Processing and Characterization of Tribological Behaviour of Silicon Nitride Reinforced Composites-A Review

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Abstract

In this study tribological behaviour of Aluminium metal powder composite reinforced with Si3N4 particles has been evaluated experimentally prepared by Powder Metallurgy route. The development of new material was done looking to its application for single point cutting tool which requires high hardness, good toughness, high wear resistance and good thermal conductivity. Four number Cylindrical preforms (Pure AP, AP+3wt.% Si3N4, AP+5wt.% Si3N4 and AP+7wt.% Si3N4) at a compaction pressure of 120 KN were prepared using a die and punch assembly on a Universal Testing Machine. Sintering at different temperatures of 450°C, 470°C and 490°C has been carried out using Electrical Muffle Furnace. The Mechanical properties were evaluated using standard practice using BIS codes. Theoretical Density and porosity were measured through rule of mixtures and the results were compared with experimental results. Hardness was measured using Digital Rockwell's Hardness Tester (B scale) at 100 kg load applied at ball point. The Sliding Wear behaviour of cylindrical sample diameter 10 mm and length 30 mm was performed on a pin-on-disc wear tester against an EN- 32 steel disc having a hardness of 60-62 HRC (10 N applied the load, distance 4000 m at 300 rpm, 1200 seconds) under dry ambient conditions. The microstructural characterization was done using Scanning Electron Microscopy (SEM) to see the distribution of the Si3N4 particles and morphology of wear surfaces. Densification and hardness of specimen were increased with the increase of Si3N4 percentage and sintering temperature. Wear resistance of the composites was found to increase with the increase of Si3N4 contents and sintering temperature.

Keywords:- Aluminium powder (AP); Silicon Nitride (Si3N4); Wear, Sintering Temperature; Hardness , Density, Porosity, SEM.

I. Introduction

Composites are the materials having superior mechanical properties and light in weight. Epoxies and polyester commonly serves as a matrix material. The reinforcing fibres are usually graphite, glass, boron, etc. New developments concerns are in metal matrix and ceramic composite materials. Ceramics-matrix cutting tools are being developed, made of silicon carbide reinforced alumina, with greatly improved tool life. A composite material contains more than one component. The compound materials are amalgamated into the composites so as to take the advantage of their attributes, thus providing an improved version of the material. Cohesive structures form by physically combining the two or more than two compatible materials. Reinforced fibre composites are materials prepared heterogeneously by associating and bonding the material in a single structure possessing different properties. Due to the complementary properties generated by the forming of two or more materials develops additional and superior properties in it. Thus these materials became the ideal material for the application where requiring high strength to weight and stiffness to weight ratios. These materials develop anisotropic properties. Commonly used fibres for composites materials are glass, boron and graphite for producing amorphous structures, ceramic and metallic for single crystals and as for poly crystals as well, carbon and boron produces multiphase structures and organic materials for macromolecular structures.

2. Literature Review

M. A. Salem et al. (2017) Analyzed the impact of the Al lattice, SiC sizes and the SiC volume part on the microstructure development, mechanical properties of the composites. They worked on Al-SiC MMCs by taking different sizes, and volume parts were manufactured using ball milling machine and powder metallurgy. Al and Al-SiC composites of various volume fractions were processed for 120 hours and then, the Al and Al-SiC composites were compact under 125 MPa and then sintered at 450 °C. Then he measured the thermal conductivity, electrical resistivity and micro hardness analysis of the prepared composite samples. He conclude as we decrease the size of Al-SiC particle and increases the volume of Al-SiC will decrease the properties of the MMC's. On the other side micro hardness was increased when we took the small particle size of Al-SiC and increases their volume fraction.

Ashok Kumar Mishra and Rajesh Kumar Srivastava (2016) He studied the wear resistance and coefficient of friction on Aluminium Al-6061 reinforced with SiC particles of 150 and 600 mesh size and taking the weight fraction varying from 5%,10%, 15%, 20%, 25%, 30%, 35%, 40%. The tested the dry sliding wear properties using pin on disk wear tester using velocity at 2m/s and sliding distance of 2000m with applied load of 10, 20 and 30KN. He commented that wear increases with increase in load and sliding distance and coefficient of friction decreases with increases in weight percentage of reinforcement. He also said that wear will reduce till 35% weight fraction only. He analyzed the wear surfaces by optimal microscopy. And he obtained the best result with 35% SiC having 600 mesh size.

Smrutiranjan Pradhan et al. (2016) Analyses the wear and friction behavior of Al-SiC MMC under three different condition i.e. dry, aqueous and alkaline medium. The pin on disc apparatus where specimen is sliding under Alumina disc and varying speed. So as the load increases; wear increases. It seems that maximum wear occurs in alkaline medium, followed by aqueous and dry conditions. The microstructural analysis and worn analysis done by SEM & EDS. And he conclude that minimum wear occurs in dry medium is dominated by adhesive and abrasive wear whereas in aqueous and alkaline medium mechanical and corrosive wear will responsible for the same.

Babalola et al. (2014) He reviewed the development of Aluminium matrix composites with SiC as an additive via fabrication through solid state and liquid state process. Then he quoted that Aluminium matrix composites can easily be prepared when combined it with non-metallic reinforcing materials like SiC, B4C, Si3N4, AIN, TiC, TiB2, TiO2 and etc. After adopting the cost-effective techniques like stir casting for manufacturing the samples and comparison is done with the powder metallurgy samples and results shows that stir casting samples have high hardness then the powdered one.

Senapati et al. (2014) Reviewed various journals in order to understand the effect of reinforcement on abrasive wear of Aluminium based metal matrix composite and he conclude that when Aluminium alloy treated with different reinforcements like ceramics, fly ash, fibers, whiskers, etc considerably improves the wear resistance and it also improves the other mechanical properties like hardness, strength and corrosive properties.

Prasanna et al. (2014) Studied the mechanical properties of Aluminium alloy (LM25) reinforced with SiC, Red Mud and E-Glass composite material by varying their percentages of each additive, and they plot their results. They studied the both reinforced and unreinforced samples of Aluminium (LM25) alloy. The main properties analyzed by them are tensile strength, impact strength, ductility and hardness. And results shows that addition of SiC, red mud and E-Glass as an additive improves the impact strength and tensile strength, reduces the % elongation. But the addition of Glass fiber decreases the hardness of the material.

Suragimath et al. (2013) Study the mechanical property like wear and impact of Aluminium (LM6) with Silicon carbide and fly ash as an additive. By keeping the percentage of silicon carbide constant i.e. 5% and varying the percentage of fly ash i.e. 5% and 15%. He prepared the samples using stir casting method, then he grind and etched the surface to see the distribution of the particulates in microstructure of the sample using optical microscope. He found in his results that upon increasing the concentration of fly ash improves the wear rate, tensile strength and decreases the %elongation.

Rahman et al. (2013) Studied the different mechanical properties of Aluminium Metal Matrix Composites reinforced with different 0%, 5%, 10%, 20% Silicon carbide. In his observations he quoted that formation of clusters of silicon carbide forms in the metal matrix due to that non-homogeneity of the particles was seen and high porosity was also observed. As the percentages of Silicon carbide increases; hardness and tensile strength increases. Wear resistance also increases with the increases in percentage of reinforcement.

Gewfiel et al. (2012) Analyzed the effects of Graphite and SiC formation on mechanical and wear properties of Aluminium-Graphite composite. Gewfiel took pure Aluminium and Silicon carbide with five weight percentages (1, 2, 3, 4, 5 wt %) of natural graphite flakes treated it with multiple process until they show uniform distribution with no acidity. For comparison he also prepared pure Aluminium samples with the same process, and then he analyzed thermal properties, phase transformation, crystalline size, microstructure, composition, hardness and wear of the composite samples. And he confirmed that increasing the graphite concentrations reduces the wear rate to a good extent.

G. Celebi Efe et al. (2011) focused on the particle size, and some properties of SiC particle reinforced Cu composites. He produces the Cu powder by cementation method and reinforced it with 1µm and 30 µm particle size of SiC and then sintered at 700°C. Then he calculated the relative densities of Cu-SiC using Archimedes principle which are in ranged from 96.2% to 90.9% with 1µm SiC particle size and their hardness found in between 130 to 155 HVN and 97% to 95% for 30 µm SiC with hardness of 188 to 229 HVN particle size. He also performs the maximum electrical conductivity test on the material and obtained the result as International Annealed Copper Standard. Then he performs the SEM analysis studied shows that SiC particles were dispersed uniformly in the copper matrix.

Duniya Abdul Saheb (2011) studied the Aluminium Silicon Carbide and Aluminium Graphite particulate composites. He tried to develop a method for producing the low-cost metal matrix composite and to obtain a homogeneous composition of the same. He took 5%, 10%, 15%, 20%, 25%, 30% of SiC with 2%, 4%, 6%, 8%, 10% Graphite while other parameters constant. He concludes that as the percentage of Silicon carbide is increasing, hardness increases, because of the stirring is done, homogeneity is maintain, best results comes out at 25% weight fraction of Silicon Carbide sample. However best results obtained with 4% weight fraction of Graphite.

Singla et al. (2009), have conducted the experiment by varying the weight percentages of silicon carbide 5% to 30% in interval of 5 in Aluminium Metal Matrix. In his experiments he also compared samples made by various processes for comparing the results. He observes that clustering of silicon carbide forms where stirring is not done and he also used manual and two step stirring process for comparing the results. He shows that as the percentages of silicon carbide increases, hardness increases, impact increases, best results obtained at weight fraction of 25% silicon carbide.

D.B. Miracle (2005) Studied the development of MMC in the course of recent decades – a period coexist with the distribution of Composites Science and Technology – metal network composites (MMCs) have been changed from a small concept to scholarly interest to a material of wide innovation and of commercial importance. The overall MMC market in 1999 represented 2500 metric tons esteemed at over $100M. The MMC applications in every segment like transportation, aerosciences, infrastructures etc. because of excellent mechanical and electrical properties. A suite of testing specialized issues has been overcome, including moderate essential furthermore, auxiliary handling, material plan and improvement procedures, and portrayal and control of interfacial properties. This article portrays the innovative highlights that describe the MMC business, lattice/fortification frameworks what's more, essential and auxiliary procedures of business criticalness will be comprehensively depicted. A few measurements that underscore the developing development of the MMC business will be talked about, including the rise of a moment level help industry and the development of institutionalized materials and strategies. MMC applications in the significant markets of ground transportation, warm administration, aviation, mechanical, recreational and foundation will be portrayed. Effective commercialization techniques will be talked about and bits of knowledge for accomplishing extended MMC applications will be given.

J.M. Torralba et al. (2003) Took the various composites and analyzed them all. And then quoted why Aluminium is widely accepted and recognized metal matrix composite because of low density and higher stiffness and can easily be manufactured by casting and powder metallurgy whereas other composites will not.

J.W. Kaczmar et al. (2000) He concentrated his focus in order to get excellent physical and mechanical properties and the development of composite materials because of the high precision application of them like in aircraft technology, electronic engineering and recently in passenger car segment. He discussed the properties and production procedures and techniques of metal matrix composite material reinforced with platelets, dispersion particles, continuous (long fibres) and non-continuous (short fibres). He discussed the different casting process for manufacture ceramic preforms with liquid metal alloy and powder metallurgy.

3.Duplex Composite Components

The materials which are subjected to very high wear and high contact stresses should be made of duplex composites. Depends upon the application the composite layer can be located on the inner or outer surface. The Aluminium composites reinforced by ceramics have been developed and having relative high strength to weight ratio, high modulus of elasticity and good wear characteristics.

Silicon Carbide particles engulf in to the surface of Aluminium alloy and heated to just below the recrystallization state and then pressure is applied to get a goof wetting between the Aluminium alloy and the Silicon Carbide particles. Experiments carried out to determine the semi-solid forming conditions. Aluminium material with Silicon carbide as an additive are heated up to the temperature for about 45 minutes so that the specimen will be homogenize. A hydraulic press is used to apply the pressure for semi-solid forming. This method of applying pressure and temperature gives the optimum desired results. Different temperature and pressure combinations will give the different results which we were discussed it in the later chapters of this dissertation work.

4 Powder Metallurgy

Powder Metallurgy is a process where metallic shapes are manufactured from metallic powders. In powder metallurgy, the metal or alloy is solid at the start and remains solid at the end of the process. Now-a-days powder metallurgy becomes an important aspect in fabrication industry. Powder Metallurgy helps us to deals with the materials like refractory materials which are difficult to machine like sintered carbides etc.

Powder metallurgy is the way toward mixing fine powdered materials, compacting the same into a coveted shape or frame inside a form taken after by warming of the compacted powder in a controlled environment, alluded to as sintering to encourage the arrangement of holding of the powder particles to shape the required part.

The powder metallurgy process generally consists of five basic steps-

1. Powder manufacture
2. Blending of powders
3. Compacting of powders in a mould or die
4. Sintering
5. Finishing.

5.Powder Manufacturing Techniques

The production method for the powder manufacturing will affects their physical and chemical property considerably. Almost all materials can be transforms in to respective powders but with the aid of a suitable method, all methods are not allow to use for every powder production, it depends upon the properties of the powder which we are going to produce. Basically there are 4 methods available for powder production-

Mechanical method:

- Milling
- Grinding
- Mechanical alloying
- Physical-Mechanical
- Water Atomization
- Gas Atomization
- Centrifugal Atomization

Chemical method:

- Reduction of Metal compounds
- Powder Making from Vapour Phase
- Hard Material Powder Making

Physical- Chemical method:

- Electrolysis
- Preparation of powders from water solutions
- Melt Electrolysis

5.1 Methods used for the conditioning and HT are as follows

(a) Sorting – The green powder which was obtained by the mentioned process are of broad size range. In order to achieve the desired properties of the powder, particle size need to be ensured of the correct dimension.

Sorting is done using the following methods-

- Sieving
- Air Sorting
- Floating

(b) Annealing – Powder reduction is necessary because of the oxidation which occurred due to surroundings. Reduction is carried out in controlled atmosphere of Hydrogen and Ammonia.

(c) Additions and Admixtures – Different additives like plastificators and lubricants are used in order to reduce the generated friction between the walls and the tool. The use of pressing additives leads to a decrease in flowability and bulk density of the powders.

(d) Mixing of Powders – Mixing is done to achieve the homogeneity. Different types of blenders available for different types of mixing like Drum mixer is available for simple mixing, Casing mixer are available for intense mixing. Proper mixing additive should be used in order to avoid the cluster formation.

Granulation of Powders – It can be done in different ways

- Using Granulation additive (like glycerol, paraffin, glycerin etc.)
- Mechanical Granulation
- Thermal Granulation

5.2 Shaping and Compaction of Powder Materials

Compaction of powder material increases its cohesiveness by the mechanical densification of powders material by cold and hot forming techniques. Powders which are cold compacted will be sintered to give strength to the green material to withstand.

5.3 Techniques which are used for compaction are as follows:

- Pressure Forming
- Die Pressing
- Extrusion
- Powder Rolling
- Isostatic Pressing
- Powder Forging
- Explosive Compaction
- Metal Injection Moulding
- Forming without external pressure
- Ceramic Casting Method
- Freeze casting of suspensions.

5.4 Sintering

It's a process by which we provide the strength and decrease the porosity of the green material by giving the heat treatment without achieving its point of liquefaction in a controlled atmosphere of Hydrogen or vacuum; sometimes when there's a non-availability of Hydrogen or vacuum, air can also acts as a working medium because air contains 78.09 % Nitrogen which almost behave as an inert but it's not an inert gas.

Normally sintering temperature can be taken as 0.6 to 0.75 of the melting point of the sintering material. Different sintering processes are available, each processes have their own characteristics and mode of their application.

Conclusion

In this work, wear, porosity, density and microstructure of Al-Si3N4 composite were investigated. Result shows that wear strongly depends on Silicon Nitride contents and sintering temperature was found that:

- Specimen at 490°C confirms minimum wear and minimum COF as compared to 470°C and 450°C.
- Specimen at 7% Si3N4 confirms minimum wear as compared to 0 %, 3%, and 5%.
- Specimen at 7% Si3N4 confirms minimum COF due to less wear as compared to 3 %, 5%, and 7%.
- Hardness and density increase with increasing Si3N4 and sintering temperature.
- At 7% Si3N4 content confirms dense structures compared to 0 %, 3%, and 5%. Density increases from 450°C to 490°C.
- In Micro cracks and porous microstructure was seen in Al-3% Silicon Nitride composite, but porous structure and micro cracks reduces in Al-5% Silicon Nitride. Black region represents Al matrix and white colour represent Dispersion of Silicon Nitride particle. Silicon Nitride particle are dispersed uniformly. In Al-3% Silicon Nitride and Al-5 % Silicon Nitride matrix, there is no porosity was observed in Al-7% Silicon Nitride matrix.

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