A Review on Microstructure and Mechanical Properties of Silicon Nitride Reinforced AMMC Using Stir Casting Method

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Abstract - *The aluminum alloys are important in many industrial applications and space applications because of their light weight and good mechanical properties. For this reason many researches had been done to enhance their properties. In this study, particles of aluminium oxide and silicon nitride are used as reinforcement in aluminium matrix alloy to fabricate AMMC through stir casting. Investigation of mechanical properties such as tensile strength and hardness is made. And the wear and surface roughness in machining of these composites with different cutting speed and feed with constant depth of cut is studied. And also the microstructure of the composites is analyzed. The aliminium alloys are of particular interest to both the aerospace industry and automotive industry because of their attractive combinations of properties such as medium strength, formability, weldability, corrosion resistance and low cost. Compared with a metal matrix material, significant improvements in the mechanical and physical properties such as strength, toughness, and thermal conductivity can be achieved in metal matrix composites (MMCs). In this work of investigation aluminium alloy AA6061 was reinforced by 5, 10 and 15% (in mass %) of Si_3N_4(silicon nitride) and AlN (aluminium nitride) by mechanical alloying in a vibratory type SPEX mill, cold uniaxial compaction and vacuum sitering in order to investigate the influence of the particulate phase in the microstructure and mechanical properties of the composites obtained. The microstructure of the powders and the sintered materials were evaluated by means of SEM and the Hardness and were evaluated by hardness test.*

Key Words: Silicon nitride, stir casting Powder Metallurgy, AA6061 Aluminum Alloy Metal Matrix Composites, Mechanical Alloying, Vacuum Sintering

1. Introduction

Composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. A common example of a composite would be disc brake pads, which consist of hard ceramic particles embedded in soft metal matrix. The most advanced examples perform routinely on spacecraft in demanding environments. Composites are made up of individual materials referred to as constituent materials. Aluminium is the most popular matrix for the metal matrix composites (MMCs). The Al alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. Aluminium matrix composites (AMCs) have been widely studied since the 1920s and are now used in sporting goods, electronic packaging, armours and automotive industries. They offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix. They are usually reinforced by Al2O3, SiC, C but SiO2, B, BN, B4C, AlN may also be considered. The aluminium matrices are in general Al-Si, Al-Cu, 2xxx or 6xxx alloys. As proposed by the American Aluminium Association the AMCs should be designated by their constituents: accepted designation of the matrix / abbreviation of the reinforcement's designation / arrangement and volume fraction in % with symbol of type (shape) of reinforcement. The mechanical alloying (MA) process, using ball-milling techniques, has received much attention as a powerful tool for the fabrication of several advanced materials including equilibrium, non-equilibrium (e.g., amorphous, quasicrystals, nano crystalline, etc.), and composite materials. The MA is a unique process in which a solid state reaction takes place between the fresh powder surfaces of the reactant materials at room temperature. Consequently, it can be used to produce alloys and compounds that are difficult or impossible to obtain by the conventional melting and casting techniques [1-6]. The main aim of this work is to report the effect of the high energy milling processes on the fabrication of aluminium matrix composite powders, reinforced with ahomogeneous dispersion of silicon nitride and aluminium nitride reinforcing particles.

2. Literature Survey

Hani Aziz Ameen et.al., [1], made an attempt to study the wear rate for different materials (Steel, Aluminum and brass) under the effect of sliding speed, time and different loads, where the apparatus pin on disc has been used to study the specification of the adhesion wear. The experiments has been performed on a group of specimens under different cases of times (5 to 30) minutes, and under different loads (0.5 to 2) Kg, and different speeds (2.5 to 9) m/sec. A mathematical model has been made for all cases that were studied depending on the method of least squares which helps in foretelling about the wear rate through the knowledge of time limits as a variable with fixing the other variables; also building a model with the same method by which foretelling the rate of adhesive wear through knowing the sliding speed as a variable after fixing the other variables, also making another model foretelling the rate of adhesive wear through knowing the variable loads. A study was made for the damaged surface from wearing for the aluminum alloy as a sample to illustrate the wear lines to the direction of the formation of wear; and from the results, it was clear that the cracks which are vertical on the direction of sliding and will meet together with the lines of weariness, and the results will show that the rate of adhesion wear will be direct proportional with (time, sliding speed and load) , and the low carbon steel has less wear rate than the other materials.

Vikas Chawla et.al., [2] made the modest attemptto develop aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two step-mixing method of stir casting technique has been adopted and subsequent property analysis has been made.

Riyadh A. Al-Samarai et.al., [3], studied theeffect of load and speed on sliding friction coefficient and performance tribology of aluminum–silicon casting alloy was evaluated using a pin-on-disc with three different loads (10, 20, and 30 N) at three speeds (200, 300, and 400 r/min) and relative humidity of 70%. Factors and conditions that had significant effect were identified. Experiments showed that the load and the speed affect the coefficient of friction and wear rate of the alloy. The results showed that the wear rate increased with increasing load and decreased with increasing sliding distance, whereas the friction coefficient decreased with increasing sliding speed before a stable state was reached. The friction coefficient also decreased with increasing load.

S.Basavarajappa et.al., [4] Studied the influence of wear parameters like applied load, sliding speed, sliding distance and percentage of reinforcement on the dry sliding wear of the metal matrix composites. Material selected for the investigation was based on the Al-Cu-Mg matrix alloy, designated by the aluminium association as AA2219 and reinforcement was SiC. The SiC particles, which were used to fabricate the composite, had an average particle size of 25 μm and average density of 3.2 g/cm3. The SiC particle reinforcement varied from 0 to 15 wt pct in steps of 5. The liquid metallurgy technique was used to prepare composite specimens. A plan of experiments, based on techniques of Taguchi, was performed to acquire data in controlled way. An orthogonal array and the analysis of variance were employed to investigate the influence of process parameters on the wear of composites. The objective is to establish a correlation between dry sliding wear of composites and wear parameters. These correlations were obtained by multiple regressions. Finally, confirmation tests were conducted to verify the experimental results foreseen from the mentioned correlations.

G. B. Veeresh Kumar et.al., [5] investigated the mechanical and tribological properties of Al6061-SiC and Al7075-Al2O3 Metal Matrix Composites. From their experiment they found that the dispersed SiC in Al6061 alloy and Al2O3 in Al7075 alloy contributed in enhancing the tensile strength of the composites. The tensile strength properties of the composites are found higher than that of base matrix and Al6061-SiC composites superior tensile strength properties then that of Al7075- Al2O3 composites. The wear resistance of the composites are higher, further the SiC contributed significantly in improving wear resistance of Al6061-SiC composites.

EmrahKoraman et.al., [6], studied Dry sliding wear behavior of Al–Fe–Si–V alloys at elevated temperatures. Dry sliding wear tests of two Al–Fe– V–Si alloys, which have finer and coarser dispersoids in their microstructures, were carried out at various temperatures ranging between 20^{0}C and 350^{0}C. The results were then evaluated with respect to the tensile properties at the same temperatures. Results showed that dispersoids size or strength have no significant effect on the wear rate at room temperature. Wear rates of both alloys exponentially increase with increasing temperature. Even though they possess higher strength, smaller dispersoids result in higher wear rate at elevated temperatures. This observation suggests that coarser dispersoids in the microstructure is more effective than strength in limiting the wear rate of Al–Fe–V–Si alloy at elevated temperatures. SEM examinations and EDS analysis within the wear tracks revealed that oxidative wear at lower temperatures, and plastic deformation and delaminating wear at elevated temperatures are dominant wear mechanisms. There is a wear transition between these two mechanismsat150^{0}C for finer dispersoids alloy and250^{0}C for coarser dispersoids alloy. Therefore coarser dispersoids in the microstructure shift wear transition to a higher temperature.

F.Labib et.al., [7], studied dry tribological behavior of Mg/SiCp composites at room and elevated temperatures. Pure magnesium and its composites reinforced with 5, 10 and 15 vol% SiC particulates were fabricated by powder metallurgy process. The tribological behavior of the samples was investigated under normal loads of 5–60 N at sliding speed of 0.4 m/s and at wear temperatures of 25–200 °C. At the weartemperatureof25 °C, results showed almost close wear rates under normal loads of 5 and 20N. However, under higher normal loads the composites showed lower wear rate than that of the unreinforced magnesium. At the higher wear temperatures of 100, 150 and200 °C, a significant lower wear rate was observed for the composites compared to the pure magnesium. Increasing the normal load resulted in a transition from mild to severe wear at all wear temperatures. Below the transition load oxidation was a dominant wear mechanism, while above that severe plastic deformation and adhesion were the main wear mechanisms. The results also showed wear rate improvement of the composites with increasing SiC content. Finally, a wear map showing mild and severe wear regimes as a function of load and wear temperature was adopted for the composites.

S.B.Chikalthankar et.al., [8], conducted experiments to studythe Effect of Silicon Carbide Content on Tribological Properties of Aluminium Zinc Alloy Composite at Elevated Temperature. The pin on-disc (by pin heating) test machine is used to study effect of wear parameters like Silicon carbide percentage, disc rpm, temperature and applied load of on the wear of the alloy have been investigated. Taguchi technique is used to conduct the experiment for acquiring the data in controlled way. An orthogonal array and the analysis of variance are employed to investigate the influence of process parameters on the wear of alloy. The objective of experimentation is to establish correlation between dry sliding wear of alloy and wear parameters. This correlation is obtained by regressions and confirmation tests. This test is conducted to verify the experimental results from the mentioned correlations. It is observed that there is a transition from severe wear to mild wear after a time of sliding that decreases at 300°c and 2Kg (low) load.

K. L. Meena et.al., [9] observed that mechanical properties of the developed SiC reinforced Al6063 metal matrix composite material using the melt stirring technique. The experiment was performed by varying the reinforced particle size as 200 mesh, 300 mesh, 400 mesh and different weight percentage, 5%, 10%, 15%, and 20% of SiC particle reinforced composite material. The stirring process was conceded at 200 rpm using a graphite impeller on behalf of 15 min. A homogenous dispersion of SiC particle in the aluminium matrix was observed. Tensile strength, hardness and breaking strength improved with the enlargement in reinforced.

Ehsan Ghasali et al.,[10] made an attempt to study on Investigation on microstructural and mechanical properties of B4C–aluminum matrix composites prepared by microwave sintering and concluded that having strong bonding strength.

P.Pugalenthi et al., [11] made an attempt to study on Evaluation of Mechanical Properties of Aluminium Alloy 7075 Reinforced with SiC and Al2O3 Hybrid Metal Matrix Composites and concluded that strength of the material increases by adding reinforcement.

Kenneth Kanayo Alaneme et.al., [12] studied the Microstructural characteristics, mechanical and wear behaviour of aluminium matrix hybrid composites reinforced with alumina, rice husk ash and graphite. Alumina, RHA and graphite mixed in varied weight ratios were utilized to prepare 10 wt% hybrid reinforced Al-Mg-Si alloy based composites using two-step stir casting. Hardness, tensile properties, scanning electron microscopy, and wear tests were used to characterize the composites produced. The results show that Hardness decreases with increase in the weight ratio of RHA and graphite in the composites; and with RHA content greater than 50%, the effect of graphite on the hardness becomes less significant. The tensile strength for the composites containing o.5wt% graphite and up to 50% RHA was observed to be higher than that of the composites without graphite. The wear resistance decreased with increase in the graphite content from 0.5 to 1.5 wt%.

Soorya Prakash Kumarasamy [13] investigated mechanical and machinability behaviour of Aluminium Metal Matrix Composite (AMMC) developed through two-step compocasting method by reinforcing constant amount of fly ash cenosphere (10%) and varying quantity of graphite (2%, 4% and 6%). Morphological analysis result shows the presence of dendritic arms and homogeneous distribution of the cenosphere and graphite in Al7075 matrix. The hardness and tensile strength upturn with addition of cenosphere and vice versa for the addition of graphite.

M. Sreenivasa Reddy et.al., [14] evaluated Hardness and Tensile Properties of Aluminium 7075 alloy reinforced with E-glass and fly ash particulates to form MMC using graphite die for casting. Hardness of the Al-cast alloy produced in this work is lower at 2% of E-Glass when compared to 4% and6%. However, after thermal treatment the water quenched specimens exhibit higher hardness. The ultimate tensile strength (UTS) of the new alloy produced is higher in 2% of E-Glass and lower in 4 and 6% E-Glass.

Pardeep Sharma et.al., [15] studied the effect of graphite particles addition on the microstructure of Al6082 metal matrix composites manufactured by conventional stir casting process. The reinforcement content was varied from 0% to 12% in a step of 3%.

Johny James.S [16] prepared hybrid aluminium metal matrix composite to study its machining and mechanical properties. Preparation of hybrid aluminium metal matrix composite is made by reinforcing Silicon carbide and Titanium di boride .

P. Pugalenthi et.al., [17] made an attempt to study on Evaluation of Mechanical Properties of Aluminium Alloy 7075 Reinforced with SiC and Al2O3 Hybrid Metal Matrix Composites In 2014

A. Baradeswaran et.al., [18] investigate," Experimental investigation on mechanical behaviour, modeling and optimization of wear parameters of B4

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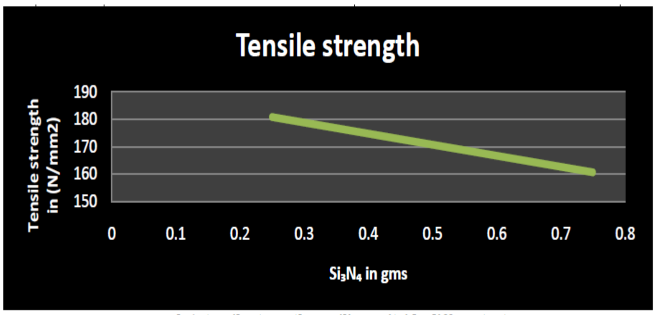
3. Experimental Results

Tensile Strength

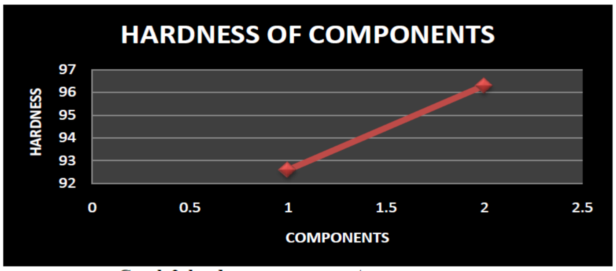
Slno	Silicon Nitride Wt(gms)	Tensile Strength (N/mm^2)
1	0.25	180.80
2	0.75	160.62



graph 1. tensile strength vs. silicon nitride different wt.

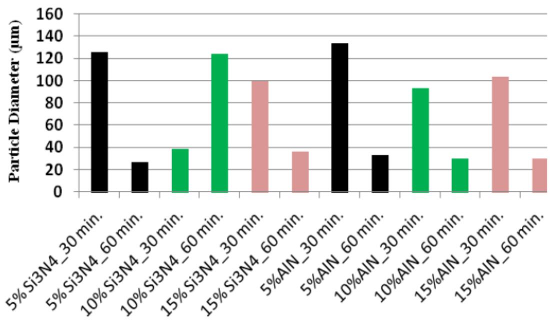
Hardness Strength

Component	Hardness (HBW, 10mm dia ball/500kgf load)
1	92.6
2	96.3

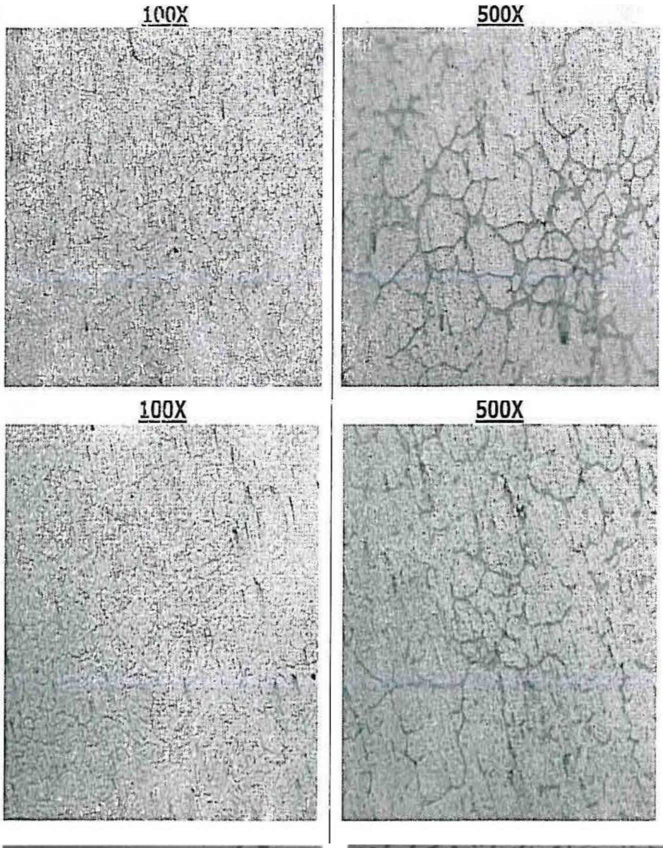


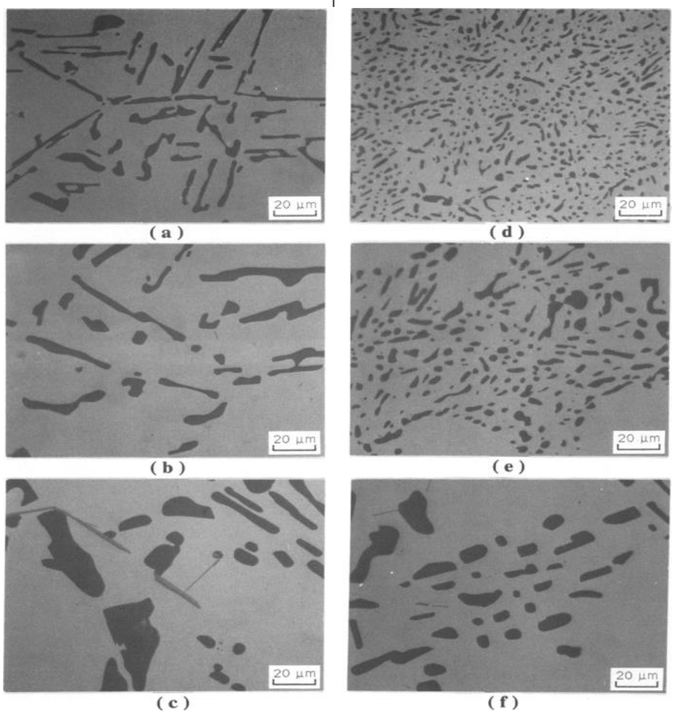
Graph 2. hardness vs. components

Effect of high-energy milling on particle diameter of the composite AA6061 + AlN and AA6061 + Si3N4



3.3 Scanning Electron Microscope Images





For both the composite rods, the microstructure shows the grain boundaries, interdendritic network of aluminium oxide and silicon nitride particles distributed in a matrix of aluminium solid solution throughout the structure.The composite reinforced with silicon nitride in (b), also presents a microstructure without porosity with uniform distribution of the reinforcing phase (Si3N4) and without the presence of agglomerations(c) showed the worn surface of heat-treated sample C. In this case the worn surface have oxide layer and parallel grooves all over the surface. (d) Showed the worn surface of sample D where the worn surface is showing minor damage. The worn surface in (e) showed finer parallel grooves with few oxide layers and less damage of the worn surface of sample E this explained that sample E exhibited high wear resistance incomparison to samples A–D for heat-treated samples. Thus heat-treated sample E showed minimum wear loss ascompared to other samples under both conditions. The existences of ploughing showed abrasive wear mechanism, while crater is a feature of delamination type of wear The adhesive wear mechanism occurred due to the transition of hard particles to the counter face, which is controlled by the hardness. Therefore, hardness plays a role in controlling the wear during sliding beside strength.

Further, the work has to be extended for Si_3N_4 and NiCr addition with Aluminum (A356) by stir casting method. Mechanical, tribological and thermal properties work has to be carried out to study the results obtained.

4. Conclusions

The AMMC with different volume fraction of silicon nitride is fabricated and various investigations were made. Hardness values of the components were found and the hardness of the component increases with the increase in Si_3N_4 percentage.

- Tensile strength of the component has been decreased when the percentage of Si_3N_4 is increased.
- The microstructure shows the grain boundaries, interdendritic network of aluminium oxide and silicon nitride particles distributed in a matrix of aluminium solid solution throughout the structure.
- The optimum speed as 270 rpm, feed as 0.110mm/min and depth as 0.5mm is obtained at low surface roughness value. With this we come to know that at these optimum values the machining can be made accurately with lower surface roughness.

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