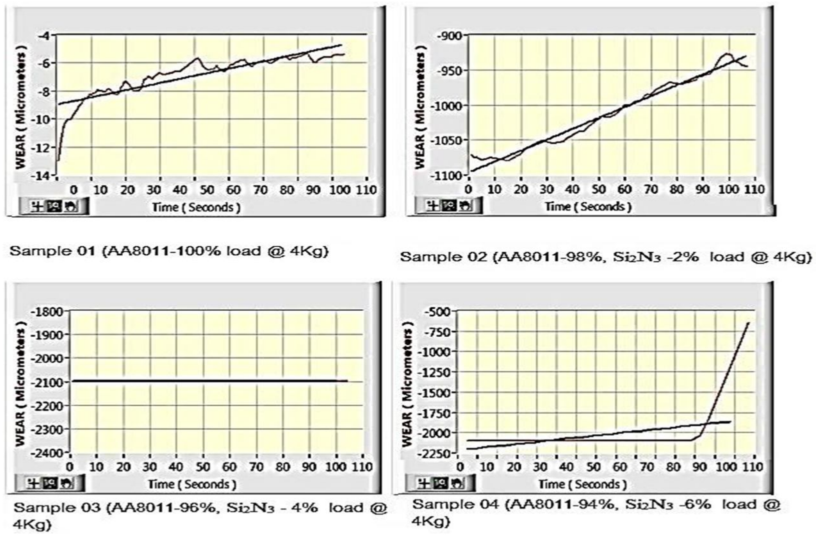


Sample 01 (AA8011-100% load @ 4Kg)

Sample 02 (AA8011-98%, Si_2N_3 -2% load @ 4Kg)

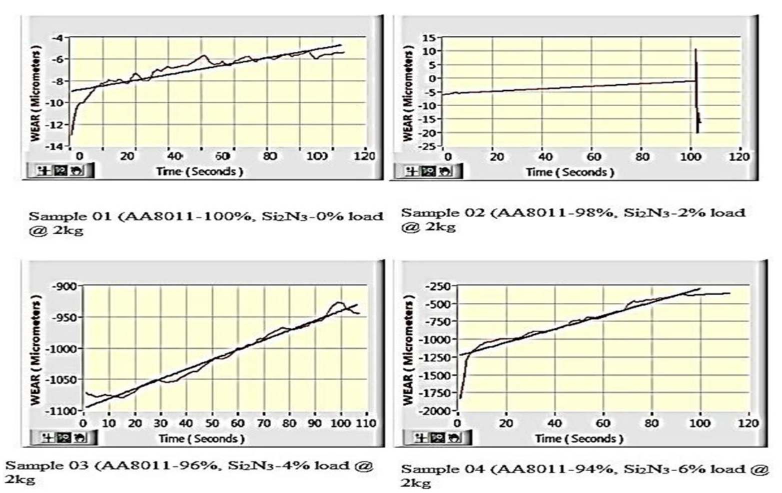
Sample 03 (AA8011-96%, Si_2N_3 - 4% load @ 4Kg)

Sample 04 (AA8011-94%, Si_2N_3 -6% load @ 4Kg)

Figure 03– wear and time graph at 4 kg load of different composites

Table 06 – Result of wear and time at 4 kg load of different composites

Parameter		Sample 1	Sample 2	Sample 3	Sample 4
RPM	1800	The wear increases rapidly in the base metal	The wear increases slowly	The wear stays constant	The wear increases very slowly
Load	4 kg				
Time	120 seconds				



Sample 01 (AA8011-100%, Si_2N_3-0% load @ 2kg

Sample 02 (AA8011-98%, Si_2N_3-2% load @ 2kg

Sample 03 (AA8011-96%, Si_2N_3-4% load @ 2kg

Sample 04 (AA8011-94%, Si_2N_3-6% load @ 2kg

Figure 04 – wear and time graph at 2 kg load of different composites

Table 07 – Result of wear and time at 2 kg load of different composites

Parameter		Sample 1	Sample 2	Sample 3	Sample 4
RPM	1800	The wear increases rapidly in the base metal	The wear increases slowly	The wear stays constant	The wear increases very slowly
Load	2 kg				
Time	120 seconds				

B. Hardness Test

The resistance of a material to indentation, penetration or deformation using abrasion, drilling, impact and scratching is known as hardness. The hardness values for casted samples were measured as shown in the table below:-

Table 06 – Hardness Value of composite samples

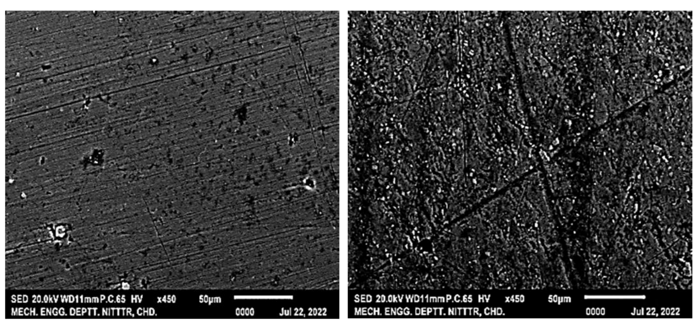
Sample No.	Wt. % of AA8011	Wt.% of Si_3N_4	Hardness Value (HV)
01	100	0	34
02	98	2	36.1
03	96	4	38.3
04	94	6	40.7

The hardness of AA8011 was found to be 34 HV. It has been observed that by increasing the wt% of Si3N4 (2%) the hardness of the composite increased to 36.1 HV. The hardness of the composite increases with the addition of wt.% of Si3N4 by (4%) the hardness value was found to be 38.3. The result of four samples has been observed and we can see that there is an increase in the hardness as the percentage of the reinforcement increases in the matrix material.

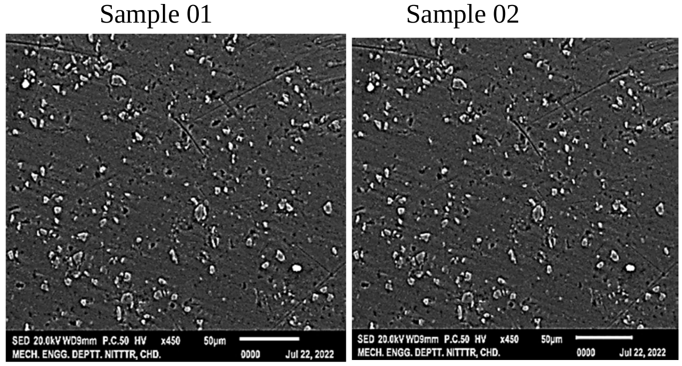
Sample 01 Sample 02 Sample 04

Figure05 -Result of Hardness test of different composite

SEM Images of different Samples



Sample 01 Sample 02



Sample 03 Sample 04

Figure06 -Result of magnification of samples of composite

Table 07 – Hardness Value of composite samples

Image Sr. Number	Wt. % of AA8011	Wt.% of Si_3N_4	Magnification
01	100	0	450X
02	98	2	450X
03	96	4	450X
04	94	6	450X

VIII. CONCLUSIONS AND FUTURE SCOPE

The present investigation is carried out to study on mechanical and microstructural properties of silicon nitride-reinforced aluminium alloy composite. The microstructure analysis is done by SEM and EDS is used to check the composition of the composite. Hardness tests and wear tests are used to study the mechanical properties of the composite.

A. Conclusion

The following conclusions are drawn based on experimental work and analysis of results on AA8011/Si3N4 composite.

1) The hardness of composite with matrix material AA8011 & reinforcement Silicon Nitride increases with an increase in weight per cent ratio of reinforcement.
2) After the addition of reinforcement of more than 6% of the weight percentage of the composite it is difficult to add more reinforcement as with this fabrication technique it does not mix well and when mixing reaction occurs between AA-8011 and Silicon Nitride white colour powder is been produced which stays above the material and do not even mix with slag or the matrix material.
3) The wear increases slowly with the increase in the reinforcement percentage in the matrix material.
4) There is no change in the coefficient of friction with the addition of the reinforcement in the matrix material.
5) The maximum hardness is obtained at 40.7 HV at 6 wt.% of Si3N4.

B. Limitations Of The Present Work

The present work voids affected mechanical properties.

The stirring of matrix and reinforcement was done at varying stirring speeds i.e. 200 to 400 rpm.

C. Scope For Future Work

The present work leaves a wide scope for future investigation to explore many other aspects of AA8011/ Si3N4 composite.

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