Wear Analysis of Al7068 Metal Matrix Composite Reinforced with Silicon Nitride

Naveen Chandra Gupta[1], Umesh Kumar Yadav[2]

[1]*M.Tech.(Mechanical Engineering) Scholar, Mechanical Engineering department, Bansal Institute of Engineering & Technology Lucknow, Uttar Pradesh, India*

[2]*Assistant Professor, Mechanical Engineering department, Bansal Institute of Engineering & Technology Lucknow, Uttar Pradesh, India*

Abstract- *In present scenario pure material is unable to provide the varieties of properties required for the variations in applications hence acquainted with the composite material are quiet relevant. Thus for these point of consideration, Metal matrix composites (MMCs) possess significantly improved properties including high strength ratio; specific modulus, damping capacity and high wear resistance compared to unreinforced ,means original basic alloys. There has been an increasing interest in composites containing light weight and low cost of component .Also These material shows required properties and it will have very less impact on environment they are easily recycled and it is very helpful for solid waste management, which is in a great concern of our country and society. In this paper Al7068 alluminium alloy reinforced with silicon nitride with varying percentage is used for fabrication of composite material. casting is done by liquid state fabrication process that is stir casting process. After casting process for insuring homogeneity of material SEM is done. And after various testing of strength, wear analysis is done by well known solid state Pin on disk ,wear analysis process. As it is great point of consideration that failure of parts due to friction is happens and about one third energy losses is due to it. But as we know silicon nitride has excellent hardness which enhance the properties of base alloy. Thus we can aspect to reduce the failure tendency of component in future. These material will have very vast application in automobile industries, aerospace as well as marine where strength and durability is main point of consideration.*

Keywords- *Metal matrix composites (MMCs), Al7068 alluminium alloy, SEM, Wear analysis, silicon nitride*

1. Introduction

The engineering community has always been in the search for materials which would suitable for all kinds of conditions during service. It originates from the requirements to make improved discoveries made by scientists,ordable. This affordability factor has persuaded various researchers to make such materials which satisfy many hitherto unexplored conditions.In the current world most materials are used for various uses and their limitations have been seen. In current world almost all materials have been used for various applications and their limitations have been met. But in today's world materials are required to face harsher environments. This situation requires that new materials should be created from various combinations of other compatible materials. It should be analysed that this method is not new, it has been considered by humans since ages. In each and every division of the world, different materials have been combined to obtain some desired properties, although each case has variation from the others, i.e. one can generate new materials with specified properties, which are user desirement and are vary from their base ingredients. This idea holds good for a type of materials called Composite materials where, various variety of matrices are combined with reinforcements that contribute to the enhancement of the properties. Neither the matrices nor the reinforcements when taken individually can fulfill the desired requirement, but the composite materials can do. This change in properties can be controlled by many different ways, by controlling the matrix and reinforcement quality, their composition or the fabrication tricks and technology. This flexibility in manufacturing of material allows to develop composites with different properties in a precisely restrict manner. It is the special mechanical as well as thermal properties of composite materials which has triggered their indentation into all fields of manufacturing. Metal Matrix Composites (MMCs) have came as a new branch of materials suitable for structural, electronic, aerospace, vehicle, thermal and damage applications due to their advance character over the conventional materials. They are far superior in terms of modulus ratio, specific strength, wear resistance, chemical inactiveness, high temperature sustainability, resistant co efficient of thermal expansion, and so on. But

on the other hand they have low toughness and high cost of manufacturing in comparison with Polymer Matrix Composites (PMCs). But MMC's have higher transverse strength and stiffness, shear strength and high temperature capabilities when compared to Polymer Matrix Composites (PMCs) . The desirable physical property are high electrical and thermal conductivities, no moisture absorption, non-flammability and resistance to most radiations. Compositionally, Metal Matrix Composite (MMCs) has at least two components, i.e the matrix and the reinforcement. The matrix is usually a metal, but often a pure one. In some cases, it is generally an alloy. The most widely used alloys are based on Aluminum and Titanium. Both of the materials have low density and are easily available in a wide range of alloy compositions. Other alloys are also used in some distinct cases, because they have their own advantages and disadvantages. For Ex Beryllium is the lightest of all manufacturing related materials and has a tensile strength greater than that of steel, but it is highly brittle, making it unsuitable for general purpose use. Magnesium is light, but has high reactivity to Oxygen. Nickel and Cobalt based super alloys are also used in some cases, but some of the alloying elements present in them have been found to have undesirable result (promoting oxidation) on the reinforcing fibers at very high temperatures .

2. Literature Review

S.Madhavarao et al. [1] studied the frictional and wear behaviour of Aluminium 7075 reinforced with 10% and 15% weight % of SiC particles. The aluminium matrix composites were manufactured by stir casting process. Wear and frictional properties of the aluminium matrix composite in dry sliding conditions were studied by using pin on disk machine. The wear experiment were conducted by using Taguchi orthogonal array DOE approach and result were analyzed by using ANOVA Method. The result shows that the sliding distance has more influence on wear rate than other parameters for AL7075+10%SiC while applied load has more influence on wear rate for Al 7075+15% SiC composite.

Bhoopati Mahendra et.al [2] calculated the mechanical properties and the micro structure of Al 2024 reinforced with Silicon Carbide and Fly Ash mixture metal matrix composite. A total of 9 specimen were prepared with varying weight percentage of SiC and Fly Ash in Al alloy 2024. The specimen were prepared by Stir Casting Method also known as liquid state method. The micro structure of the composites were studied under optical micrograph. The test shows non-uniform distribution of the reinforcement in the case of Al/(5% SiC),Al/(10% SiC),Al/(5% fly ash) and Al/(10% fly ash).While uniform distribution of the reinforcement is seen in Aluminum mixed with SiC-Fly Ash mixture at various composition. Mechanical Properties such as Tensile Strength, Yield Strength, Hardness and Elongation were evaluated for all the specimen. The test results shows that both tensile strength and yield strength increases compared to unreinforced Al alloy. Tensile strength of unreinforced Al is 235 N/mm2 and this number increases to 267 N/mm2 for Al/(10%SiC), 263 N/mm2 for Al/(10%fly ash) and 293 N/mm2 for Al/(10%SiC+10%fly ash)composite, which is about 57% improvement to that of the unreinforced matrix when compared. Similar results of increasing trend had been observed both in hardness and yield strength.

Mir IrfanUl Haq et.al [3] studied the effect of sliding speed on friction and damage properties of AA7075-Si3N4 composites has been studies. The tribological testing was held on a unidirectional pin on disc tribometer at three variable sliding speeds (1 m/s, 3 m/s, and 7 m/s) at a constant load of 32 N. The wear loss increased with an increase in speed and coefficient of friction decreased with an increase in speed. The morphologies of the worn samples were investigated by SEM and it was observed that in case of unreinforced alloy and lower concentrations (2 wt% and 4 wt%) delamination was the dominant wear mechanism and, in case of higher Si 3N4content (8 wt%) abrasive wear was the dominant wear mechanism. Heavy plastic deformation and deeper grooves were seen in case of higher speeds. Mechanically Mixed Layer (MML) formation was also proved by EDS. The developed material could serve various high speed sliding wear applications in automotive sector. Graphite and silicon carbide Metal-Matrix Composite by Tagauchi and ANOVA method. Aluminum alloys of grade 356 were used with addition of reinforcement in different weight percentage constituents such as SiC 2%,Alumina 2%,Al356 and SiC 2%,Alumina 4%,Al356. The material was fabricated by stir casting method. The wear nature of the material was investigated by pin on disk wear testing equipment. The experimental result showed that the value of coeffcient of friction μ of the material decreases as the reinforcement increases and increasing the sliding time and increases as load increases.

SN Prashant et al. [4] studied the mechanical and wear properties of Aluminum 6061 reinforced with SiC and Graphite form 6% to 12% increasing in the steps of 3%. The specimen were prepared by stir casting method and were stirred automatically for 10mins to ensure the uniform distribution of reinforcement. Mechanical Test such as Hardness Test and Ultimate Tensile Strength and wear test were performed on the hybrid composite. It can be concluded from the test that when SiC and Graphite are

mixed with Aluminum gives opposite result to each other. Hardness of SiC reinforced composite increases with the composition while that of graphite decreases. It test result concludes that the ultimate tensile strength of hybrid composite is greater than the unreinforced Aluminum. The wear test was performed at different loads(10N, 30N and 50N) by keeping the sliding speed constant at 1.6m/s. It is found that the wear for SiC reinforced composite decreases at all compositions and nominal load while wear rate for graphite reinforced composite decreases uptil 6% after which starts decreasing.

Mohammed Amair et al.[5]says that the utility and advantage of metal matrix composites are increasing day to day because of high strength to weight ratio. The hybrid aluminum composites can be taken into mind as an outstanding and uncomparable material where high strength and wear-resistant components are of bigger importance, predominantly in the aerospace and craft and automotive like cars of various variety in engineering sectors. In the present work , Al7068 reinforced with that of the tur husk ash(THA) and Al2O3 hybrid metal matrix composite is formed from sintering of mechanically alloyed powder (ball milling) in powder metallurgy process. Different combinations of compositions (Al7068 reinforced with 0%,4%,8%,12% 0F THA and Al2O3) were taken with total 16 combinations. Hardness was found to be increasing with increasing percentage of Al2O3 but was decreasing with increasing percentage of THA.

3. Work & Methodology

Working Steps:

The material is selected to reduce the cost and also improve the mechanical properties such as strength of the materials, hardness, toughness and wear resistance of the components.

- After doing literature survey we select an aluminium alloy AL7068 as metal matrix and Si_3N_4 as reinforcement. Since Aluminium alloys gives good strength to weight ratio. Aluminium 7068 alloy is a heat operable wrought alloy with well anodizing results, high thermal conductivity & good fatigue strength. It is manufactured as a higher strength alternative to other aluminium alloys such as Al7075 for ordnance applications. It also gives the highest mechanical strength of all aluminium alloys. Silicon nitride is the most thermodynamically stable as a reinforcement and also have very high strength.
- Stir casting is used for casting of the composite material as it is relatively less costly than other methods of fabrication and also gives comparatively good results. Since we know Powder metallurgy is one of the best processes but it is too costly and complicated process.
- In stir casting we use Silicon Nitride micro powder of 20- 40 μm which stirred with Al7068 alloy.
- After stir casting various mechanical testing such as tensile strength (by UTM),hardness will be analysed such that we can observe the improved properties of the composite.
- Finally wear analysis will be done by the Pin on disc method so that the rate of wear of composite can be calculated and also compared with the other reinforcing element.

4. Materials and Methods

4.1 Instruments used and materials required

This chapter describes the experimental process adopted in the present project work. The instruments used for the several experiments in this work are taken into paper are below. A detailed report is also given on the raw materials utilised for fabrication of the test work piece and the characterization of the original material used for fabrication process. Details of each working steps accepted for the fabrication of the testing work piece, the process of mechanical testing carried out, the generation of the micrograph through Scanning Electron Microscopy(SEM) has been furnished. The instrument / equipments used for the manufacturing of Aluminium alloy composite reinforced with Silicon nitride to perform the various mechanical and wear test are as follows:

1. Digital Weighing Machine
2. Stir Casting Machine
3. Moulds
4. Stirrer
5. Crucible
6. Universal Testing Machine(UTM)
7. Brinell Hardness Machine
8. Pin on Disk Machine
9. Scanning Electron Microscope(SEM)

4.2 Material used

4.2.1 Al7068 Alloy:

The material used is Al7063 with SiN3 which is a composite made by using Stir-casting process. Its advantages are: Cost reduction can be achieved by changing the microstructure of the connecting rod and strength to weight ratio is high. This material exhibits high wear resistance in compare to the conventional connecting rod and can be splitted in to the 2 pieces (the big body and the cap) by fracturing it with an instant impact loads. There is always a demand for a light-weighting material with improved fuel efficiency in aerospace and automobile industries. This lead to increase the use of materials like aluminum over traditional metals as steel for increasing both range and efficiency. Powder metallurgy is one of the best technology for mass production of the parts in these industries. Aluminum is having excellent specific strength , thermal properties and stiffness, it is also cost effective for the mass production. However, it suffers from poor wear resistance so its usefulness lowers in moving parts applications. The inclusion of ceramic reinforcements to give the metal matrix composites (MMCs) which can increase both specific mechanical properties as well as frictional and wear properties of aluminium. The silicon nitride is a ceramic material having high strength, low coefficient of thermal expansion and stiffness. It also have high toughness for a ceramic material hence when combines to give it the extremely high thermal shock resistance.[22] Aluminum Alloy 7068 is selected as a matrix material. Aluminum Alloy 7068(AA7068) and Silicon Nitride is purchased Parshwamani metals, mumbai, India. AA7068 alloy consists of mainly other elements as Zn, Mg, Cu, Fe, Si, Cr, Mn and Ni. The chemical constituents are shown in below table.

Table 1 Aluminium 7068 Composition

Al	Zn	Mg	Cu	Fe	Mn	Ti	Si	Cr	Ni
85.51	8.30	3.03	2.42	.192	0.034	0.05	0.142	0.05	0.0075

Al7068 alloy has one of the maximum mechanical strength of all aluminium alloys and much more than that of certain steels. This is the outstanding alloy combining yield strength of up to 710 MPa (which is up to over 31% more than that of the Al7075 alloy) and the good ductility with the corrosion resistance which is similar to Al7075 and the other features is high working component/equipment designers. It is developed in middle of 1990‟s, Al7068 alloy was made as a higher ability alternative to the Al7075 for the ordnance usefulness. It is the very high attractive with a overall of the mixture mechanical properties (which allows it to retain at the elevated temperatures better than Al7075) and the other important characteristics of Al7068 have also resulted in a widespread specifications of alloy to markedly reducing the weight/cross section and widely increase in the strength of the critical components in the diverse market sectors.

Table 2 Typical properties AL7068

Tensile strength	586MPa
Ultimate strength	642MPa
Young's modulus	73GPa
Hardness (Brinell)	188
Nominal Density (68 ºF / 20 ºC) Specific heat(212 ºF / 100 ºC) 1050J/kg ºK	2850kg/m3
Melting Range	476 ºC - 635 ºC

4.2.2 Silicon nitride :

Silicon nitride is a preferred ceramic for the high mechanical working engineering applications. This ceramic can also be considered great candidate for the biomedical applications because of the same properties which makes it so important for the engineering application like high wear resistance, chemical stability, low friction coefficient and it is mainly because of mechanical behaviour under the articulation which is generally considered better than that for the alumina ceramics. Silicon nitride (Si3N4) is strong and the heat resistant material which can manufactured in many different forms with specific benefits of different types like surgical implants. Silicon nitride was first produced in year 1955 for thermocouple tubes and molten metal crucible and also used in rocket nozzles. Such materials were formed by nitriding silicon powder compacts. Considerable changes in internal arrangement took place to form silicon nitride crystal which grows with the pre existing pores of silicon powder compact as this is heated in nitrogen at 1200 degree celcius. After that they observed its original dimensions of component remain same by nitriding then they heated to provide strength. The final material contains 20-30% microporosity that limits its strength (<200MPa) for certain applications. So,

finally sintered to produce the dense and high strength material.

Silicon nitride exhibits :

- High fracture resistance.
- High flexural strength .
- Good creep resistance .
- High hardness number .
- Very good resistance to errosion .

Table 3 properties of Silicon Nitride

DENSITY	3020 kg/m3
HARDNESS	20.5GPa
ELASTIC MODULUS	280GPa
COMPRESSIVE STRENGTH	4900MPa
TENSILE STRENGTH	420MPa
THERMAL EXPANSION	2.5x10-6 /oC

4.3 fabrication of metal matrix composite (casting method):

4.3.1 Stir casting method:

Among the above mentioned fabrication methods in the introduction part, stir casting method comes out to be the most promising and economical way of the production.

Stir Casting:

In this casting process,the process constitutes electric powered furnace,a preheater for preheating the reinforcement particle so that working temperature difference can be minimised, mechanical stirrer & electric motor. The temperature of the of the furnace is maintained at 700-780°C . The dies of particular shape is placed inside the furnace before the alloy so that it can be preheated about 250-300°C. It is to ensure for proper solidification to obtain a desirable grain growth as if boundaries cools faster strength will vary. Graphite crucibles are used to hold and keep aluminium alloy bars for placing inside the furnace. The matrix material Al 7068 is being heated in a crucible about 750°C and preheated silicon nitride ceramic particles for reinforcing into the metal fluid are mixed into the crucible at a not changingrate. The ceramics were preheated in an electric furnace up to350- 400 °C. The stirrer connected to machine powered by an electric motor was rotated at an RPM of 250-300.The stirring done for around 20-30minutes so that proper mixing can be ensured.Also Mg tablet mixed to improve wetability.Four different workpiece of AA7068-Si3N4 are prepared by stir casting . The ceramic reinforcement was varied in four different levels by weight (1, 3,5 and 7).The liquid form of composite was added into the permanent mould, which was thereafter allowed to cool in ambient conditions. The cast samples were machined to form cylindrical pin of 8 mm diameter and 8 mm height. The presence of silicon nitride ceramic was confirmed by EDS method,before the hardnesstesting, the samples were rubbed by different grades of emery papers.and final polished component is sent for different testings so that desirable properties can be confirm.

4.4 Wear Theory:

When two surfaces of relative motion interact with each other, wearing of the surfaces occurs. Wear can be defined as the gradual loss of material from the contact surface during relative motion. Scientists have generate various wear theories, which take into account the physical and mechanical properties and physical conditions of the material (such as the resistance of the friction body and the stress state of the contact area). In 1940, Holm calculated the volume of the worn material on the unit sliding path from the atomic mechanism of wear. Kragelski put forward the theory of wear fatigue. Due to the irregularities in the solid, their in teraction on the slide is discrete, and the various locations where they touch together occur, forming the actual contact area. Under the action of normal force, these irregularities penetrate or flatten each other, and the corresponding stress and strain rise in the actual contact area. During the sliding process, a fixed volume of matter is subjected to many more repetitions, which weakens the material andeventually causes cracking and fracture.

5. RESULTS & CONCLUSION

5.1 Evaluation of Mechanical Properties

This chapter contains the results obtained from the tests performed on the composite materials. Mechanical Test such as Tensile Strength Test and Brinell Hardness Test and Wear Test were conducted on the composite materials. The test specimens for all the experiments were conducted according to ASTM standards. To study the micro structure of the materials SEM micrographs have also been provided.

5.1.1 Tensile Strength Test

To determine the Ultimate Tensile Strength and Yield Strength of the hybrid composite materials, Tensile Strength Test was conducted by using Universal Testing Machine (UTM). The test was conducted in the workshp. The test specimen length is 100mm.

σuts =F/a

where

Futs is the Ultimate Tensile Load (kN)

Fyield is the Yield Load (kN)

Ao is the initial cross sectional of the specimen (mm3)

Table 4 UTS AND YS of the Material

S.No	Material composition	UTS(MPa)	Yield Strength(MPa)
1	0% Si3N4	600	630
2	3%	622	615
3	5%	739	725
4	7%	748	733

5.1.2 Brinell Hardness Test

To determine the Hardness No. of the composite materials, Hardness Test was conducted by

using Brinell Hardness Machine. The test was conducted in the workshop. The test specimen had a length of 30mm and diameter of 30mm.

Table 5 Hardness comparison

S.No	Material composition	Hardness BHN
1	0 % Si3N4	167
2	3	180
3	5	190
4	7	230
5		

5.1.3 Charpy Impact Test

To calculate the impact energy means the toughness value ,charpy test was conducted in the workshop. the test specimen was of dimention 10*10 mm.

Table 6 Impact strength Comparison

S.No	Material composition	Impact value (j)
1	0%	23
2	3%	18
3	5%	14
4	7%	10

5.1.4 Wear calculation and analysis

to calculate wear rate the reduction in weight is calculated after pin on disk test. The test was also conducted in the workshop. the weight deduction is variable for different composition.

S.No	Material composition	Load (N)	SLIDING SPEED (m/s)	Wear rate (mm3/ min)	COF
1	0%	40	.25	.442	0.127
2	3%	40	.25	.135	0.084
3	5%	40	.25	.0682	0.061
4	7%	40	.25	0.0125	0.043

6. Conclusions & Future Scope

Based on the study of various research paper, model was developed by adding ceramic as a reinforcing agent Si3N4 in the Al7068 aluminium alloy, the following conclusion can be obtained :

* There are an more value in the hardness value with an increase in Si3N4 content. With an increase in Si3N4 content from 0 wt% to 7 wt%, the hardness of the component is seen to increase from 61.2 to 123 (BHN). It means that the increment in the hardness of the 7 wt% Si3N4 mixed Aluminium composites.

* The tensile strength increased from 98 MPa to 175MPa from neat Aluminium to the 7wt% of the Al-Si3N4 composites. It shows that with an introducing Si3N4 into Aluminium alloy improves material properties because of good compatibility and the interfacial adhesion between the Si3N4 and the Aluminium matrix.

* It is observed that the occurrence of the hard and the brittle Si3N4 particles in soft and ductile Al alloy matrix reduces the ductility content of the fabricated metal composite due to the small ductile content of matrix metal in composite, which considerably enhances hardness of the fabricated AMCs.

* The brittleness nature of Si3N4 particles shows significant role in compromising its ductility; because, Si3N4 as reinforcement is a brittle and it improves brittleness in the newly formed composites, which in-turns reduced ductility content of the composites. Further, increment in wt. % of the Si3N4 particles in composites reject the flow-ability of aluminium matrix and decreases ductile matrix content, which results in decrease of percentage elongation of the composites. Identical consequences of the reduce in percentage elongation with the increasing value of reinforcement in aluminium matrix on comparision of fabrication process of the composites were achieved.

Thus we can expect that this composite material definitely reduce the cost or reduce the weight of component without compromising the quality requirement.

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