STUDY ON SLIDING WEAR OF FLY ASH METAL MATRIX COMPOSITES

A Project Report

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In partial fulfillment for the award of degree
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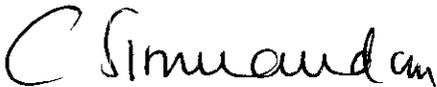
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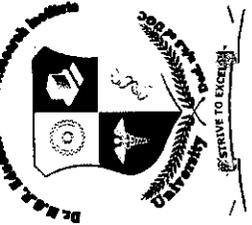
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ABSTRACT

The ever increasing demand for light weight, fuel efficiency and comfort in automobile industries has led to the development of advanced materials along with optimized composition. Metal Matrix Composites (MMC's) are one such advanced material which is widely used in industries as they have excellent mechanical properties. Most popular MMC used now-a-days is the aluminium silicon carbide which has been used for connecting rods, brake rotors, drive shafts and several other components because of their high thermal conductivity coupled with low thermal expansion and also high strength along with exceptional thermal shock resistant qualities. However, the high cost of this MMC remains a major barrier in their widespread use.

In order to reduce the cost of composites, it has been identified that the fly ash particles, a waste byproduct from power plants can be incorporated in this MMC. Also it has some excellent properties such as low density, high specific strength and modulus, superior wear resistance and low coefficient of thermal expansion.

In this project work MMCs were developed by reinforcing Fly ash and silicon carbide particles to the aluminium alloy metal matrix based on the Design of experiments using liquid metal stir casting technique by varying 2 to 10 weight percent of fly ash and silicon carbide particles and are machined as per ASTM standards.

The objective is to optimize the composition of MMCs based on the wear resistance. Wear testing has been conducted on Pin on Disc apparatus by keeping the parameters like sliding speed, sliding distance and load constant.

ஆய்வு சுருக்கம்

இன்றைய சூழ்நிலையில் குறைந்த எடை, எரிபொருள் திறன் மற்றும் சொகுசான பயணம் இவை அனைத்தும் வாகன தயாரிப்பு துறையில் இதன் தேவைகள் அதிகரித்துள்ளதால் அவற்றை பூர்த்தி செய்ய மிகவும் நவீன பொருட்கள் தேவைபடுகிறது. இவற்றை உகப்பு நிலை கலவையினால் உருவாக்க வேண்டியுள்ளது. கலப்பு பொருட்களின் அணி கூட்டு ஒரு நவீன பொருட்களில் ஒன்று, அதன் இயந்திர குணாதிசயங்கள் மிகவும் நேர்த்தியாக உள்ளது. தற்போது உள்ள நிலையில் இதில் பயன்படுத்தப்படும் முக்கிய பொருள்களாக அலுமினியம், சிலிக்கான் கார்பைடு உள்ளன, இவை அதிகமாக வாகனத்துறையில் பயன்படுத்தப்படுகிறது. இவ்வாறு பயன்படுத்துவதற்கு காரணம் என்னவெனில் அதிக வெப்பத்தை கடத்தும் தன்மை மற்றும் குறைந்த வெப்பத்தால் விரியும் தன்மை மற்றும் வெப்ப அதிர்ச்சியை எதிர்க்கும் தன்மை போன்றவை இதில் இருந்தாலும் இவற்றில் அதனை பயன்படுத்துவதற்கான விலைவாசி மிகவும் அதிகமாக இருக்கிறது.

இப்பொருட்களின் விலையை குறைக்க இதில் "ப்ளை ஆஷ்" என்ற பொருள் சேர்க்கப்படுகிறது. இது அணுமின் நிலையிலிருந்து வரும் கழிவுப் பொருட்களில் பெறப்படுகிறது. அவ்வாறு பெறப்படும் பொருளில் அதிக வலிமை, குறைந்த அடர்த்தி அதிக மாடுலஸ் போன்ற குணாதிசயங்களை கொண்டுள்ளது.

இந்த ஆய்வில் பொருள் அணி கூட்டை தயாரிக்க சிலிக்கான் கார்பைடு மற்றும் அலுமினியம் கலப்பு உலோகம் தயாரிக்க "டிசைன் ஆப் எக்ஸ்பிரிமெண்ட்" முறையை அடிப்படையாக கொண்டு "லிக்யூட் மெட்டல் ஸ்டிர் காஸ்டிங்" முறையின் மூலம் அதில் உபயோகபடுத்தப்படும் "ப்ளை ஆஷ்" மற்றும் சிலிக்கான் கார்பைடு பொருட்களின் அளவுகளில் 2 முதல் 10 வரை எடை சதவீதங்களை மாற்றி தயாரிக்கப்படுகிறது. அவ்வாறு தயாரிக்கப்படும் பொருட்களை "ஏ எஸ் டி எம்" நெறிமுறைக்கு ஏற்றவாறு தயாரிக்கப்படுகிறது.

இந்த ஆய்வின் குறிக்கோள் யாதெனில் கலவைகளின் உகப்பு நிலையை கண்டறிய தேய்மானச் சோதனை செய்யப்படுகிறது. இத்தேய்மானச் சோதனை "பின் ஆன் டிஸ்க்" பொருளில் நழுவும் வேகம், நழுவும் தொலைவு மற்றும் சுமை மாறிலி ஆகிய அளபுருக்கள் உபயோகப் படுத்தப்படுகிறது.

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NOMENCLATURE

Symbol	Definition
MMC	Metal Matrix Composites
CMC	Ceramic Matrix Composites
PMC	Polymer Matrix Composites
PCD	polycrystalline diamond tooling
SWR	Specific Wear Rate
ASTM	American Standard For Testing Methods
μ	Microns
SiO_2	Silicon Dioxide
Al_2O_3	Aluminium Oxide
Fe_2O_3	Ferric Oxide
MgO	Magnesium oxide
CaO	Calcium oxide
TiO	Titanium oxide
K_2O	Potassium Oxide
Na_2O	Sodium Oxide
SO_3	Sulfur Trioxide

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION:

Metal matrix composite materials are advanced materials, which combine tough metallic matrix with a hard ceramic or soft reinforcement to produce composite materials. These materials have superior properties compared to the monolithic materials and can be tailorable to specific applications. MMC's are widely used in industries as they have excellent mechanical properties. Particle reinforced composites cost less than fiber-reinforced composites owing to the lower cost of fibers and manufacturing cost. In addition to improved physical and mechanical properties, particle reinforced composites are generally isotropic and they can be processed through conventional methods used for metals. Thus, the silicon carbide reinforced aluminum composites are increasingly used as substitute material for cylinder heads, liners, pistons, brake rotors and calipers in automobile industry.

1.2 PROBLEM CHOSEN AND ITS IMPORTANCE

In last few years considerable development has occurred in the potential use of metal matrix composites for automotive applications. Metal matrix composites like aluminium silicon carbide has been used for connecting rods, brake rotors, drive shafts and several other components. How ever cost still remains a major barrier in designing Aluminium composite components for wider applications in automobile industries. Hence it is needed to optimize the characteristics of the composite materials. Thus an attempt has been made to reduce the wear rate of the material.

1.3 SOLUTION

The choice of the material selected is Aluminium alloy (LM6) along with Silicon carbide and Fly ash reinforcements. In order to reduce the cost of the composites, the fly ash particles, a waste by-product from power plants, have been incorporated in molten aluminium alloy to make low cost aluminium fly ash composites .In these composites, fly ash generally act as filler replacing energy properties. In certain cases, the properties of the metal also improved as a result of addition of fly ash. Fly ash is a coal combustion by-product, which consists primarily of aluminosilicates, and the oxides or mixes oxides of silicon, aluminium, iron, and calcium. Small amount of other oxides of common elements such as magnesium and titanium are also present. Fly ash particles generally contain either solid spheres called precipitator fly ash or hollow spheres termed cenosphere fly ash. The particle size of the fly ash as received from the power plants generally lies in the range from 1 to 350 μm. This project studied the dry sliding wear characteristics of the fly ash metal matrix composites. Keeping in mind the specific characteristics of fly ash particles namely high hardness, spherical shape, porous wall, smooth surface, hollow structure, and the major constituent of glassy phase complex compounds. In many applications, monolithic aluminum alloys have been found to have inadequate wear resistance, and the dispersion of fly ash particles in the matrix of aluminum alloys may enhance this property to extend its area of applications. Since fly ash represents an inexpensive resource material, this new composite is likely to overcome the cost barrier for widespread applications in automotive and small engine application.

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Following are the overview of the relevant work done earlier related to the problem identified and the methodology to be adopted to solve the chosen problem for this work. It gives the description of literature reviewed from various research papers published in international and national journals, proceedings of various conferences and books

Sudarshan et al (2007) studied the Dry sliding wear of fly ash particle reinforced A356 Al composites. In his study aluminium alloy (A356) composites containing 6 and 12 vol. % of fly ash particles have been fabricated. The dry sliding wear behaviour of unreinforced alloy and composites are studied using Pin-On-Disc machine at a load of 10, 20, 50, 65 and 80N at a constant sliding velocity of 1 m/s. Results show that the dry sliding wear resistance of Al-fly ash composite is almost similar to that of Al2O3 and SiC reinforced Al-alloy. Composites exhibit better wear resistance compared to unreinforced alloy up to a load of 80 N. Fly ash particle size and its volume fraction significantly affect the wear and friction properties of composites. Microscopic examination of the worn surfaces, sub surfaces and debris has been done. At high loads (>50 N), where fly ash particles act as load bearing constituents, the wear resistance of A356 Al alloy reinforced with narrow size range (53–106 μm) fly ash particles were superior to that of the composite having the same volume fraction of particles. He has concluded that the incorporation of 6 vol. % of fly ash particles into A356 Al alloy results in decrease in dry sliding wear rates at low loads (10 and 20 N). Twelve volume percent of fly ash reinforced composites show lower wear rates compared to the unreinforced alloy in the load range 20–80 N. In the

case of composites with 12 vol. % fly ash, narrower the particles size, lower is the wear rate.

Basavarajappa et al (2006) presented a methodology for the application of Taguchi technique to study dry sliding wear behavior of metal matrix composites. The objective was to investigate which design parameter significantly affects the dry sliding wear. It shows that graphite particles are effective agents in increasing dry sliding wear resistance of Al/Sic composites. A pin on disc test apparatus was used to investigate the dry sliding wear characteristics of the composites as per ASTM G99-95 standards. The wear specimen with 10 mm diameter and 30 mm height was cut from cast samples, machined and then polished metallographically.

Rohatgi et al (1997) presented the mechanism of abrasive wear of Al-Si hypoeutectic alloy containing 5-vol % fly ash. With 5-vol% fly ash, the density of composite decreases to 2.58g/cm^3 .The hardness increased to 82 HRF compared to the hardness of matrix alloy 79kg/mm^2 Morphology of the worn surfaces of aluminium fly ash composites under scanning electron microscopy, after wear test shows that under the load of 2.97 N the worn surface having relatively less ploughing and cutting. However at the load of 11.9 N fractured fly ash particles are frequently present on the worn surface. The specific wear rate (SWR) of the composite is lower at loads lower than 8 N as compared to the SWR of the matrix alloy. At higher loads greater than 8 N at sliding velocity 1m/s the SWR of the aluminium alloy fly ash composite is slightly higher than that of the al-alloy

Rajan et al (2007) presented the Fabrication and characterization of Al-7Si-0.35Mg/Fly ash metal matrix composites processed by different stir casting routes. The comparison of mechanical properties of some of the common aluminium matrix composites with aluminium. fly ash composite has shown that the addition of alumina and silicon carbide particles in cast and wrought aluminium alloy has enhanced the tensile properties while that of fly ash particles reduced. However these fly ash particles reinforced composites are preferred for application were improved wear

resistance, damping properties. Earlier studies in the laboratory have shown the possibility of incorporating up to 10 wt % as received fly ash particle (75-100 microns) after preheating in Al-12Si alloy through liquid stir casting. Surface treatment of Fly ash particles is a pre-requisite for getting an acceptable level of its dispersion in 356 alloy with minimum agglomeration and porosity. The separation of fly ash particles and its dispersion are more effective in compocasting method than in liquid metal stir casting due to the shearing of fly ash particles by the solid primary phases existing in semi solid slurry. Modified compocasting cum squeeze casting route results in the best distribution of fly ash particles followed by compocasting alone and liquid metal stir casting in metal moulds.

Natarajan et al (2006) presented the wear behaviour of A356/25SiC aluminium matrix composites sliding against automobile friction material. The wear tests have been carried out on a pin on disc machine, using pin as brake shoe lining of a commercial passenger car. The gray cast iron disc has been machined from a brake drum of a commercial passenger car. The aluminium MMC disc has been manufactured by stir casting technique using A356 Aluminium alloy and 25% silicon carbide particles and machined to the required size. The friction and wear behaviour of aluminium MMC, gray cast-iron and semi-metallic brake shoe lining have been investigated at different sliding velocities, loads and sliding distance. In his investigation MMCs had considerable higher wear resistance than conventional gray cast iron while sliding against automobile friction material under identical conditions. A gradual reduction of friction coefficient with increase of applied load is observed for both cast iron and aluminium MMC materials. However, in all the test it is observed that the friction coefficient of Al MMC is 25% more than the cast iron while sliding under identical conditions.

Samrat Mohanty et al (2007) presented the research carried out on development of fly ash based automotive brake lining. An attempt has been made through his research to incorporate more than 50 wt% of fly ash particles in automotive brake lining friction composites. Ingredients such as phenolic resin, aramid pulp, glass fiber, potassium titanate, graphite, aluminium fiber and copper powder were used in composite

development phase. Fly ash particles were found thermally resilient enough not to decompose at typical braking temperatures. Aramid pulp and potassium titanate provided sufficient structural reinforcement to the composite matrix that contained large percentage of fly ash particles. Addition of graphite helped the fly ash composite samples maintain stable friction performance. But, a metallic constituent in the form of copper fiber/powder was needed to scrap off excess lubricating layer generated by graphite. Composite samples that contained glass fiber, aluminum fiber could not provide desirable coefficients of friction and wear rates. The recent most brake lining compositions containing copper fiber/powder have shown encouraging results for further testing and optimization. The developed compositions are 50-60% lighter than current commercial brake lining for similar friction, wear and temperature performance under dry and wet conditions.

COMPOSITE MATERIALS

CHAPTER 3

COMPOSITE MATERIALS

Composite materials (or composites for short) are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure.

3.1 CLASSIFICATION OF COMPOSITES

Composite materials are commonly classified at following two distinct levels.

The first level of classification is usually made with respect to the matrix constituent. The major composite classes include organic matrix composites (OMCs), Metal matrix composites (MMCs) and ceramic matrix composites (CMCs). The term organic matrix is generally assumed to include two classes of composites, namely polymer matrix composites (PMCs) and carbon matrix composites is commonly referred to as carbon-carbon composites.

The second level of classification refers to the reinforcement form – fibre reinforced composites, laminar composites and particulate composites.Fibre reinforced composites can be further divided into those containing discontinuous or continuous fibres

3.2 ADVANTAGES OF COMPOSITES

Composite materials offer the greatest advantage in terms of weight reduction. However, there are additional factors, which tend to further encourage the use of composite materials. Some of these are

- High resistance to fatigue and corrosion degradation
- High strength or stiffness to weight ratio
- Improved friction and wear properties
- Improved dent resistance is normally achieved. Composite panels do not sustain damage as easily as thin gage sheet metals
- High resistance to impact damage.

3.3 METAL MATRIX COMPOSITE

3.3.1 Introduction:

Metal matrix is a composite material with at least two constituent parts; one being a metal the other 1 may be a different metal or another material such as ceramic or ceramic compounds. Metal matrices offer high strength, fracture toughness and stiffness.

Matrix: The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement

Compared to monolithic metals, MMCs have:

- Higher strength-to-density ratios
- Higher stiffness-to-density ratios
- Better fatigue resistance
- Better elevated temperature properties
  - o Higher strength

- o Lower creep rate
- Lower coefficients of thermal expansion
- Better wear resistance

The advantages of MMCs over polymer matrix composites re:

- Higher temperature capability
- Fire resistance
- Higher transverse stiffness and strength
- No moisture absorption
- Higher electrical and thermal conductivities
- Better radiation resistance
- No outgassing
- Fabricability of whisker and particulate-reinforced MMCs with conventional metalworking equipment.

Some of the disadvantages of MMCs compared to monolithic metals and polymer matrix composites are:

- Higher cost of some material systems
- Relatively immature technology
- Complex fabrication methods for fiber-reinforced systems (except for casting)

3.3.2 Matrix Materials and Key Composites

Numerous metals have been used as matrices. The most important have been aluminium, titanium, magnesium, and copper alloys and super alloys.

The most important MMC systems are:

Aluminum matrix

- Continuous fibers: boron, silicon carbide, alumina, graphite
- Discontinuous fibers: alumina, alumina-silica
- Whiskers: silicon carbide
- Particulates: silicon carbide, boron carbide

Composition of Metal Matrix (LM6)

CHEMICAL COMPOSITION	%
Copper	0.1 max.
Magnesium	0.10 max.
Silicon	10.0-13.0
Iron	0.6 max.
Manganese	0.5 max.
Nickel	0.1 max.
Zinc	0.1 max.
Lead	0.1 max.
Tin	0.05 max.
Titanium	0.2 max.
Aluminium	Remainder

Magnesium matrix

- Whiskers: silicon carbide
- Particulates: silicon carbide, boron carbide

Titanium matrix

- Continuous fibers: silicon carbide, coated boron
- Particulates: titanium carbide

Copper matrix

- Continuous fibers: graphite, silicon carbide
- Wires: niobium-titanium, niobium-tin
- Particulates: silicon carbide, boron carbide, titanium carbide.

Super alloy matrices

- Wires: tungsten

3.3.3 Reinforcement

The reinforcement material is embedded in to the matrix. The reinforcement doesn't always serve a purely structural task, (Reinforcing the compound), but also used to change physical properties such as wear resistance, frictional coefficient or thermal conductivity. The reinforcement can be either continuous or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metal working techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD).

Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

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                    ┌─────────────────┐
                    │  Reinforcements │
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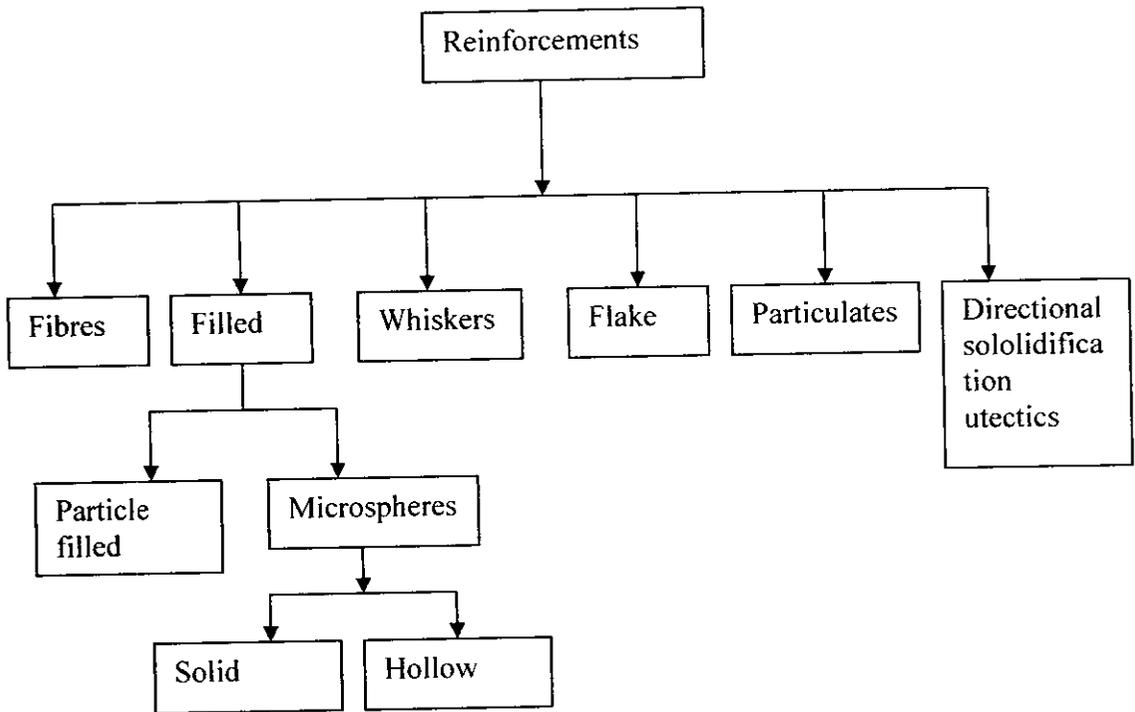
Figure 3.1 Classification of reinforcements

3.4 MANUFACTURING AND FORMING METHODS

Ash alloy metal matrix composites can be prepared using various techniques. The following are the different methods.

- Stir Casting
- Powder Metallurgy
- Pressure Infiltration

3.4.1 Stir Casting

Aluminum alloys (LM 6) were used in this work, which was conducted at the Kumaraguru College of Technology. In the stir casting process, the alloy is melted at a controlled temperature and the desired quantity of preheated fly ash and Silicon carbide is added to the molten aluminum alloy. The molten alloy is stirred continuously to create a vortex force that helps in mixing the lighter particles into the melt. Stirring continues to disperse the fly ash particles as uniformly as possible in a short time. The material is stirred again and then poured into preheated permanent

molds. It is then cooled, cut to shape, and surface cleaned. Microscopic view of aluminum alloy (LM 6), with a 10% volume of precipitator fly ash showed that fly ash particles tend to segregate along the aluminum dendrite boundary due to particle pushing. Fly ash particles tend to float to the top of the cast ingots due to their lower density. However, the distribution is reasonably uniform except for the top layer.

3.4.2 Powder Metallurgy

Powder metallurgy is a forming and fabrication technique consisting of three major processing stages. First, the primary material is physically powdered, divided into many small individual particles. Next, the powder is injected into a mold or passed through a die to produce a weakly cohesive structure (via cold welding) very near the dimensions of the object ultimately to be manufactured. Finally, the end part is formed by applying pressure, high temperature, long setting times (during which self-welding occurs), or any combination thereof

When the quantity of fly ash in the composite increased above 10% by weight, the hardness significantly decreased, and thus it was concluded that powder metallurgy did not seem very promising for producing ash alloy composite parts.

3.4.3 Pressure Infiltration

Gas pressure infiltration (GPI) is process for preparation of composite materials where molten matrix material is infiltrated into the pores of preform under the influence of high gas pressure. Technology usually has several steps: evacuation of pressure vessel (some material as Mg are heated under protective gas because of the evaporation which can damage equipment), heating under vacuum until matrix material is melted, immersion of porous preform into the melt, infiltration under high pressure and withdrawal of the sample from the melt (in case of some material systems were wettability is not sufficient, sample solidifies together with matrix in crucible). In some cases bonding between constituents is established due to the chemical reaction at the interface (for example formation of carbides), but sometimes this bond is only mechanical.

Steps of gas pressure infiltration process: a) porous preform above matrix material during heating b) immersion of porous preform into the molten matrix material and inlet of pressurized gas c) infiltrated sample in molten matrix and d) withdrawal of infiltrated sample from the melt. As mentioned before, terms which are very often related with gas pressure infiltration technology are wettability or wetting angle. Wetting is determinated by contact angle between liquid phase and solid substrate. GPI process is used because in some cases wetting angle between molten matrix and solid porous reinforcement is relatively high. To overcome this problem high pressure must be used. If wetting angle is 90° or lower, this is considered as good. Sometime, wetting angle between constituents is so high (pure copper/carbon fibres) that not even extremely high pressure cannot ensure good infiltration results.

WEAR AND ITS CHARACTERISTICS

CHAPTER 4

WEAR AND ITS CHARACTERISTICS

Wear is one, which leads to the loss of material during sliding of one surface over the other solid surface or the destruction of material produced as a result of repeated disturbance of the frictional body.

4.1 MECHANISMS OF WEAR

Wear is defined as the removal of material (mass) from the surface of an object through contact with another surface and not merely the deformation or dislocation of that material to a different part of the object.

Wear can be split in to two major categories: wear dominated by the mechanical behavior of materials and wear dominated by the chemical behavior of materials.

There are seven mechanical wear mechanisms listed, however there are only three types of surface to surface interactions that can cause them: sliding (one surface sliding relative to another over long distances), fretting (one surface oscillates over minute distance relative to other) and erosion (solid particles impinging on a single surface from an external source). In this project only dry (non-lubricated) sliding wear will be considered.

The actual mechanism for sliding wear depends on a number of variables including: surface finish, surface geometry, and orientation, sliding speed, relative hardness (of one surface relative to the other or relative to the abrasive particles between the surfaces), material microstructure and more. From these variables, it can be seen that wear rate is not a pure material property and does not always occur uniformly.

4.2 WEAR CLASSIFICATION AND MECHANISMS

Table 4.1 Wear classifications

Classification	Wear mechanisms	Wear coefficient k (range)
Wear dominated by mechanical behaviour of materials	1. Asperity deformation and removal 2. Wear caused by plowing 3. Delamination wear 4. Adhesive wear 5. Abrasive wear 6. Fretting wear 7. Wear by solid particle impingement	10-4 10-4 10-4 10-4 10-2 to 10-1 10-6 to 10-4 --
Wear dominated by chemical behavior of materials	1. Solution wear 2. Oxidation wear 3. Diffusion wear 4. Wear by melting of the surface layer 5. Adhesive wear at high temperatures	

4.3 THE ARCHARD EQUATION

The starting point for any discussion of wear on the macro scale is the Archard equation, which states that

$$W = K * S * P$$

Where   W is the worn volume

            P is the applied load

            K is the wear per unit load per sliding distance

Archard says "[K] may be described as the coefficient of wear and, in a series of experiments with same combination of materials, changes in K denotes changes in surface conditions. "Archard equation assumes that the wear rate is independent of apparent area of contact. However it makes no assumption about the surface topography (surface roughness effects are encompassed by the experimental wear

coefficient)and it also makes no assumption about variation with time. It must also be stated that although it is widely used, the Archard equation only provides for an order of magnitude estimate and is a true calculation of wear.

One of the more common methods for determining the value of K is to press a stationary pin using a preload of P in to the surface of a rotating disk. The load P is known and the sliding distance S can be determined from the rotational speed of the disk and time that disk has rotated. The amount of wear of the pin is determined by change in mass (weight) of the pin and the constant K calculated.
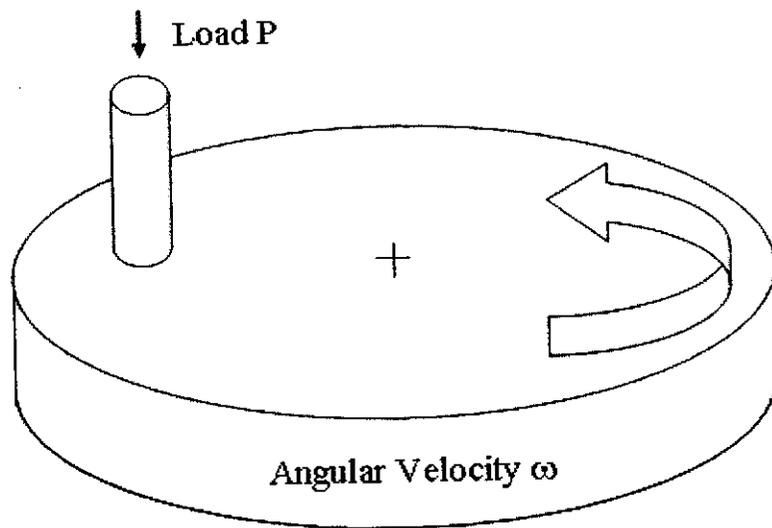
Figure 4.1 Pin on Disk configuration for measuring wear

SAMPLE PREPARATION

CHAPTER 5

SAMPLE PREPARATION

5.1 PREPARATION OF SAMPLE
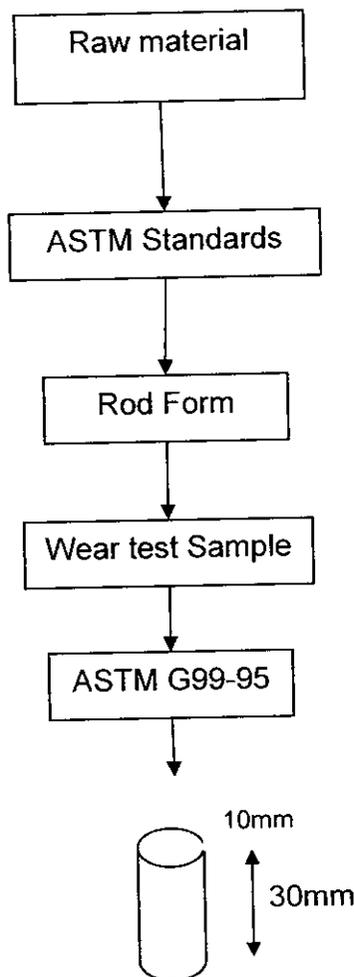
Fig 5.1: Flow chart explaining the material preparation by ASTM standards

5.2 PROCEDURE

Aluminium cast alloy (LM6) is chosen as the matrix alloy with fly ash and silicon carbide particles as reinforcements. Fly ash is a waste product of power plants, which contain both hollow and cenosphere.

Chemical composition of raw fly ash

Compound	Weight percent
SiO_2	44.8
Al_2O_3	22.2
Fe_2O_3	24.0
MgO	0.9
CaO	1.8
TiO	0.8
K_2O	2.4
Na_2O	0.9
SO_3	1.4
Others	0.8

Specimens required for the wear tests were prepared by liquid metal stir casting technique into a mold of 12 mm diameter based on the design of experiments for four factor, five level, central composite method. Trials are being conducted with various μm of fly ash and silicon carbide particle and are done by sieving in sieve shaker. 2 to 10 weight percentage of fly ash and silicon carbide particles has been added to the base metal in order to prepare the specimen. Muffle furnace is used to melt the base metal at a temperature of about 700°C.Pre heated silicon carbide and fly ash are added gradually while stirring with a stirrer having 600 rpm. Magnesium is added to promote the wetting. Pin samples of diameter 10 mm and length 30 mm, machined from the middle of the composite ingots, have been used for the wear tests.
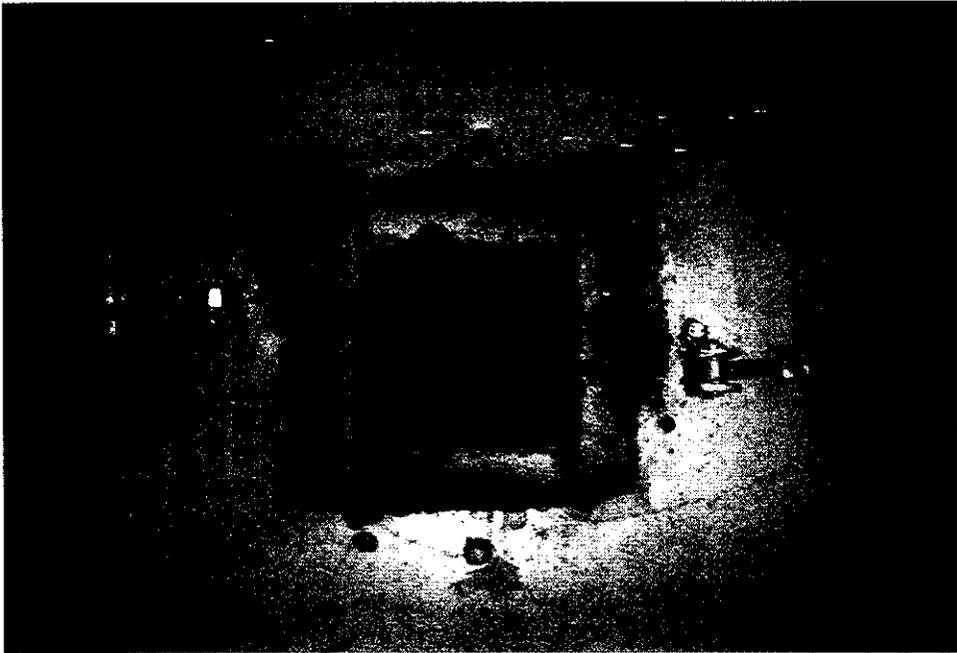
Figure 5.2:Muffle furnace

Figure 5.3: Muffle furnace with stirrer arrangement

WEAR TESTING

CHAPTER 6

WEAR TESTING

6.1 PROCEDURE TO EVALUATE DRY SLIDING WEAR

Step by step procedure used to evaluate the dry sliding wear of fly ash metal matrix composites is shown below.

```
┌──────────┐      ┌──────────┐      ┌──────────┐
│ Cast     │ ───▶ │ Machining│ ───▶ │ Surface  │
│ Specimen │      │          │      │ Preparati│
│          │      │          │      │ on       │
└──────────┘      └──────────┘      └──────────┘
                                          │
                                          ▼
┌──────────┐      ┌──────────┐      ┌──────────┐
│ Final    │ ◀─── │ Wear     │ ◀─── │ Initial  │
│ Weight   │      │ Test     │      │ Weight   │
└──────────┘      └──────────┘      └──────────┘
      │                                   │
      │          ┌──────────────┐         │
      └────────▶ │  Difference  │ ◀───────┘
                 └──────────────┘
                        │
                        ▼
                 ┌──────────────┐
                 │    Wear      │
                 └──────────────┘
```

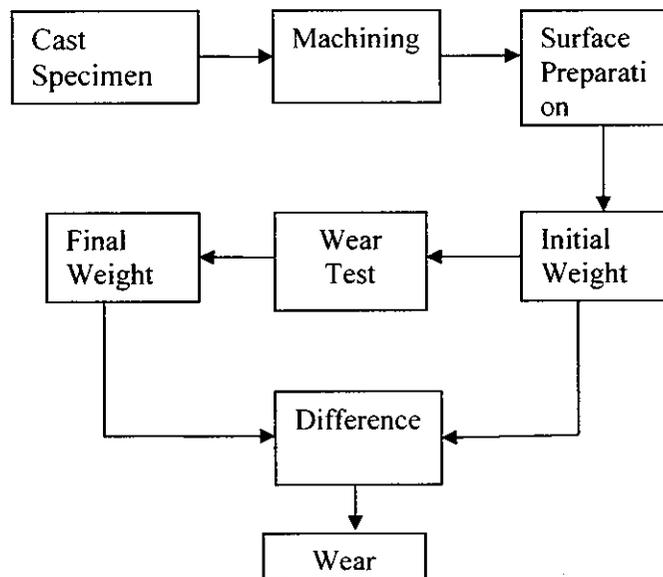**Figure 6.1 Procedure to evaluate dry sliding wear**

6.2 WEAR TESTING METHOD

The materials pin is made in the required form and this has to be fixed in to the correct position in the equipment holder mainly the pin and disk holders. Before the specimens are to be fixed up on to the holders they are to be cleaned ultrasonically and the initial weight of the pin is to be found out. The disk specimen is cleaned by

acetone so that dust and foreign particles can be removed easily. The pin should be in the firm position so that it should not be slipped due to the vertical load. After the testing has been done the samples are removed and the weight loss is measured. By comparing the initial and final weight volume of wear can be calculated.

Specific wear rate (SWR) can be calculated by the following equation:

Specific wear rate (SWR) = M/ (SL)

Where   M is the average pin weight loss measured in milligrams,
             S is total test distance determined in meter and
             L is the load given in Newton, the specific wear rate, SWR.

The coefficient of friction can estimate by the following equation

Coefficient of friction μ = T / (LR)

Where   T is the torque on the pins,
             R is the radius of the wear track,
             L is the applied load.
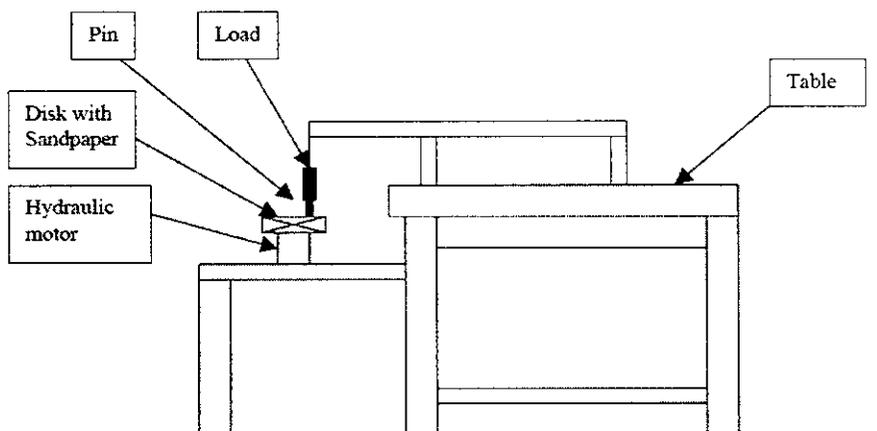
6.3 PIN-ON-DISK EXPERIMENTAL SETUP

Figure 6.2 Pin-on-disk Experimental setup

6.4 DATA ACQUISITION SYSTEM

The instrument consists of a controller with arrays of switches, electrically controlled display windows and controller knobs and buttons for setting various parameters. It permits measurement of time, RPM, wear frictional force. Pc acquires data online and displays. Acquired data can be displayed in several ways. Graphs of individual test can be printed. Results of different tests can be superimposed for comparative viewing. Data can be exported to other software

6.5 TECHNICAL DETAILS OF THE EQUIPMENT

Table 6.1 Details of the equipment

S. No.	Description	Units	Size
1	Disk diameter	mm	200
2	Disk rotation speed	Rpm	31 – 2000
3	Pin Dimensions	mm	6,8,10,12
4	Normal Load	N	5- 200
5	Test	Hrs	0-99.59.59
6	Electrical	VAC	23/1/50
7	Power	Kva	2
8	Motor	Seimens, 6 terminal1415 rpm, 15kw flange mounted

6.6 EXPERIMENTAL METHOD

The material pin is made in the required form and this has to be fixed into the correct position in the equipment holder. Before the specimens are to be fixed up on to the holders they are to be cleaned ultrasonically and the initial weight of the pin is to be found out. The disk specimen is cleaned ultrasonically by means of acetylene so that the dust and the foreign particles can be removed easily. The pin should be in the firm position so that it should not be slipped due to the vertical load. During loading see to it that in unloaded condition. After the testing has been done the samples are removed and the weight loss is measured in the specimen. By comparing the initial and the final weight difference between them. With the volume of wear calculated from the mass loss of the sample.

Figure 6.3 Wear testing on Pin-on-disk machine

The result from the wear test can be presented in three forms, the volume of the material lost due to wear, the wear rate or the wear factor. The volume of the material lost due to wear is simply the primary data from the experiment and does not account for the experimental conditions. The wear can be defined as the volume of material lost due to wear per unit of sliding distance (equation 1) and is the gradient of the wear volume versus sliding distance graph. Thus the effect of sliding distance can be removed.

$$\text{Wear rate} = \frac{\text{volume loss due to wear}}{\text{Siding distance}} \qquad \text{Equiv 1}$$

$$= \frac{mm^3}{m}$$

The wear factor as defined in equation 2, is derived from the wear rate but also accounts for he magnitude of applied load. Conventional wear theory suggests that

the wear factor is a constant for a given material combination and sliding conditions and is thus independent of the load or sliding distance.

$$\text{Wear Factor} = \frac{\text{Volume loss due to wear}}{\text{Sliding distance x Load}} \qquad \text{Equiv 2}$$

$$= \frac{mm^3}{N\,m}$$

DESIGN OF EXPERIMENTS

CHAPTER 7

DESIGN OF EXPERIMENTS

A Design of Experiment (DOE) is a structured, organized method for determining the relationship between factors (Xs) affecting a process and the output of that process (Y).

Other Definitions:

1 - Conducting and analyzing controlled tests to evaluate the factors that control the value of a parameter or group of parameters.

2- "Design of Experiments" (DOE) refers to experimental methods used to quantify indeterminate measurements of factors and interactions between factors statistically through observance of forced changes made methodically as directed by mathematically systematic tables

Design of Experiments" refers to experimental methods used to quantify indeterminate measurements of factors and interactions between factors statistically through observance of forced changes made methodically as directed by mathematically systematic tables. A Design of Experiment (DOE) is a structured, organized method for determining the relationship between factors (Xs) affecting a process and the output of that process (Y).It is used for conducting and analyzing controlled tests to evaluate the factors that control the value of a parameter or group of parameters.

7.1 IMPORTANCE OF DESIGNED TESTS

- When theory is unknown or inadequate
- When the risk is high
- There are a lot of unknowns
- For new products
- When other people are not convinced

If we can understand the underlying mechanism inherent in a system and can formulate a model between design and response variables, then we may not need a designed test. But this is usually not the case. Using DOE results in empirical models being developed which are more than adequate as replacements for theoretical models.

When the risk of making incorrect product decisions is high we need DOE. For example, when making a change to a profitable product we usually want concrete evidence that the change is for the better. Using DOE is like taking out an insurance policy against making bad product decisions.

DOE is especially useful when making decisions involving a lot of unknowns. For example, when developing a new product there are usually a lot of unknowns about how best to design the product. DOE can turn unknowns into accurate estimates of the effects of variables. Many times people involved in product development need to be convinced that a certain direction is best. These people require hard evidence on which to base decisions. They are not willing go forward on the basis of product expert's recommendations. A properly designed test will convince the skeptics of the best course of action.

7.2. CENTRAL COMPOSITE DESIGN

In statistics, a central composite design is an experimental design, useful in response surface methodology, for building a second order (quadratic) model for the response variable without needing to use a complete three-level factorial experiment.

After the designed experiment is performed, linear regression is used, sometimes iteratively, to obtain results. Coded variables are often used when constructing this design.

7.3 IMPLEMENTATION

The design consists of three distinct sets of experimental runs:

1. A factorial (perhaps fractional) design in the factors studied, each having two levels;
2. A set of *centre points*, experimental runs whose values of each factor are the medians of the values used in the factorial portion. This point is often replicated in order to improve the precision of the experiment;
3. A set of *axial points*, experimental runs identical to the centre points except for one factor, which will take on values both below and above the median of the two factorial levels, and typically both outside their range. All factors are varied in this way

7.4. DESIGN OF EXPERIMENTS PROCESS

The DOE process is divided into three main phases, which encompass all experimentation approaches. The three phases are

        (1) The planning phase,
        (2) The conducting phase, and
        (3) The analysis phase.

The planning phase is by far the most important phase for the experiment to provide the expected information. The planning phase is when factors and levels are selected and, therefore, is the most important stage of experimentation. Also, the correct selection of factors and levels is non-statistical in nature and is more dependent upon product and process expertise.

The second most important phase is the conducting phase, when test results are actually collected. If experiments are well planned and conducted, the analysis is actually much easier and more likely to yield positive information about factors and levels.

The analysis phase is when the positive or negative information concerning the selected factors and levels is generated based on the previous two phases. The analysis phase is least important in terms of whether the experiment will successfully yield positive results. This phase, however, is the most statistical in nature of the three phases of the DOE by a wide margin. Because of the heavier involvement of statistics, the analysis phase is typically the least understood by the product or process expert.

The major steps to complete an effective designed experiment are listed in the following text. The planning phase includes steps 1 through 9, the conducting phase is step 10, and the analysis phase includes steps 11 and 12.

1. State the problem(s) or area(s) of concern.
2. State the objective(s) of the experiment.
3. Select the Quality characteristic(s) and measurement system(s).
4. Select the factors that may influence the selected quality characteristics.
5. Identify limits of factors
6. Select levels for the factors.
7. Select the appropriate design
8. Select interactions that may influence the selected quality characteristics or go back to step 4 (iterative steps).
9. Assign factors to design and locate interactions.
10. Conduct tests described by trials in design.
11. Analyze and interpret results of the experimental trials.
12. Conduct confirmation experiment.

These steps are fundamentally the same regardless of whether one is designing a Taguchi-based experiment or a classical design. All designed experiments require that a certain number of combinations of factors and levels be tested to observe the results of those test conditions. Two or more passes through the process are often utilized; earlier rounds of experimentation provide a growth of knowledge and a basis for later rounds of experimentation.

7.5. RESPONSE SURFACE METHODOLOGY

Experimentation and making inferences are the twin features of general scientific methodology. Statistics as a scientific discipline is mainly designed to achieve these objectives. Planning of experiments is particularly very useful in deriving clear and accurate conclusions from the experimental observations, on the basis of which inferences can be made in the best possible manner. The methodology for making inferences has three main aspects. First, it establishes methods for drawing inferences from observations when these are not exact but subject to variation, because inferences are not exact but probabilistic in nature. Second, it specifies methods for collection of data appropriately, so that assumptions for the application of appropriate statistical methods to them are satisfied.

7.6 ADVANTAGES OF DOE

1. DOE eliminates the 'confounding of effects' whereby the effects of design variables are mixed up. Confounding of effects means we can't correlate product changes with product characteristics.

2. DOE helps us handle experimental error. Any data point may contain bad data, i.e.

   - Experimental Error
   - The effects of variation in:
   - Raw Materials
   - Test Instruments

- Machine Operators

3. DOE helps us determine the important variables that need to be controlled.

4. DOE helps us find the unimportant variables that may not need to be controlled.

5. DOE helps us measure interactions, which is very important

METHODOLOGY

CHAPTER 8

METHODOLOGY

8.1 EXPERIMENTAL DESIGN PROCEDURE

The experimental design procedure used for this study is briefly explained below.

8.1.1 IDENTIFYING THE IMPORTANT FUNCTION CONTROL VARIABLES.

Among the many independently controllable process parameters affecting the wear characteristics of metal matrix composites, fly ash % (F), Sic % (S), fly ash grain size (F_g) and SiC grain size (S_g) are selected as factors to carry out the experimental works and the development of mathematical models.

The working ranges of all process variables selected had to be determined to fix their levels and to develop the design matrix. This is achieved with the assistance of trial runs carried out by varying one of the process variables while keeping the rest of them at constant value. A large number of trial runs have been conducted. In conducting the experiment, the upper limit of a factor was coded as +2 and the lower limit as −2, the coded values for intermediate values were calculated from the following relationship

$$X_i = \frac{2(2X-(X_{max}+X_{min}))}{(X_{max}-X_{min})} \quad 8.1$$

Where X_i is the required coded value of a variable X, X is any value of the variable from X_{min} to X_{max}, X_{min} is the lower limit of the variable and X_{max} is the upper limit of the variable. The coded values for intermediate values have been calculated using

equation 8.1. The selected process parameters of the experiment, with their limits, units and notations are given in Table 8.1.

Table 8.1 Limits of Process parameters

Parameter	Units	Notation	Factor Levels				
			-2	-1	0	+1	+2
Fly ash	%	F	2	4	6	8	10
Sic	%	S	2	4	6	8	10
Fly ash Grain size	μm	F_g	0-40	40 - 106	106 -150	150-180	180 - 250
SiC Grain Size	μm	S_g	0-25	25 - 40	40 - 63	63 - 90	90 -106

8.1.2 DEVELOPMENT OF DESIGN MATRIX

In factorial design, the experiments are conducted for all possible combinations of the parameter levels and these combinations written in the form of a table where the rows correspond to different trials and the columns to the levels of the parameters, form a design matrix. The design matrix selected for experiment is a four factor five level central composite rotatable design consisting of 31 sets of coded conditions.

All process parameter variables at the intermediate (0) level constitute the centre points and the combinations of each of the process parameter variables at either its lowest (−2) or highest (+2) with two other variables of the intermediate levels constitute the star points. The design matrix has allowed the estimation of linear, quadratic and two-way interactive effects of the selected process parameter variables on the wear characteristics. Table 8.2 shows the design matrix.

Table 8.2 Design matrix and response

Design matrix value and responses (four factors, five levels)					
Design of matrix					**Response**
Trial no	F_g	S_g	**F**	**S**	
1	-1	-1	-1	-1	20.4
2	+1	-1	-1	-1	24.4
3	-1	+1	-1	-1	19.3
4	+1	+1	-1	-1	25.6
5	-1	-1	+1	-1	24
6	+1	-1	+1	-1	32
7	-1	+1	+1	-1	18.2
8	+1	+1	+1	-1	30
9	-1	-1	-1	+1	26
10	+1	-1	-1	+1	27.6
11	-1	+1	-1	+1	25.1
12	+1	+1	-1	+1	29
13	-1	-1	+1	+1	36
14	-1	+1	+1	+1	33.5
15	+1	-1	+1	+1	40
16	+1	+1	+1	+1	38.2
17	-2	0	0	0	24.2
18	+2	0	0	0	34
19	0	-2	0	0	25.2
20	0	+2	0	0	21.6
21	0	0	-2	0	21.1
22	0	0	+2	0	35
23	0	0	0	-2	22.14
24	0	0	0	+2	38.6
25	0	0	0	0	21
26	0	0	0	0	21.1
27	0	0	0	0	19.5
28	0	0	0	0	20
29	0	0	0	0	19.5
30	0	0	0	0	19.7
31	0	0	0	0	20

F_g, Fly ash grain size; S_g, Silicon carbide; F, Fly ash %; S, Silicon carbide%

8.1.3 EVALUATION OF REGRESSION COEFFICIENTS AND DEVELOPMENT OF MATHEMATICAL MODEL.

The response function representing any function can be expressed as

$$Y = f(X1, X_2, X_3, X_4)$$

Where Y = Wear (W) in mg, X_1= Fly ash grain size (F_g) in microns, X_2=Silicon carbide grain size (S_g) in microns ^0C, X_3=Fly ash (F) in %, X_4 = Silicon carbide (S) in %

The second order response surface model for the four selected factors is given by the equation

$$Y = \beta_0 + \sum_{i=1} \beta_i X_i + \sum_{i=1} \beta_{ii} X_i^2 + \sum_{i<j} \beta_{ij} X_i X_j$$

The response function representing wear can be expressed as $w = f(F, S, F_g, S_g)$ and the relationship selected being a second order response surface. The function is as follows

$$W = B_0 + B_1 F_g + B_2 Sg + B_3 F + B_4 S + B_{11} F_g^2 + B_{22} Sg^2 + B_{33}F^2 + B_{44} S^2 + B_{12} F_g Sg + B_{13} F_g F + B_{14} F_g S + B_{23} SgF + B_{24} Sg S + B_{34} F S$$

Where the coefficients B_1, B_2, B_3, $B_4$are linear terms and B_{11}, B_{22}, B_{33}, B_{44} are second order terms and B_{12}, B_{13}, B_{14}, B_{23}, B_{24}, B34 are the interaction terms.Quality America – DOE PC IV, software package was used to calculate these coefficients. The mathematical model developed is as below

$$W = 20.114 + 2.663 F_g - 0.779 Sg + 3.429 F + 3.934 S + 2.305 F_g^2 + 0.880 Sg^2 + 2.042 F^2 + 2.622 S^2 + 0.569 F_g Sg + 0.794 F_g F - 0.994 F_g S - 0.794 SgF + 0.244 Sg S + 1.594 F S$$

OPTIMIZATION OF COMPOSITION BASED ON THE WEAR RESISTANCE

CHAPTER 9

OPTIMIZATION OF COMPOSITION BASED ON THE WEAR RESISTANCE

9.1 SYSTAT- INTRODUCTION

SYSTAT is a comprehensive, general purpose, easy to use, and highly integrated statistical software package most popularly used from microcomputers. SYSTAT includes basic Statistics (e.g., descriptive Statistics, frequencies, cross tabs, correlations) and advanced statistics (e.g., regression, ANOVA, MANOVA, factor analysis, cluster analysis, discriminant analysis, and time series). SYSTAT has an excellent graphics interface for data visualization, is quick and easy to use for exploratory work, and has extensive options for Presentation graphics.

SYSTAT offers a large number of scientific and technical graphing options and a great deal of interactivity for a desktop statistics package. Compare subgroups, overlay charts, transform coordinates, and add geographic projections, change colors, symbols and more to create insightful presentations. Change graph locations, point-and-click to alter axis labels, scales, colors and symbols. Create unique graphs that bring out the true meaning in your data with advanced chart options including normal and kernel densities, multiplots, maps, Voronoi tessellations, function plots, contours, scatter plot matrices with 20 diagonal density choices and 126 non-parametric smoothing options, just to name a few. Analysis can be done at a faster rate by rotating your 3-D graphs to visually determine the perfect power or log transformation to normalize your data using the Dynamic Explorer. Create insightful

presentations with advanced chart types such as maps, multiplots and kernel densities. Analysis with SYSTAT's interactive graphic tools is really interesting.

Thus by using SYSTAT a final graphical surface generation can be done for which a program has to be written and fed into the SYSTAT software, for which ANOVA regression is done and the equations are generated. These equations are used in a program written for SYSTAT. The program is similar to a normal program written for a CNC machine or a numerical controlled machine but it involves expressions and parameters like fplot, facet, zlab, xcuy, zmin, facet and many others. ANOVA regression plays a major role in the generation of an equation, program and thereby helps in surface generation.

9.2 SYSTAT SOFTWARE

SYSTAT 10.2 is one of the most powerful statistical and graphical analysis packages now on the market. SYSTAT is a comprehensive statistical software package for analyzing data and presenting results. It is set up in a graphical environment and most commands can be executed by using menus and selecting options in dialog boxes. While some may think Microsoft's Excel provides all the data graphing capabilities they will ever need, many computer users regularly need more powerful statistical analysis capability than is built into Excel. Businesses with a major commitment to quality control and continuous improvement require constant sampling of their product specifications to produce data that must be diligently managed by a team of engineers and other staff with the technical skills and knowledge to accurately perform these tests and correctly interpret the results. A spreadsheet alone cannot meet the needs of these professionals. Instead, they turn to highly specialized, powerful statistical analysis packages.

Professionals involved in medical research also need such powerful software to handle the research tools and techniques that are essential in being able to make carefully reasoned decisions based on data produced in their testing processes. In addition, higher level students will likely find themselves regularly involved in the

design and implementation of research projects, and they too need SYSTAT to help them with the important statistical analysis of the results of the data gathering phase of their project. This analysis of research data is a good example of how important it is to integrate specialized statistical analysis software programs in these organizations and for these purposes. This is where the SYSTAT 10.2 program will provide the quality tool needed by these sophisticated computer users.

9.3 FEATURES OF SYSTAT

- Increases analytical power
- Meaningful results with less effort
- Complete automation of analysis
- More Graphical features
- Less effort

9.4 OPTIMIZATION USING SYSTAT

Optimization of Fly ash metal matrix composites is done using SYSTAT software.

9.4.1 Interactive Effect of fly ash grain size and fly ash percentage on wear While Keeping silicon carbide percentage and grain size Constant

The program for generating the response surface of fly ash grain size and fly ash percentage is given below.

```
PROGRAM:
EYE -6,-8, 6
BEGIN
FACET XY
FPLOT Z=20.114+2.663*X-0.779*-2+3.429*Y+3.934*-2+2.305*X*X+0.880*-2*-
2+2.042*Y*Y+2.622*-2*-2+0.569*X*-2+0.794*X*Y-0.994*X*-2-0.794*-
2*Y+0.244*-2*-2+1.594*Y*-2;,CONTOUR,SURFACE=XYCUT
CUT=8,ZTICK=8,XPIP=5,YPIP=5,XLAB=" , YLAB=" , ZLAB=",
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*X-
0.779*0+3.429*Y+3.934*0+2.305*X*X+0.880*0*0+2.042*Y*Y+2.622*0*0+0.569
*X*0+0.794*X*Y-0.994*X*0-
0.794*0*Y+0.244*0*0+1.594*Y*0;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB='Fly ash grain sizeµm' ,  YLAB='Fly ash %' ,
ZLAB='Wear',
ZMIN=15,ZMAX=40,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*X-
0.779*2+3.429*Y+3.934*2+2.305*X*X+0.880*2*2+2.042*Y*Y+2.622*2*2+0.569
*X*2+0.794*X*Y-0.994*X*2-
0.794*2*Y+0.244*2*2+1.594*Y*2;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB=" , YLAB=" , ZLAB=",
ZMIN=15,ZMAX=40,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


END
```
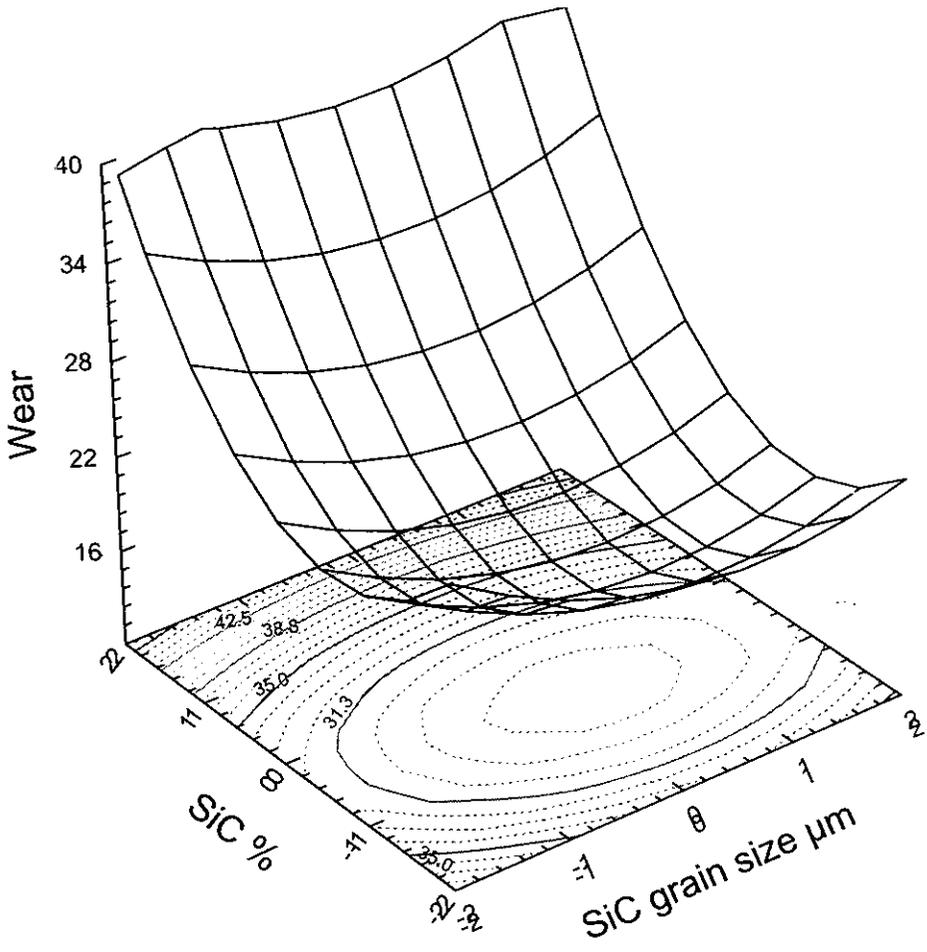
FIGURE 9.1 Interactive Graphs of fly ash grain size and fly ash percentage

9.4.2 Interactive Effect of silicon carbide grain size and silicon carbide percentage on wear while Keeping fly ash percentage and grain size Constant

The program for generating the response surface of silicon carbide grain size and silicon carbide percentage is given below.

PROGRAM:

```
EYE -6,-8, 6
BEGIN
FACET XY
FPLOT Z=20.114+2.663*-2-0.779*X+3.429*-2+3.934*Y+2.305*-2*-
2+0.880*X*X+2.042*-2*-2+2.622*Y*Y+0.569*-2*X+0.794*-2*-2-0.994*-2*Y-
0.794*X*-2+0.244*X*Y+1.594*-2*Y;,CONTOUR,SURFACE=XYCUT
CUT=8,ZTICK=8,XPIP=5,YPIP=5,XLAB=", YLAB=", ZLAB=",
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2
END

FACET
FPLOT Z=20.114+2.663*0-
0.779*X+3.429*0+3.934*Y+2.305*0*0+0.880*X*X+2.042*0*0+2.622*Y*Y+0.569
*0*X+0.794*0*0-0.994*0*Y-
0.794*X*0+0.244*X*Y+1.594*0*Y;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB='SiC grain size µm', YLAB='SiC %',
ZLAB='Wear',
ZMIN=10,ZMAX=45,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2

FACET
FPLOT Z=20.114+2.663*2-
0.779*X+3.429*2+3.934*Y+2.305*2*2+0.880*X*X+2.042*2*2+2.622*Y*Y+0.569
*2*X+0.794*2*2-0.994*2*Y-
0.794*X*2+0.244*X*Y+1.594*2*Y;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB=", YLAB=", ZLAB=",
ZMIN=10,ZMAX=45,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


END
```

FIGURE 9.2 Interactive Graphs of silicon carbide percentage and silicon carbide grain size

9.4.3 Interactive Effect of fly ash percentage and silicon carbide percentage on wear while keeping fly ash and silicon carbide grain size Constant

The program for generating the response surface of fly ash percentage and silicon carbide percentage is given below.

PROGRAM:

```
EYE -6,-8, 6
BEGIN
FACET XY
FPLOT Z=20.114+2.663*-2-0.779*-2+3.429*X+3.934*Y+2.305*-2*-2+0.880*-2*-
2+2.042*X*X+2.622*Y*Y+0.569*-2*-2+0.794*-2*X-0.994*-2*Y-0.794*-
2*X+0.244*-2*Y+1.594*X*Y;,CONTOUR,SURFACE=XYCUT
CUT=8,ZTICK=8,XPIP=5,YPIP=5,XLAB=" , YLAB=" , ZLAB=",
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*0-
0.779*0+3.429*X+3.934*Y+2.305*0*0+0.880*0*0+2.042*X*X+2.622*Y*Y+0.569
*0*0+0.794*0*X-0.994*0*Y-
0.794*0*X+0.244*0*Y+1.594*X*Y;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,   XLAB='Fly ash %' , YLAB='SiC %' , ZLAB='Wear',
ZMIN=15,ZMAX=40,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2

FACET
FPLOT Z=20.114+2.663*2-
0.779*2+3.429*X+3.934*Y+2.305*2*2+0.880*2*2+2.042*X*X+2.622*Y*Y+0.569
*2*2+0.794*2*X-0.994*2*Y-
0.794*2*X+0.244*2*Y+1.594*X*Y;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,   XLAB=" , YLAB=" , ZLAB=",
ZMIN=15,ZMAX=40,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2

END
```
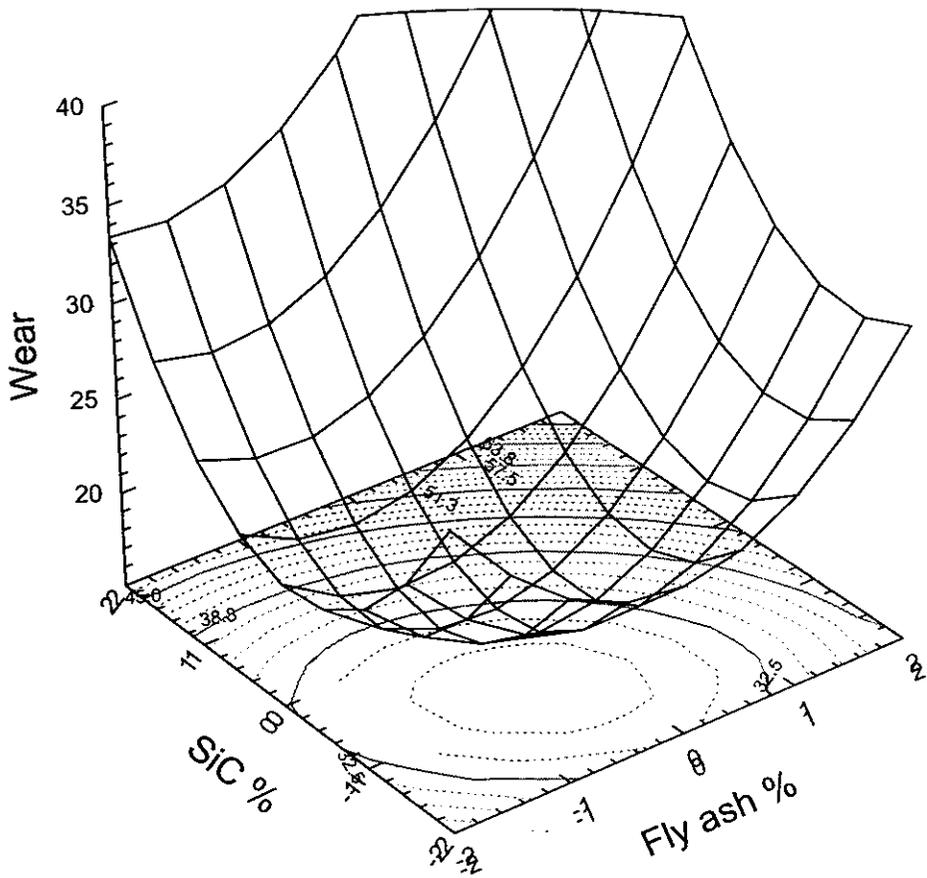
FIGURE 9.3 Interactive Graphs of silicon carbide percentage and fly ash percentage

9.4.4 Interactive Effect of fly ash grain size and silicon carbide grain size percentage on wear while keeping fly ash percentage and silicon carbide percentage Constant
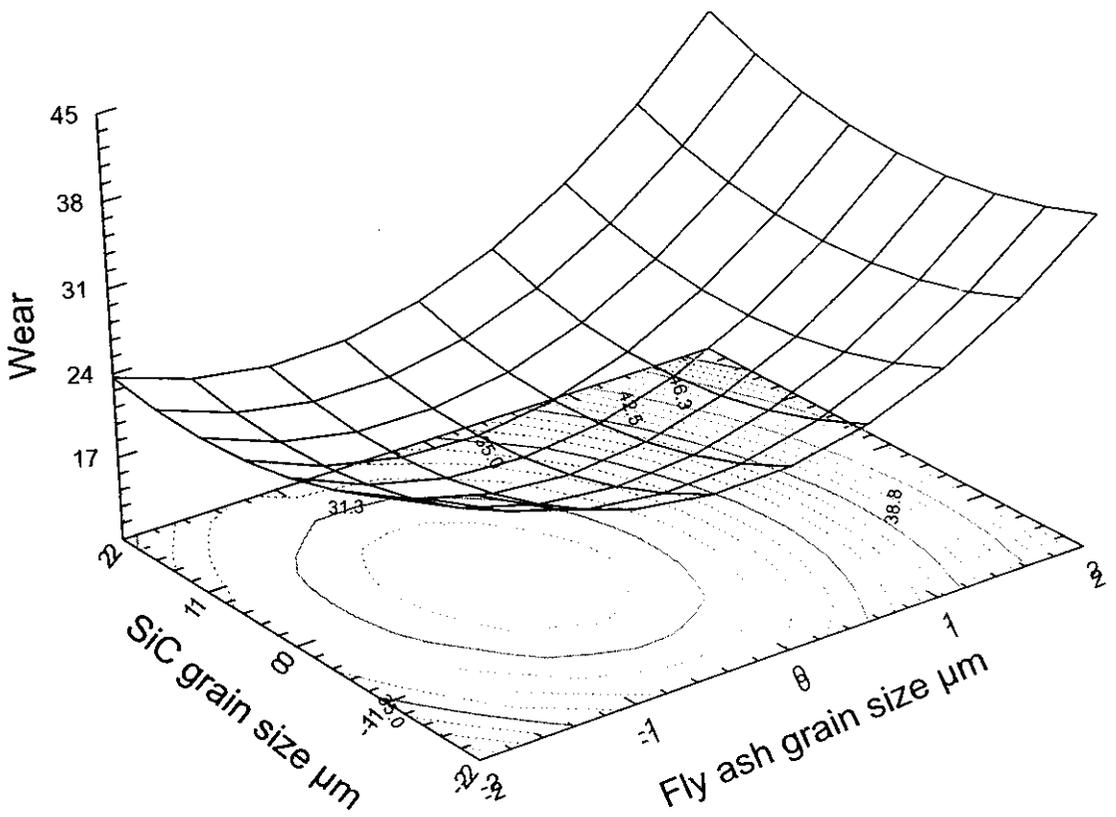
The program for generating the response surface of fly ash grain size and silicon carbide grain size is given below.

```
PROGRAM:
EYE -6,-8, 6
BEGIN
FACET XY
FPLOT Z=20.114+2.663*X-0.779*Y+3.429*-2+3.934*-
2+2.305*X*X+0.880*Y*Y+2.042*-2*-2+2.622*-2*-2+0.569*X*Y+0.794*X*-2-
0.994*X*-2-0.794*Y*-2+0.244*Y*-2+1.594*-2*-
2;,CONTOUR,SURFACE=XYCUT CUT=8,ZTICK=8,XPIP=5,YPIP=5,XLAB=" ,
YLAB=" , ZLAB=",
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*X-
0.779*Y+3.429*0+3.934*0+2.305*X*X+0.880*Y*Y+2.042*0*0+2.622*0*0+0.569
*X*Y+0.794*X*0-0.994*X*0-
0.794*Y*0+0.244*Y*0+1.594*0*0;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,   XLAB='Fly ash grain size μm' ,  YLAB='SiC grain size
μm' , ZLAB='Wear',
ZMIN=10,ZMAX=45,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2

FACET
FPLOT Z=20.114+2.663*X-                         ---
0.779*Y+3.429*2+3.934*2+2.305*X*X+0.880*Y*Y+2.042*2*2+2.622*2*2+0.569
*X*Y+0.794*X*2-0.994*X*2-
0.794*Y*2+0.244*Y*2+1.594*2*2;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,   XLAB=" , YLAB=" , ZLAB=".
ZMIN=10,ZMAX=45,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2

END
```
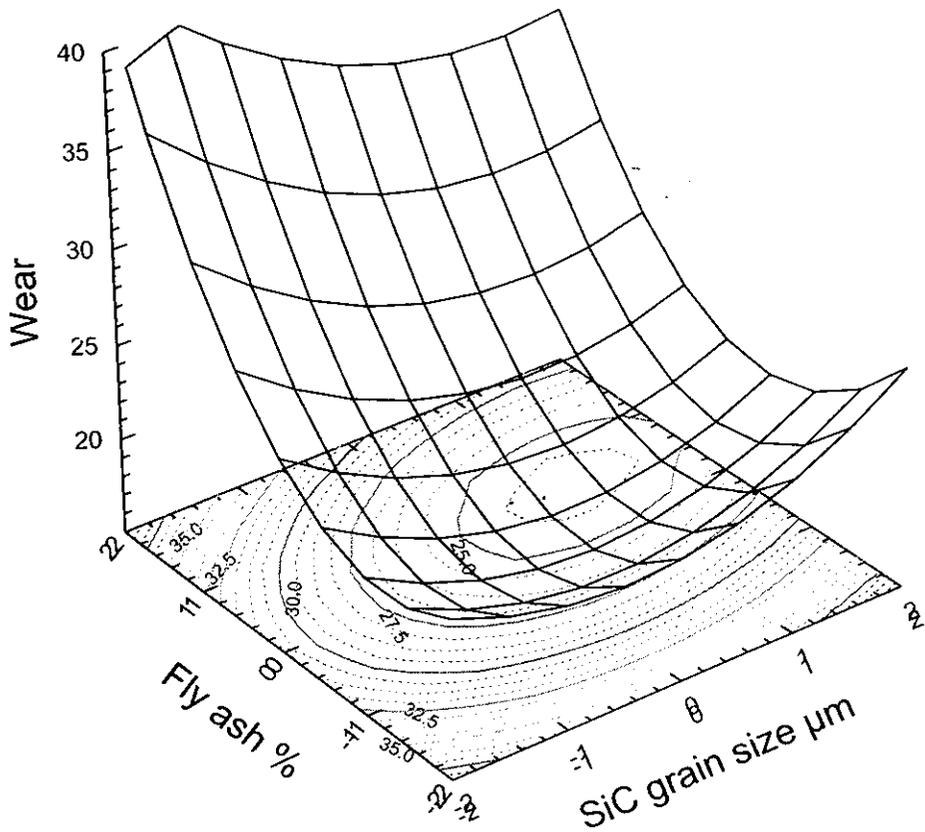
FIGURE 9.4 Interactive Graphs of fly silicon carbide grain size and fly ash grain size

9.4.5 Interactive Effect of Silicon Carbide grain size and Fly ash percentage on wear while keeping silicon carbide percentage and fly ash grain size Constant

The program for generating the response surface of fly ash grain size and silicon carbide grain size is given below

```
PROGRAM
EYE -6,-8, 6
BEGIN
FACET XY
FPLOT Z=20.114+2.663*-2-0.779*X+3.429*Y+3.934*-2+2.305*-2*-
2+0.880*X*X+2.042*Y*Y+2.622*-2*-2+0.569*-2*-2+0.794*-2*Y-0.994*-2*-2-
0.794*X*Y+0.244*X*-2+1.594*Y*-2;,CONTOUR,SURFACE=XYCUT
CUT=8,ZTICK=8,XPIP=5,YPIP=5,XLAB=" , YLAB=" , ZLAB=",
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*0-
0.779*X+3.429*Y+3.934*0+2.305*0*0+0.880*X*X+2.042*Y*Y+2.622*0*0+0.569
*0*0+0.794*0*Y-0.994*0*0-
0.794*X*Y+0.244*X*0+1.594*Y*0;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB='SiC grain size µm' , YLAB='Fly ash %' ,
ZLAB='Wear',
ZMIN=15,ZMAX=40,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*2-
0.779*X+3.429*Y+3.934*2+2.305*2*2+0.880*X*X+2.042*Y*Y+2.622*2*2+0.569
*2*2+0.794*2*Y-0.994*2*2-
0.794*X*Y+0.244*X*2+1.594*Y*2;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB=" , YLAB=" , ZLAB=",
ZMIN=10,ZMAX=40
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


END
```

FIGURE 9.5 Interactive Graphs of fly ash percentage and silicon carbide grain size

9.4.6 Interactive Effect of fly ash grain size and silicon carbide percentage on wear while keeping fly ash percentage and silicon carbide grain size Constant

The program for generating the response surface of fly ash grain size and silicon carbide percentage is given below

PROGRAM

```
EYE -6,-8, 6
BEGIN
FACET XY
FPLOT Z=20.114+2.663*X-0.779*-2+3.429*-2+3.934*Y+2.305*X*X+0.880*-2*-
2+2.042*-2*-2+2.622*Y*Y+0.569*X*-2+0.794*X*-2-0.994*X*Y-0.794*-2*-
2+0.244*-2*Y+1.594*-2*Y;,CONTOUR,SURFACE=XYCUT
CUT=8,ZTICK=8,XPIP=5,YPIP=5,XLAB=" , YLAB=" , ZLAB=".
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*X-
0.779*0+3.429*0+3.934*Y+2.305*X*X+0.880*0*0+2.042*0*0+2.622*Y*Y+0.569
*X*0+0.794*X*0-0.994*X*Y-
0.794*0*0+0.244*0*Y+1.594*0*Y;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB='Fly ash grain sizeµm' , YLAB='SiC %' ,
ZLAB='Wear',
ZMIN=15,ZMAX=40,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


FACET
FPLOT Z=20.114+2.663*X-
0.779*2+3.429*2+3.934*Y+2.305*X*X+0.880*2*2+2.042*2*2+2.622*Y*Y+0.569
*X*2+0.794*X*2-0.994*X*Y-
0.794*2*2+0.244*2*Y+1.594*2*Y;,SURFACE=XYCUT
CUT=8,ZTICK=5,ZPIP=5,  XLAB=" , YLAB=" , ZLAB=".
ZMIN=15,ZMAX=40,
XMIN=-2,XMAX=2,
YMIN=-2,YMAX=2


END
```
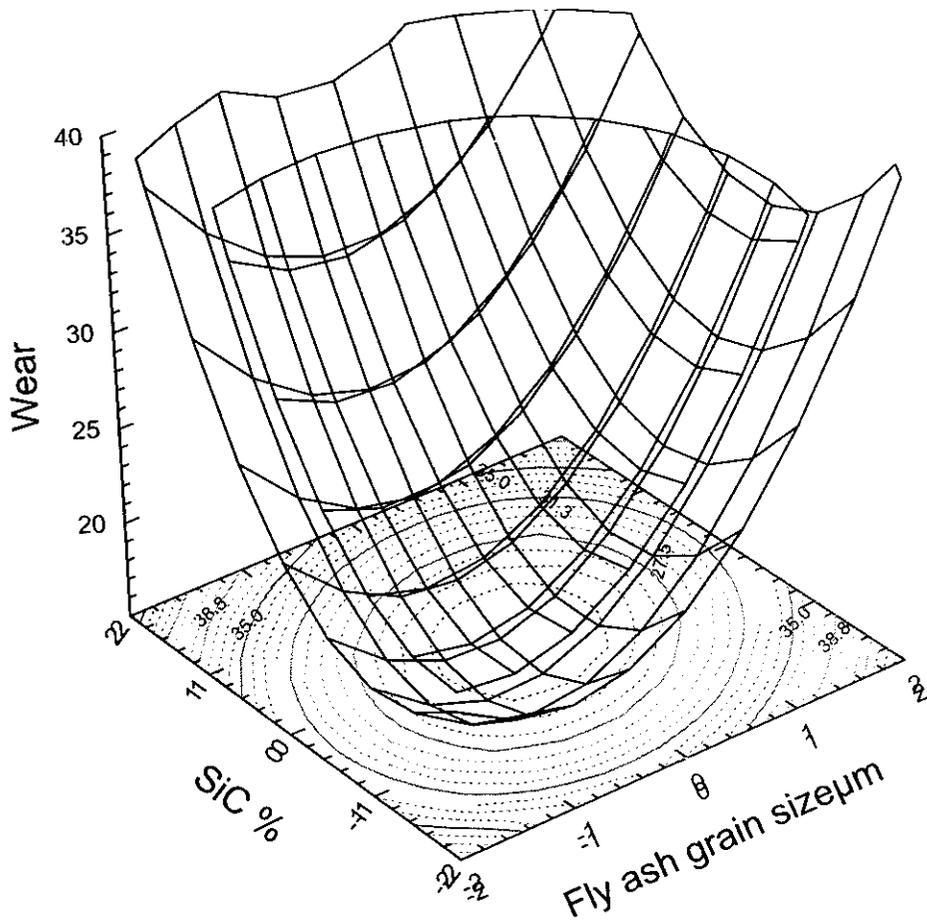
FIGURE 9.6 Interactive Graphs of silicon carbide percentage and fly ash grain size

Interactive graph of (F and F_g), (S and S_g), (S and F), (F_g and S_g) (S_g and F), (F_g and S) on wear is shown above. It shows the effect of various parameters (Fly ash %, Silicon carbide %, Fly ash grain size and Silicon carbide grain size) on wear characteristics.

# RESULTS AND DISCUSSIONS

CHAPTER 10

RESULTS AND DISCUSSIONS

10.1 COMPARISON OF EXPERIMENTAL AND CALCULATED WEAR

The below tabulations (table 10.1) describes the percentage deviations of wear from actual to theoretical and the deviations falls with in the limit of 95% confidence level. Also the comparison of wear is shown in the figure 10.1

Table 10.1 Comparison of experimental and calculated wear

S. No	Wear		Percentage error (%)
	Experimental	Calculated	
1	20.4	20.129	-1.29918
2	24.4	24.717	3.974093
3	19.3	18.533	0.792969
4	25.6	25.397	0.8375
5	24	23.799	1.365625
6	32	31.563	-4.54396
7	18.2	19.027	3.11
8	30	29.067	-1.18846
9	26	26.309	2.460145
10	27.6	26.921	-2.34661
11	25.1	25.689	1.458621
12	29	28.577	-0.98611

| S. No	Wear		Percentage error (%)
	Experimental	Calculated	
13	36	36.355	2.808955
14	33.5	32.559	-0.3575
15	40	40.143	-1.10733
16	38.2	38.623	0.793388
17	24.2	24.008	-1.94118
18	34	34.66	0.031746
19	25.2	25.192	-2.2037
20	21.6	22.076	-1.53555
21	21.1	21.424	-0.4
22	35	35.14	-2.68293
23	22.14	22.734	0.336788
24	38.6	38.47	4.219048
25	21	20.114	4.672986
26	21.1	20.114	-3.14872
27	20.4	20.129	1.328431
28	24.4	24.717	-1.29918
29	19.3	18.533	3.974093
30	25.6	25.397	0.792969
31	24	23.799	0.8375
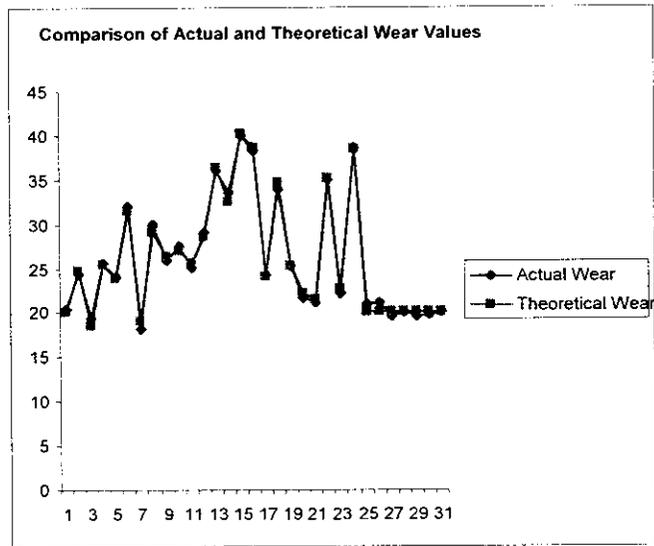
Figure 10.1 Comparison of Wear values

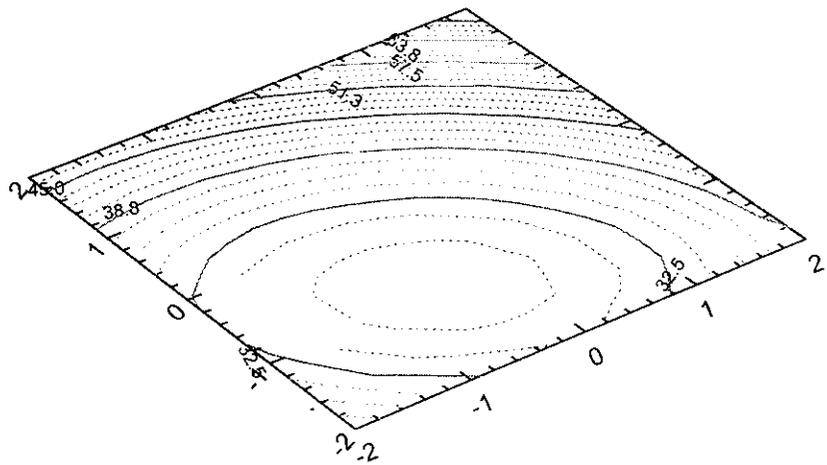## 10.2 INTERACTIVE EFFECTS ON WEAR

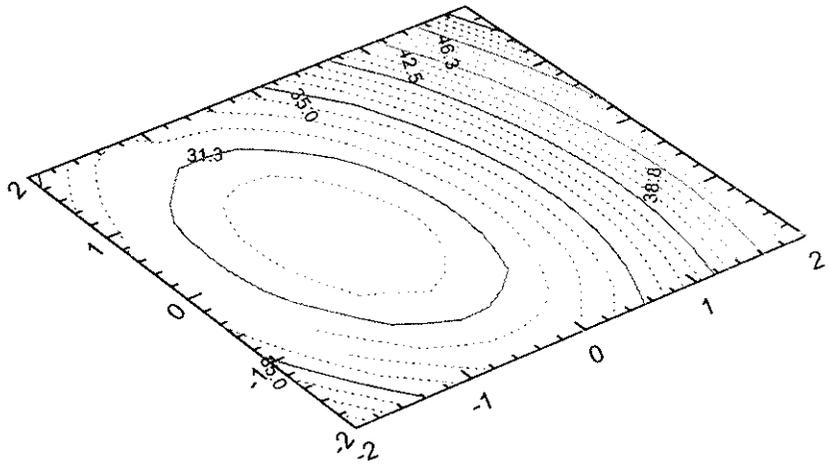Interactive effects of various parameters on wear is shown below
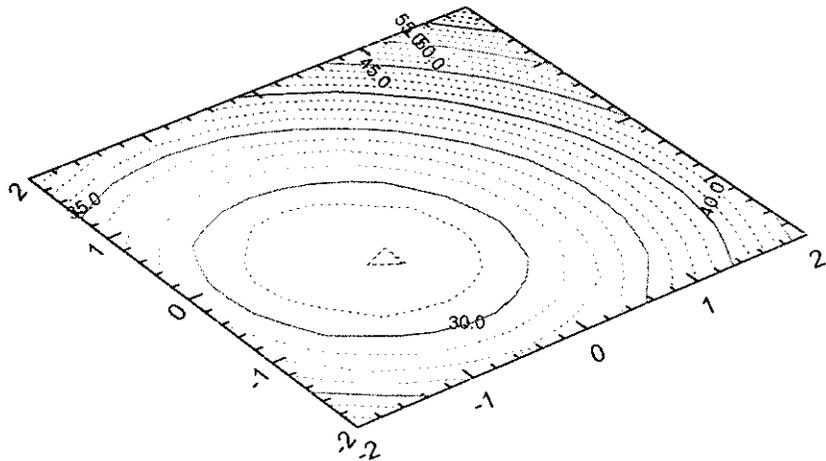
Figure 10.2 Interactive effects of fly ash grain size and fly ash percentage
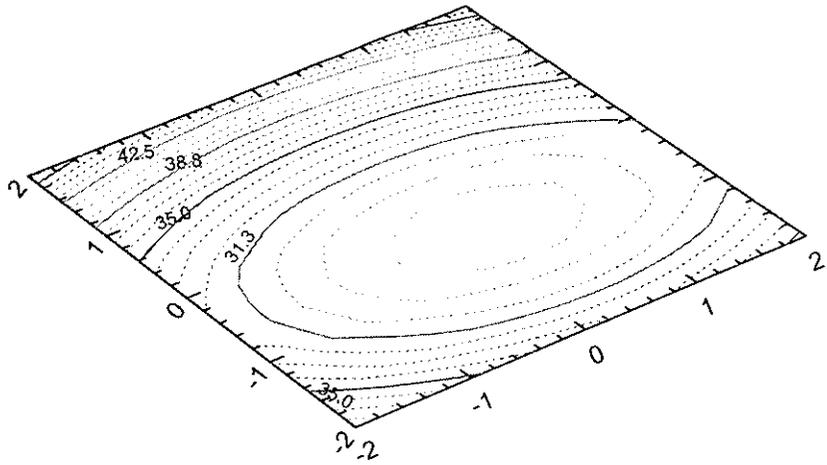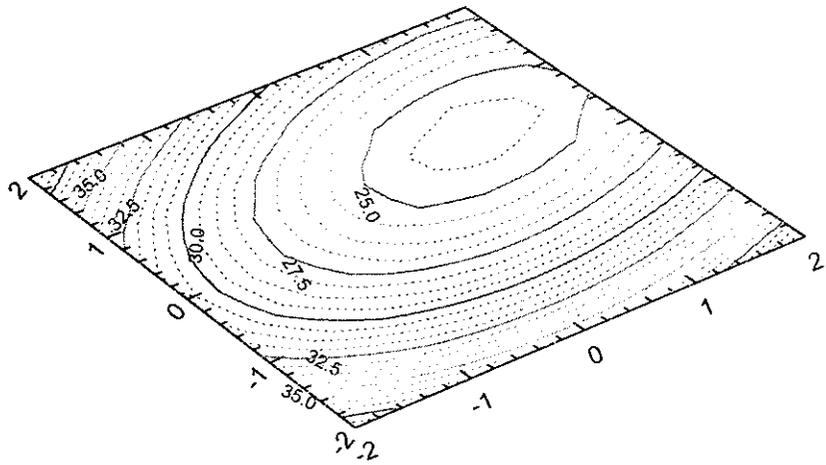
Figure 10.3 Interactive effects of silicon carbide percentage and silicon carbide grain size
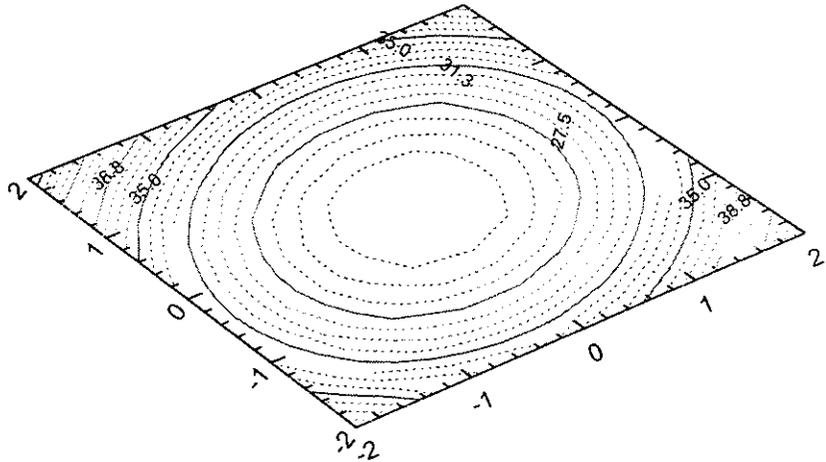

Figure 10.4 Interactive effects of silicon carbide percentage and fly ash percentage

Figure 10.5 Interactive effects of fly silicon carbide grain size and fly ash grain size

Figure 10.6 Interactive effects of fly ash percentage and silicon carbide grain size

Figure 10.7 Interactive effects of silicon carbide percentage and fly ash grain size

From the contour surface, the wear is minimum when the four parameters are at the middle level (0). Further increases or decreases from that level, wear gradually increases

CONCLUSION

CHAPTER 11

CONCLUSION

To study the wear characteristics of the fly ash metal matrix composites, composite material has been developed by using liquid metal stir casting technique based on design of experiments and are machined as per ASTM standards.

Wear resistance have been improved in the fabricated composite material when compared to the aluminium alloy

The result analysis shows that the sample which has the composition of

Fly ash grain size 40 – 106 µm

Silicon carbide grain size 63 – 90 µm

Fly ash 4%

Silicon carbide 4 %

has less wear when compared with other sample.

The experiments were conducted as per the design matrix using Design of Experiments (DOE). Mathematical model was generated using the Quality America software to analyze the wear for the input parameters fly ash %.Silicon carbide %, Fly ash grain size and silicon carbide grain size. The mathematical model developed is useful to predict the wear characteristics of metal matrix composites. The calculated wear is compared with the experimental wear and the deviations falls with in the limit of 95% confidence level.

The optimization of the composite material is done using SYSTAT software. The interactive effects of (F and F_g), (S and S_g), (S and F), (F_g and S_g) (S_g and F), (F_g and S) on wear is analyzed. It can be concluded that the minimum wear is obtained when the fly ash grain size and silicon carbide percentage is constant with varying fly ash percentage and silicon carbide grain size.

SCOPE FOR FUTURE WORK

CHAPTER 12

SCOPE FOR FUTURE WORK

In this work the material samples have been prepared using liquid metal stir casting technique. This work can be further extended by preparing the material samples using Modified compocasting cum squeeze casting route and the characteristics of the material can be studied to know the merits of the process.

This work can be extended by studying the characterization of the material using scanning electron microscopy analysis to know the dispersion pattern of the material samples and hence the effectiveness of the process can also be predicted.
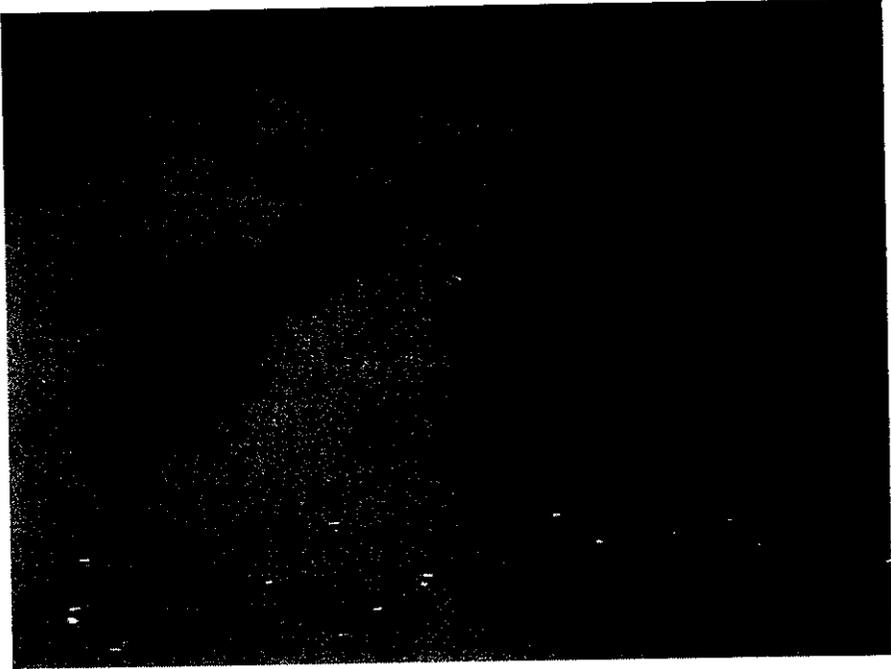
These material samples can be further subjected to thermal analysis hence the properties of these composite material can be studied.
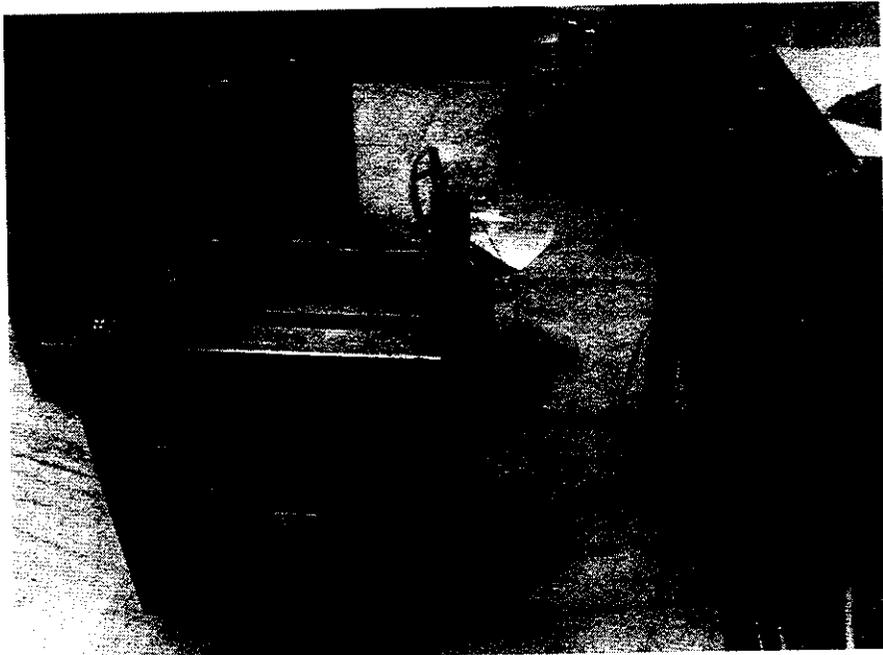
APPENDIX

APPENDIX A

Wear Samples

Experimental Setup Used For Wear Test

REFERENCE

REFERENCES

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