EFFECT ON TRIBOLOGICAL PROPERTIES OWING TO INCLUSION OF SiC/Al2O3 REINFORCEMENTS IN Al-6061

A project report submitted in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the project report entitled "**EFFECCT ON TRIBOLOGICAL PROPERTIES OWING TO INCLUSION OF SiC/Al2O3 REINFORCEMENTS IN Al-6061**" has been carried out by **BUDIDA PAVAN KUMAR (318126520126), RONGALI YERNAIDU(319126520L25), MANDAPATI UGENDRA VARMA (319126520L27), AKULA LOKESHWAR (318126520117), VECHALAPU MOUNIKA (318126520169)** under the esteemed guidance of **Mrs. P.RAMYA**, in partial fulfilment of the requirements for the award of the Degree of Bachelor of Technology in Mechanical Engineering by Anil Neerukonda Institute Of Technology & Sciences(A), Visakhapatnam.

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ABSTRACT

In comparison to the base alloys, aluminium-based hybrid matrix composites(HMMC's) have superior wear resistance, strength-to-weight ratio, and tribological properties. They are used in a variety of industries, including automotive, aerospace and heavy machineries. The stir casting process can be used to overcome problems in composite manufacturing, such as high manufacturing costs, poor machinability and non-uniform reinforcement distribution in the matrix. The stir casting process was used to prepare an Al-6061/SiC/Al2O3 hybrid composite and various tribological properties were examined at varied loads velocities and other conditions in this study. The inclusions of reinforcements improved the base aluminium's tribological capabilities, according to the results.

Keywords:- Al-6061 hybrid metal matrix composite, Silicon Carbide(SiC), Aluminium Oxide(Al2O3), Wear performance characteristics.

1 INTRODUCTION

1.1 WHAT IS A COMPOSITE:

A composite material (also called a composition material or shortened to composite, which is the common name) is a material which is produced from two or more constituent materials. These constituent materials have notably dissimilar chemical or physical properties and are merged to create a material with properties unlike the individual elements. Within the finished structure, the individual elements remain separate and distinct, distinguishing composites from mixtures and solid solutions.

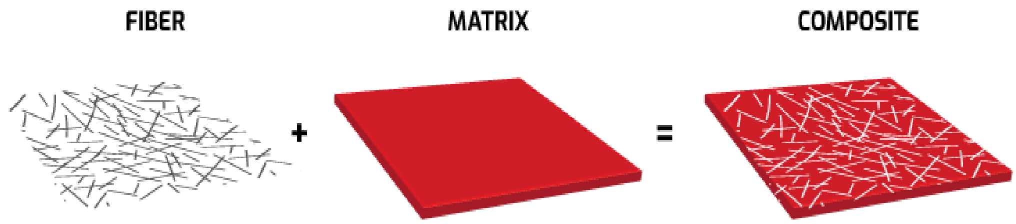

Fig 1.1 COMPOSITES

1.2 HISTORY OF COMPOSITE:

The earliest composite materials were made from straw and mud combined to form bricks for building construction. Ancient brickmaking was documented by Egyptian tomb paintings.

Wattle and daub are one of the oldest composite materials, at over 6000 years old. Concrete is also a composite material and is used more than any other synthetic material in the world. As of 2006, about 7.5 billion cubic metres of concrete are made each year-more than one cubic metre for every person on Earthward plants, both true wood from trees and such plants as palms and bamboo, yield natural composites that were used prehistorically by mankind and are still used widely in construction and scaffolding.

- Plywood, 3400 BC, by the Ancient Mesopotamians; gluing wood at different angles gives better properties than natural wood.
- Cartonnage, layers of linen or papyrus soaked in plaster dates to the First Intermediate Period of Egypt c. 2181–2055 BC and was used for death masks.
- Cob mud bricks, or mud walls, (using mud (clay) with straw or gravel as a binder) have been used for thousands of years.
- Concrete was described by Vitruvius, writing around 25 BC in his Ten Books on Architecture, distinguished types of aggregate appropriate for the preparation of lime mortars. For structural mortars, he recommended pozzolana, which were volcanic sands from the sand like beds of Pozzuoli brownish-yellow-grey in colour near Naples and reddish-brown at Rome.
- Papier-mâché, a composite of paper and glue, has been used for hundreds of years.
- The first artificial fibre reinforced plastic was a combination of fibre glass and Bakelite, performed in 1935 by Al Simson and Arthur D Little in Owens Corning Company.
- One of the most common and familiar composites is fiberglass, in which small glass fibres are embedded within a polymeric material (normally an epoxy or polyester). The glass fibre is relatively strong and stiff (but also brittle), whereas the polymer is ductile (but also weak and flexible). Thus, the resulting fiberglass is relatively stiff, strong, flexible, and ductile.

1.3 APPLICATION OF COMPOSITE MATERIALS:

The first known application of composite materials occurred several thousand years ago when the Egyptians started using straw strengthened, sun dried, and clay bricks in construction activities. Since that time great strides have been made in the development of composite materials. They now offer the promise of new products with extraordinary strength, stiffness, chemical and temperature resistance.

The largest tonnage application for composite materials is in civil engineering structures such as roadways, and buildings where ceramic (cement) matrix composite materials are extensively used.

The remaining market for composite materials can be categorized into two classes, reinforced plastics, and advanced composites. The military has been the primary customer of the advanced composites. A well-defined need for faster and more survivable aircraft and missiles has sparked much innovation and development in this area. Also, the military and civil aerospace were often the only customers who could afford the high prices and long lead times of low volume advanced materials. With respect to civilian applications, reinforced plastics comprise 90 percent of the market, and are based on glass fibre reinforcements in commodity, thermosetting resins, mainly unsaturated polyesters and their derivatives. Fibre Reinforced plastics (FRP) has been in existence for about fifty years and will be the focus of this report. They have generally been used to replace traditional materials such as wood, aluminium and steel. Significant advantages of fibre reinforced plastics over these traditional materials include higher strength, lighter weight, greater corrosion resistance, dimensional stability, higher dielectric strength, and improved design flexibility.

1.4 TYPES OF COMPOSITES:

Matrix:

The composite materials have a continuous bulk phase which is known as the matrix. It holds the reinforcement to form the desired shape.

Examples: Polymers, Metals or Ceramics.

Reinforcement:

The dispersed non-continuous phase is usually harder and stronger is known as reinforcement. It improves the overall mechanical properties of the matrix.

Example: Fibres, Particles, Flakes, and fillers.

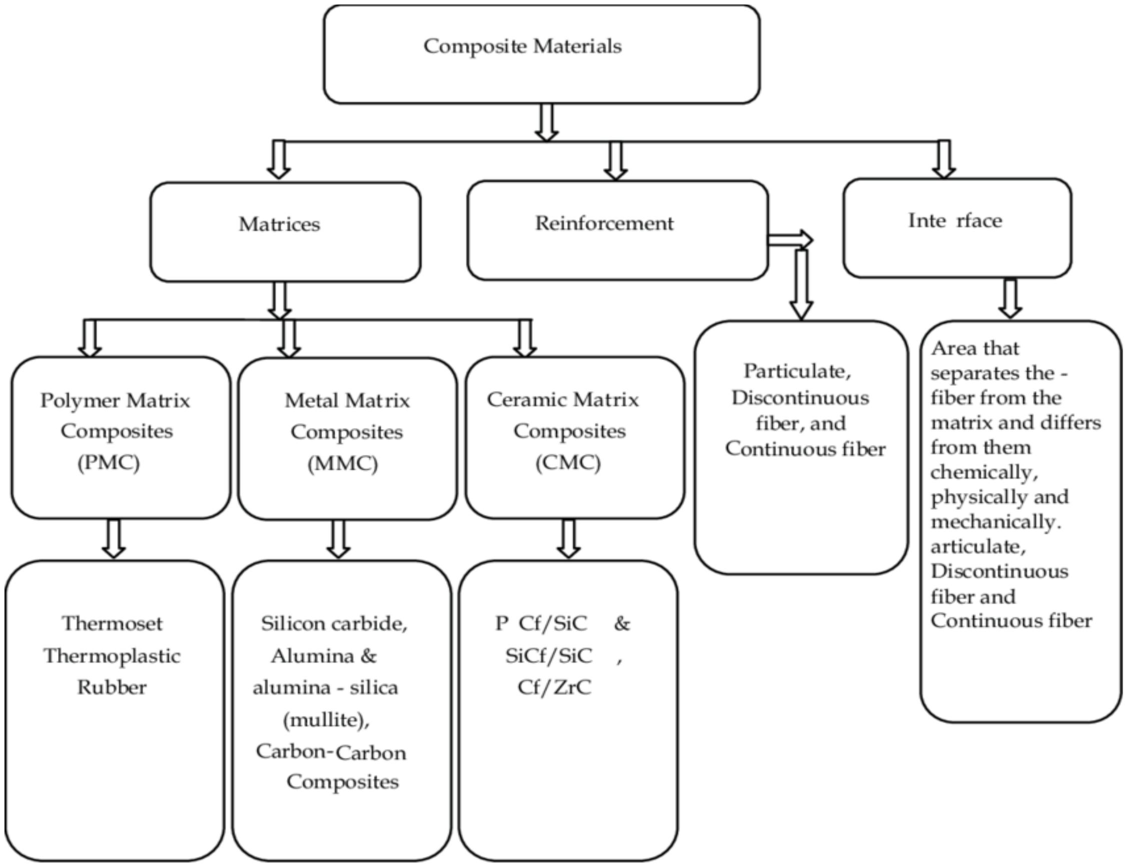

Fig 1.2 FLOW CHART OF COMPOSITE MATERIALS

1.4.1 TYPES OF MATRIXES:

Ceramic matrix - Ceramic matrix composites (CMCs) are a subgroup of composite materials. They consist of ceramic fibres embedded in a ceramic matrix, thus forming a ceramic fibre reinforced ceramic (CFRC) material. The matrix and fibres can consist of any ceramic material. CMC materials were designed to overcome the major disadvantages such as low fracture toughness, brittleness, and limited thermal shock resistance, faced by the traditional technical ceramics.

Metal matrix - Metal matrix composites (MMCs) are composite materials that contain at least two constituent parts – a metal and another material or a different metal. The metal matrix is reinforced with the other material to improve strength and wear. Where three or more constituent parts are present, it is called a hybrid composite. In structural applications, the matrix is usually composed of a lighter metal such as magnesium, titanium, or aluminium. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common. Typical MMC's manufacturing is basically divided into three types: solid, liquid, and vapour. Continuous carbon, silicon carbide, or ceramic fibres are some of the materials that can be embedded in a metallic matrix material. MMCs are fire resistant, operate in a wide range of temperatures, do not absorb moisture, and possess better electrical and thermal conductivity. They have also found applications to be resistant to radiation damage, and to not suffer from outgassing. Most metals and alloys make good matrices for composite applications.

Polymer matrix - Polymer matrix composites (PMCs) can be divided into three sub-types, namely, thermoset, thermoplastic, and rubber. Polymer is a large molecule composed of repeating structural units connected by covalent chemical bonds. PMCs consist of a polymer matrix combined with a fibrous reinforcing dispersed phase. They are cheaper with easier fabrication methods. PMCs are less dense than metals or ceramics, can resist atmospheric and other forms of corrosion, and exhibit superior resistance to the conduction of electrical current.

1.4.2 TYPES OF REINFORCEMENTS:

Positive reinforcement: This involves adding something to increase response, such as praising a child when they complete a designated task. This would motivate the child to get involved in the task.

Negative reinforcement: This involves removing something to increase response, such as withholding payment until the person completes the job. The person would remain motivated till the end of the job to acquire the payment.

Punishment: This involves adding something aversive to modify behaviour. For example, yelling at a child for misbehaving. In this example, the child would associate every negative behaviour with punishments. This would prevent the child from repeating such behaviour.

Extinction: This involves removing or taking away something to modify a certain response. This is called negative punishment or extinction. For instance, a teenager comes home late, and the parents curb their phone usage. Next time, the teenager would think before breaking the curfew.

1.5 COMPOSITES MANUFACTURING METHODS:

There are various methods to manufacture composites. They are

1. Solid state methods:
    - Powder Metallurgy
    - Foil Diffusion
2. Liquid state methods:
    - Electroplating and Electroforming
    - Stir Casting
    - Pressure Infiltration
    - Squeeze Casting
    - Spray Deposition
    - Reactive Processing
3. Physical Vapour Deposition
4. In-situ Fabrication Technique

1.6 SOLID STATE METHODS:

1.6.1 Powder Metallurgy:

Powder metallurgy (PM) is a metal working process for farming precision metal components from metal powders. The metal powder is first pressed into product shape at room temperature. This is followed by heating that causes the powder to fuse together without melting. In the PM process the following three steps are followed in sequence mixing. compacting, and sintering.

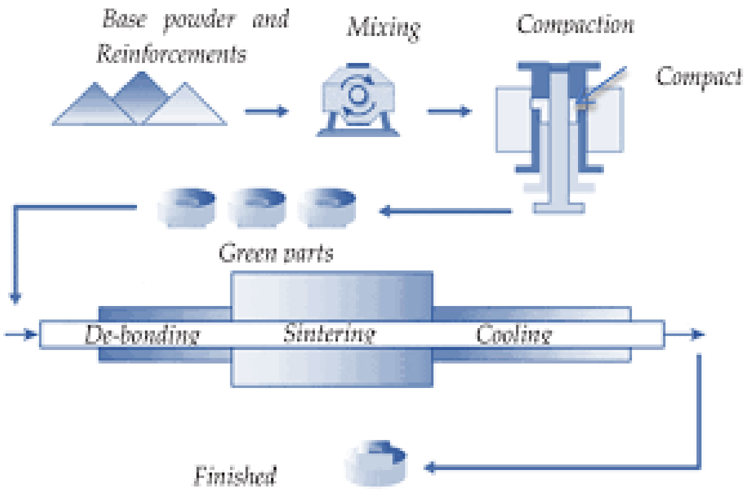

Fig 1.3 POWDER METALLURGY

Mixing:

A homogenous mixture of elemental powders or alloy powders is prepared. Depending upon the need, powders of other alloy or lubricants may be added.

Compacting:

A controlled amount of the mixed powder is introduced into a precision die and then it is pressed or compacted at pressure in the range 100 MPA to 1000 MPA The Compacting pressure required depends on the characteristics and shape of the particles, the method of mixing and the lubricant used. This is generally done at room temperature. The model is generally called "green compact".

1.6.2 FOIL DIFFUSION BONDING:

Layers of metal foil are sandwiched with long fibres, and then pressed through a matrix. This method is normally used to manufacture fibre reinforced MMC with sheets or foils of matrix material Here primarily the metal or metal alloys in the form of sheets and the reinforcement material in the form of fibre are chemically surface trusted for the effectiveness of inter diffusion. These fibres are placed on the metal foil in predetermined orientation and bonding takes place by press forming directly However sometimes the fibres are coated by plasma spraying or ion plating for enhancing the bonding strength before diffusion bonding the solid line show this After bonding secondary machining work is carried out. The applied pressure and temperature as well as their duration for diffusion bonding to develop vary with the composite systems. However, this is the most expensive method of fabricating MMC materials

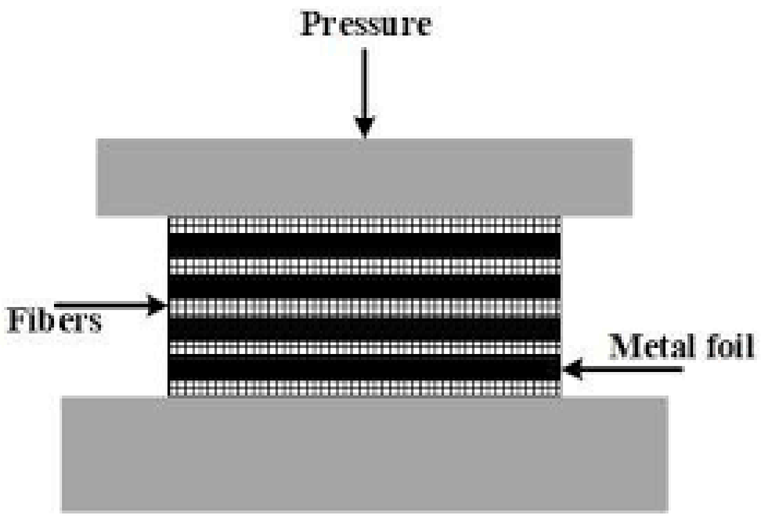

Fig 1.4 FOIL DIFFUSION BONDING

At the microscopic level, diffusion bonding occurs in three simplified stages:

Micro asperity deformation- before the surfaces completely contact, asperities (very small surface defects) on the two surfaces contact and plastically deform. As these asperities deform, they interlink, forming interfaces between the two surfaces.

Diffusion-controlled mass transport- elevated temperature and pressure causes accelerated creep in the materials; grain boundaries and raw material migrate and gaps between the two surfaces are reduced to isolated pores.

Interface migration- material begins to diffuse across the boundary of the abutting surfaces, blending this material boundary and creating a bond.

1.7 LIQUID STATE METHODS:

1.7.1 ELECTROPLATING AND ELECTROFORMING:

Electroplating is a process that uses electric current to reduce dissolved metal so that they form a thin coherent metal coating on an electrode The term is also used for electrical oxidation of anions on to a solid substrate Electroplating is primarily used to change the surface properties of an object (such as abrasion and wear resistance, corrosion protection, lubricity, aesthetic qualities), but may also be used to build up thickness on undersized parts or to form objects by electroforming The process used in electroplating is called electro deposition. It is analogous to a concentration cell acting in reverse. The part to be plated is the cathode of the circuit in one technique, the anode is made of the metal to be plated on the part Both components are immersed in a solution called an electrolyte containing one or more dissolved metal salts as well as other ions that permit the flow of electricity. A power supply supplies a direct current to the anode, oxidizing the metal atoms that it comprises and allowing them to dissolve in the solution. At the cathode, the dissolved metal ions in the electrolyte solution are reduced at the interface between the solution and the cathode, such that they "plate out" onto the cathode. The rate at which the anode is dissolved is equal to the rate at which the cathode is plated, vis-à-vis the current through the circuit. In this manner, the ions in the electrolyte bath are continuously replenished by the anode.

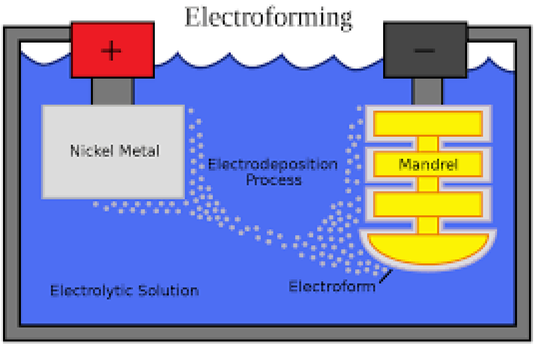

Fig 1.5 ELECTROPLATING AND ELECTROFORMING:

1.7.2 STIR CASTING:

Stir casting techniques are currently the simplest and most commercial method of production of MMCs This approach involves mechanical mixing of the reinforcement particles into a molten metal bath and transferred the mixture directly to a shape mould prior to complex solidification in the process, the crucial thing is to create good wetting between the particulate reinforcement and the molten metal. This process has the major advantage that the production costs of MMCs are very low.

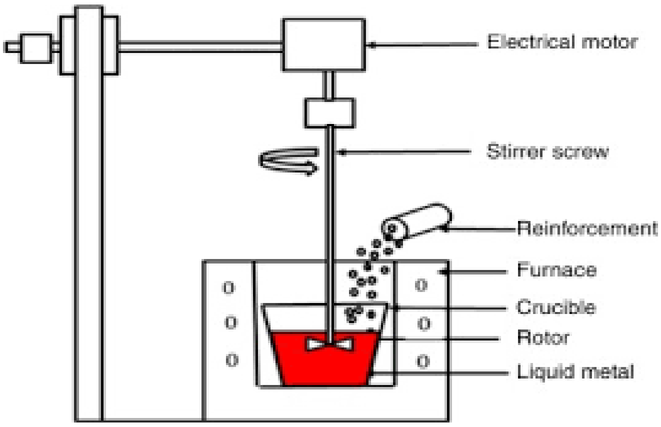

Fig 1.6 STIR CASTING

Various steps involved in stir casting process is shown in Figure 2. In this process, the matrix material is kept in the bottom pouring furnace for melting. Simultaneously, reinforcements are preheated in a different furnace at certain temperature to remove moisture, impurities etc. After melting the matrix material at certain temperature, the mechanical stirring is started to form vortex for certain time period then reinforcements particles are poured by the feeder provided in the setup at constant feed rate at the center of the vortex, the stirring process is continued for certain time period after complete feeding of reinforcements particles. The molten mixture is then poured in preheated mold and kept for natural cooling and solidification. Further, post casting process such as heat treatment, machining, testing, inspection etc. has been done. There is various impeller blade geometry are available. Melting of the matrix material is very first step that has been done during this process

1.7.3 PRESSURE INFILTRATION:

Molten metal is infiltrated into the reinforcement through use a kind of pressure such an gas pressure This process can also be called their-tow infiltration Fibre tows can be infiltrated by passing through a bath of molten metal Usually the fibres must be coated in line to promote wetting Once the infiltrated wines produced they must be assembled into to perform and gives a secondary consolidation process to produce a component Secondary consolidation is accomplished through diffusion bonding or hot molding in the two phase liquid and solid region. This method is desirable in producing relatively small size composite specimens having unidirectional properties.

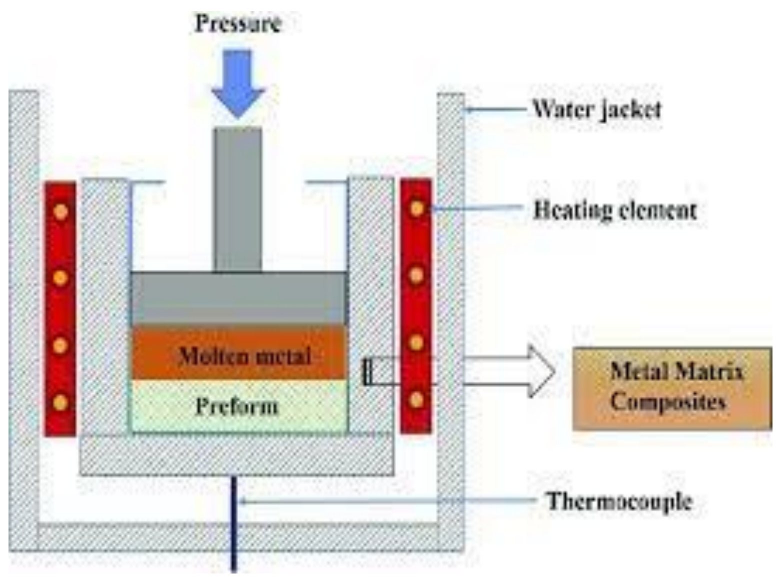

Fig 1.7 PRESSURE INFILTRATION

1.7.4 SQUEEZE CASTING:

Squeeze casting is a combination of casting and forging processes that can result in the Highest mechanical properties attainable in a cast product. The development of squeeze casting process can usher in tremendous possibility for manufacturing of components of Aluminium alloys, which are not properly commercialized and yet It can also be effective in import substitution of critical components. The process starts when the molten metal is poured into the bottom half of a preheated die. As soon as the metal starts solidifying. The Upper half of the die closes and starts applying pressure during the solidification process. The extent of pressure applied is significantly less than that in forging.

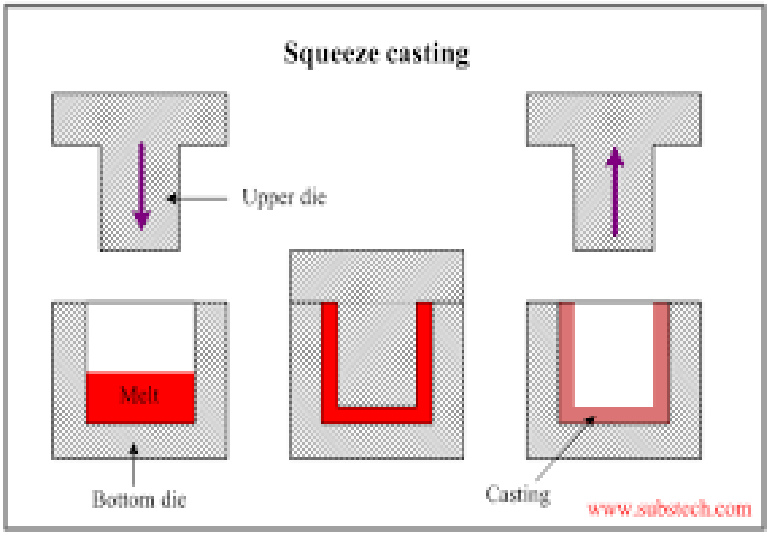

Fig 1.8 SQUEEZE CASTING

Creating Squeeze Casts:

1. Heat metal to melting temperature
2. Inject into die and add 15,000 psi to shape molten metal
3. Heat over melting temperature
4. Extract material and rinse through water
5. Remove metal produced from die to cool down

1.7.5 SPRAY DEPOSITION:

Spray forming, also known as spray casting spray deposition and in-situ compaction is a method of casting near net shape metal components with homogeneous microstructures via the deposition of semi-solid sprayed droplets onto a shaped substrate in spray forming an alloy is melted, normally in an induction furnace, then the molten metal is slowly poured through a conical tundish into a small-bore ceramic nozzle. The molten metal exits the furnace as a thin freefalling stream and is broken up into droplets by an annular array of gas jets, and these droplets then proceed downwards, accelerated by the gas jets to impact onto a substrate. The process is arranged such that the droplets strike the substrate whilst in the semi-solid condition, this provides sufficient liquid fraction to stick the solid fraction together. Deposition continues, gradually building up a spray formed billet of metal on the substrate.

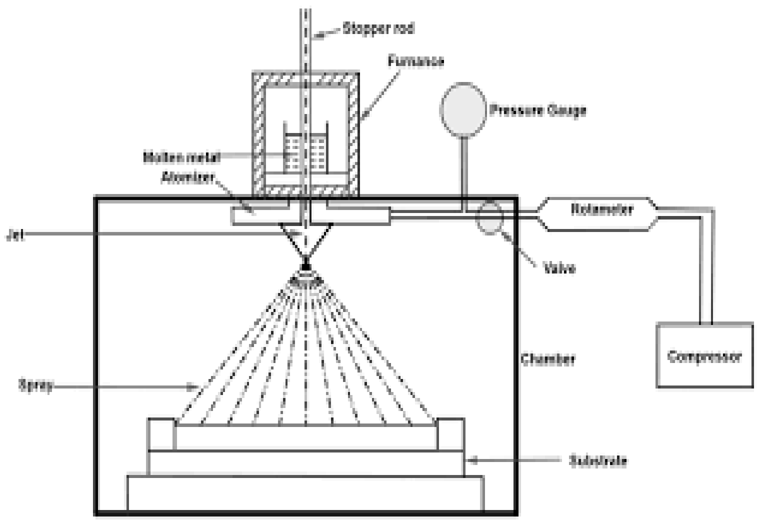

Fig 1.9 SPRAY DEPOSITION

In spite of the problems associated with the spray forming process there has been sustained industrial interest in spray forming over the last 35 years. Sandvik-Osprey (former Osprey Metals Ltd) of Neath, South Wales holds the patents on the process and have licensed the technology to a range of industries. There are currently approximately 25 licensees operating around the world, ranging from small research and development plants to full-scale commercial operations. Main applications are prematernal for low temperature Nb3Sn super conductors (CuSn), oil drilling equipment (high strength material CuMnNi) and for forming tools (CuAlFe with high Al-content). In all of these applications, research concerns the reconciliation of the cost disadvantages and complexity of spray forming with the demand for high performance alloys in niche applications.

1.7.6 PHYSICAL VAPOUR DEPOSITION:

Physical vapour deposition (PVD) describes a variety of vacuum deposition methods which can be used to produce thin films and coatings PVD is characterized by a process in which the material goes from a condensed phase to a vapour phase and then back to a thin film Condensed phase. The most common PVD processes are sputtering and evaporation PVD is used in the manufacture of items which require thin films for mechanical, optical, chemical, or electronic functions. The source material is unavoidably also deposited on most other surfaces interior to the vacuum chamber, including the fixturing used to hold the parts.

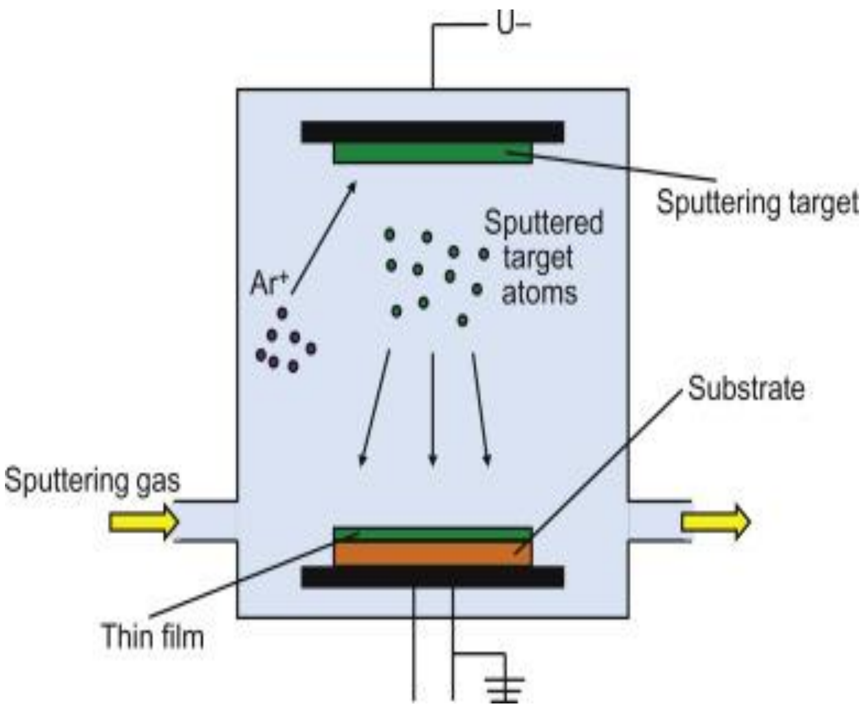

Fig 1.10 PHYSICAL VAPOUR DEPOSITION

1.8 **CASTING:**

Casting is a manufacturing process in which a liquid material is usually poured into a mould, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mould to complete the process. Casting materials are usually metals or various time setting materials that cure after mixing two or more components together; examples are epoxy, concrete, plaster, and clay. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods. Heavy equipment like machine tool beds, ships' propellers, etc. can be cast easily in the required size, rather than fabricating by joining several small pieces.

1.9 TYPES OF CASTING:

1.9.1 **SAND CASTING**:

Sand casting, also known as sand molded casting, is a metal casting process characterized by using sand as the mold material. The term "sand casting" can also refer to an object produced via the sand casting process. Sand castings are produced in specialized factories called foundries. Over 60% of all metal castings are produced via sand casting process.

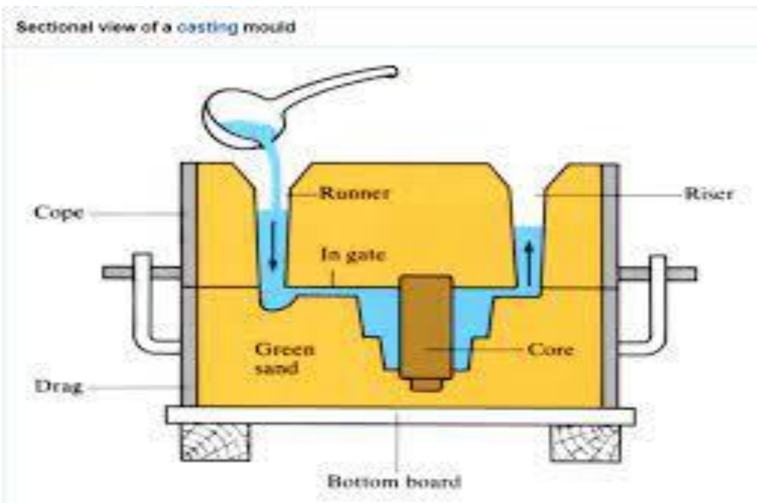

Fig 1.11 SAND CASTING

Advantages:

- Nearly Any Alloy
- Low Tooling Cost
- Versatile – Size, Weight, Shape
- Any Quantity
- Timing

Disadvantages:

- Lower Dimensional Accuracy
- Pattern Maintenance
- Surface Finish

Applications:

- Bearings blowers & impellers
- bushings
- cams
- electronic equipment
- engine crankcases
- engine oil pans
- fittings

1.9.2 INVESTMENT CASTING:

A kind of casting method that usually refers to making patterns in fusible materials, covering the surface of the pattern with several layers of refractory materials, and then melting the pattern out of the mould shell to obtain a mould without a parting surface, which can be filled after baking at high temperature.

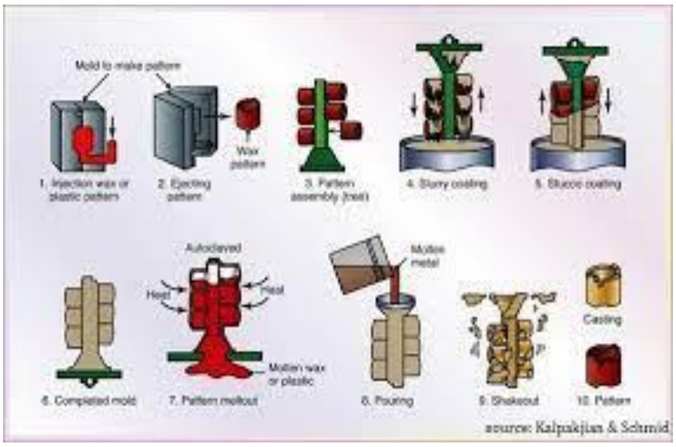

Fig 1.12 INVESTMENT CASTING

Advantages:

- Excellent surface finish.
- Tight dimensional tolerances.
- Complex and intricate shapes may be produced.
- Capability to cast thin walls.
- Wide variety of metals and alloys (ferrous and nonferrous) may be cast.
- Draft is not required in the moulds design.
- Low material waste.

Disadvantages:

- Individual patterns are required for each casting.
- Limited casting dimensions.
- Relatively high cost (tooling cost, labour cost).

Applications:

It is suitable for the production of small parts with complex shapes, high precision requirements, or other processing that is difficult to perform, such as turbine engine blades.

1.9.3 DIE CASTING:

The high-pressure metal liquid is pressed into a precision metal mould cavity at high speed, and the metal liquid is cooled and solidified under pressure to form a casting.

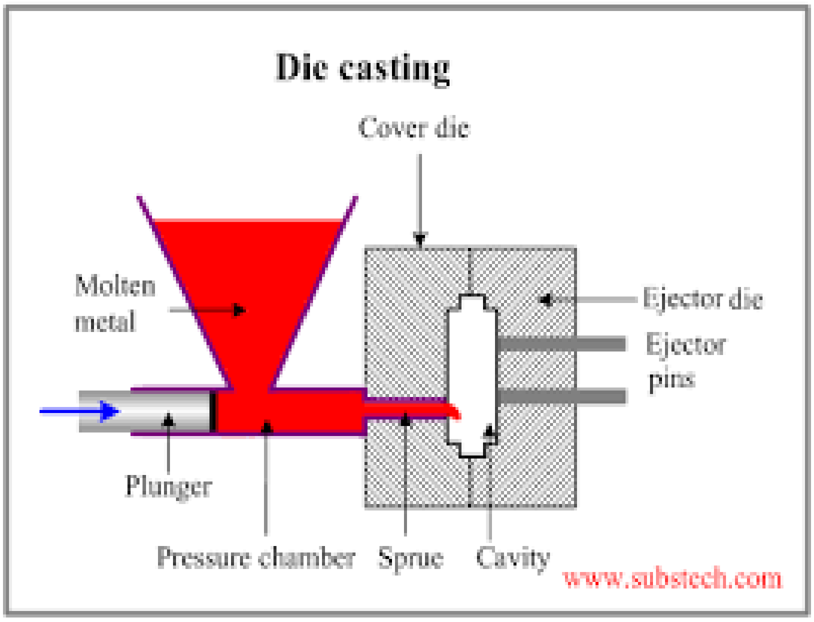

Fig 1.13 DIE CASTING

Advantages:

- The metal liquid is subjected to high pressure and the flow rate is fast during die casting.
- Good product quality, stable size, and good interchangeability.
- High production efficiency and die casting moulds can be used many times.
- It is suitable for mass production with good economic benefits.

Disadvantages:

- The casting is prone to produce fine pores and shrinkage.
- The die-casting parts have low plasticity and should not work under impact load and vibration.
- When die casting of high melting point alloy, the life of the mould is low, which affects the expansion of die casting production.

Applications:

Die castings were first applied in the automotive industry and the instrument industry, and then gradually expanded to various industries, such as agricultural machinery, machine tool industry, electronics industry, national defense industry, computers, medical equipment, clocks, cameras, and daily hardware. The technique is often performed on nonferrous metals like magnesium, aluminum, etc. Die casting is one of the largest casting methods that is used to manufacture consumer, commercial and industrial products like automobiles, toys, parts of the sink faucet, connector housing, gears, etc.

1.9.4 LOW PRESSURE CASTING:

Refers to the method of making liquid metal fill a mould under a low pressure (0.02 – 0.06MPa) and crystallize under pressure to form a casting.

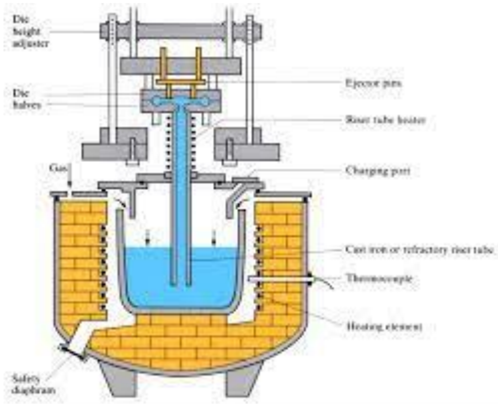

Fig 1.14 LOW PRESSURE CASTING

Advantages:

- The filling of pure molten metal improves the purity of castings. The slag generally floats on the surface of the liquid metal, and the mould filling is realized by the liquid metal at the lower part of the crucible through the riser in low pressure casting, which completely avoids the possibility of the slag entering the mould cavity.

- The filling of molten metal is stable, which reduces or avoids the tumbling, impact and splash of metal liquid during filling, and reduces the formation of oxidation slag.

- LPDC casting has good formability. The filling of liquid metal under pressure can improve the fluidity of liquid metal, which is beneficial to the formation of castings with a clear outline and smooth surface and is more favorable for the forming of large thin-wall castings.

- When the casting crystallizes and solidifies under pressure, it can get sufficient feeding and compact structure.

- The recovery rate of liquid metal is improved. Generally, a riser is not required, and the non-condensed metal in the riser can be refluxed to the crucible for reuse, which greatly improves the recovery rate of liquid metal.

- Convenient production and operation, good working conditions, high production efficiency, easy to realize mechanization and automation.

Disadvantages:

- Large investment in equipment and moulds

- In the production of aluminium alloy castings, the crucible and riser are in contact with the liquid metal for a long time, which is easy to be eroded and scrapped, and will also increase the iron content of the liquid metal and deteriorate the performance.

APPLICATIONS:

Low-pressure die casting is mainly used to produce aluminium alloy and magnesium alloy parts, such as automobile hubs in the automobile industry, cylinder block, cylinder head, piston, missile shell, impeller, wind guide wheel and other castings with complex shape and high-quality requirements. Low-pressure casting can also be applied to small copper alloy castings, such as pipe fittings, faucets in bathrooms, etc. When low-pressure casting is used to produce cast steel, such as cast steel wheels and liquid risers, special refractory materials should be used.

1.9.5 **CENTRIFUGAL CASTING:**

It is a casting method in which molten metal is poured into a rotating mould, and the mould is filled and solidified under the action of centrifugal force.

Typical materials that can be centrifugal cast are metals, cements, concretes, glass, and pottery materials. Typical metals cast are iron, steel, stainless steels, and alloys of nickel, aluminum, and copper.

Two materials can be combined by introducing a second material during the process. A common example is cast iron pipe coated on the interior with cement.

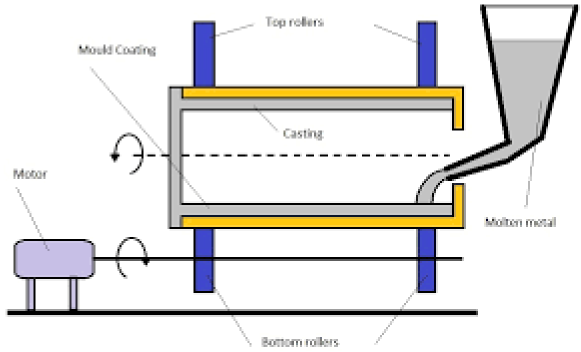

Fig 1.15 CENTRIFUGAL CASTING

Advantages:

- There is almost no metal consumption in the pouring system and the riser system, which improves the process yield.
- The core can be omitted when producing hollow castings, so the metal filling ability can be greatly improved when producing long tubular castings.
- The casting has high density, few defects such as pores and slag inclusion, and high mechanical properties.
- It is easy to manufacture composite metal castings of barrels and sleeves.

Disadvantages:

- There are certain limitations when used in the production of special shaped castings.
- The diameter of the inner hole of the casting is not accurate, the surface of the inner hole is rough, the quality is poor, and the machining allowance is large.
- The casting is prone to specific gravity segregation.

Applications:

Centrifugal casting was first used to produce cast pipes. At home and abroad, metallurgy, mining, transportation, irrigation and drainage machinery, aviation, national defense, automotive and other industries have used centrifugal casting processes to produce steel, iron, and non-ferrous carbon alloy castings.Among them, the production of centrifugal cast iron tubes, internal combustion engine cylinder liners and shaft sleeves is the most common.

1.9.6 GRAVITY DIE CASTING:

It refers to a moulding method in which liquid metal is filled with a metal mould under the action of gravity and cooled and solidified in the mould to obtain a casting.

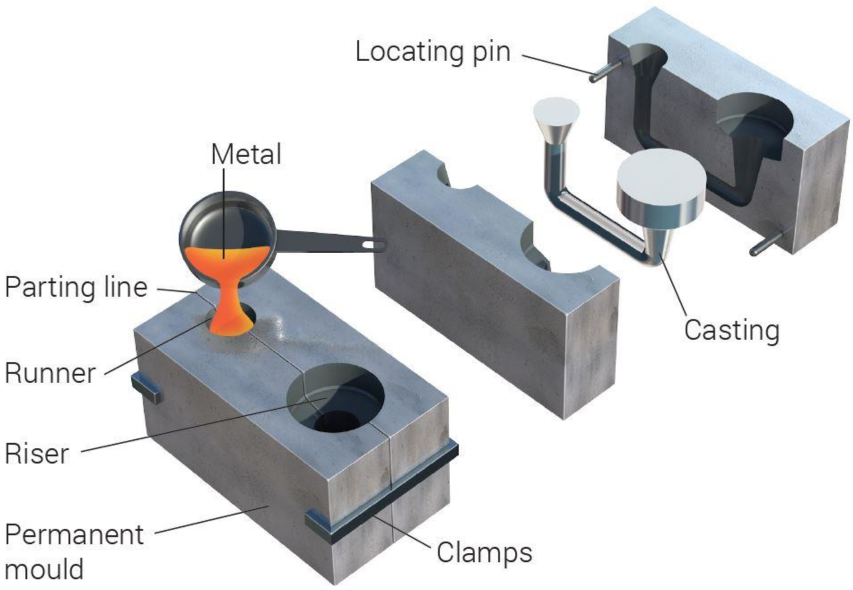

Fig 1.16 GRAVITY DIE CASTING

Advantages:

- The metal mould has large thermal conductivity and heat capacity, fast cooling speed, dense casting structure, and mechanical properties about 15% higher than sand casting.

- It can obtain castings with higher dimensional accuracy and lower surface roughness and has good quality stability.

- Because the sand core is not used and rarely used, the environment is improved, dust and harmful gases are reduced, and labour intensity is reduced.

Disadvantages:

- The metal mould itself is non-breathable, and certain measures must be taken to evacuate the air and air generated by the sand core in the cavity.

- The metal mould has no concession, and cracks are easy to occur when the casting is solidified.

- Metal moulds have a longer manufacturing cycle and higher cost. Therefore, good economic effects can only be shown when mass produced.

Applications:

Metal casting is suitable for large-scale production of non-ferrous alloy castings such as aluminium alloys and magnesium alloys with complex shapes, as well as iron and steel metal castings and ingots.

1.9.7 **VACUUM DIE CASTING:**

An advanced die-casting process that improves the mechanical properties and surface quality of die-casting parts by removing or significantly reducing the pores and dissolved gases in the die-casting part by extracting the gas in the die-casting mould cavity during the die-casting process. The common process of Vacuum Die Casting is explained below:

- Firstly, the metal alloy is molten
- The molten metal is moved into the shot chamber with the help of a plunger in Hot Chamber machines and using a ladle in Cold Chamber Machines

- Then vacuum creation and metal injection under high pressure is carried out
- Air will be removed from the die cavity, and which will enable the molten metal to uniformly reach all recesses
- Then it is left to solidify and cool down
- The completed casting can be retrieved after ejecting the die

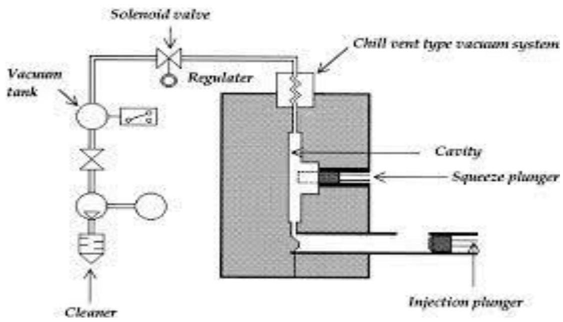

Fig 1.17 VACUUM DIE CASTING

Advantages:

- It can eliminate or reduce the air holes inside the die casting, improve the mechanical properties and surface quality of the die castings as well as the plating performance.

- To reduce the back pressure of the cavity, lower specific pressure and alloy with poor casting performance can be used. It is possible to die-cast larger castings with small machines.

- It improved filling conditions, can cast thinner castings.

Disadvantages:

- The mould sealing structure is complicated, making and installing is difficult, so the cost is high.

- If the vacuum die casting method is not properly controlled, the effect will not be very significant.

Applications:

- Good processing properties
- Offers high electrical conductivity
- It has high corrosion resistance
- High strength and hardness
- High thermal conductivity
- Good EMF/RFI isolation
- It offers the potential to develop novel refined material microstructures for a broad range of alloy compositions.

2 LITERATURE REVIEW

1. **Neeraj Sharma, Rajesh Khanna, Gurpreet Singh & Vinod Kumar** has done his research on Fabrication of 6061 aluminium alloy reinforced with Si3N4/n-Gr and its wear performance optimization using integrated RSM-GA, Particulate Science and Technology.

In his research work the dry sliding wear behavior of a hybrid aluminum metal matrix composite is evaluated. Al 6061 is used as a matrix material while Si3N4 and nano graphite powder (3–15 wt.%) are used as reinforcements. These two reinforcements (50 wt.% of each) were blended in a high-energy ball mill for homogeneous mixing. The hybrid composite is made by the stir casting route and its wear rate was investigated . Analysis of variance (ANOVA) shows that sliding distance plays a major role on the dry sliding wear rate followed by load, sliding speed and reinforcements. Transition of wear mechanism takes place with the increase of speed (i.e., temperature between the two rubbing surfaces) from abrasive to adhesive.

2. **P. Gangadhara Rao, A. Gopala Krishna, Pandu R Vundavilli** Department of Mechanical Engineering has studied the Optimization of Wear Phenomenon of Al6061/Gr MMCs using Non-Traditional Optimization Methods.

Researchers had tested several materials such as Al2O3, SiC, TiC, B4C, TiB2 and ZrC etc. as reinforcement materials and examined for their wear characteristics. It was observed that the infiltration of SiC increased the resistance to wear of Al alloys. They used GA to optimize the nonlinear regression equation of wear rate obtained from RSM approach. They considered sliding speed, percentage of silicon and applied load as the input process parameters and wear rate as response. Futherused particle swarm optimization (PSO) algorithm to optimize the stir casting process that produce more uniform composites. Further, wear test was conducted on those samples.

3. **P. Gangadhara Rao, Pandu R V, K. Meera Saheb** has studied Mechanical and Dry Sliding Wear Behaviour of Al6061/Gr MMCs and its Multi Response Optimization using Hybrid Fuzzy.

In this work an effort is made to produce the Al6061/Graphite MMC through stir casting then examines the mechanical properties and wear behavior of the prepared composite. While studying the wear behavior, the concept of RSM has been utilized to perform experiments and to establish the non-linear regression equation for the responses, namely wear loss and coefficient of friction. In the experimentation, the factors, which includes reinforcement percentage, load, sliding distance, and sliding velocity for wear are considered as the input process parameters to generate the statistical modal. ANOVA is used to test the statistical adequacy once the non-linear model is developed. Finally, the adequacy of the model has been verified by experimental test cases. Moreover, microstructural examinations are conducted using SEM to evaluate the wear phenomenon for specimens before and after T6 treatment of AMMCs.

4. **K.R Padmavathi and R.Ramakrishnan** international journal of mechanical engineering has studied Wear Studies on the Heat Treated Al6061-µSIC and Al6061-NSIC Metal Matrix Composites.

Metal matrix composites (MMCs) have a potential for enhanced wear conflict in excess of the unreinforced aluminum alloy and are the most capable in achieving enhanced mechanical properties. In the present investigation, composites of Aluminum 6061(Al6061) matrix material are reinforced with micron size Silicon carbide (µSiC) reinforcement with 5, 10 and 15 weight percentages (wt.%) and nano size SiC (nSiC) with 0.5, 1.0 and 1.5 wt.% are fabricated by stir casting technique. The stir casted composites are further heat treated and the specimens are prepared as per ASTM standards to conduct hardness and wear tests. They have concluded that the fabricated and heat treated nano composites showed enhancement in hardness and wear resistance more than the micro composites.

5. **Ashok Kumar Mishra and Rajesh Kumar Srivastava** have conducted Wear Behaviour of Al-6061/SiC Metal Matrix Composite.

Aluminium Al-6061 base composites, reinforced with SiC particles having mesh size of 150 and 600, which is fabricated by stir casting method and their wear resistance and coefficient of friction has been investigated in the present study as a function of applied load and weight fraction of SiC varying from 5, 10, 15, 20, 25, 30, 35 and 40 %. The dry sliding wear properties of composites were investigated. The result shows that the wear of the test specimens increases with the increasing load and sliding distance. The coefficient of friction slightly decreases with increasing weight percentage of reinforcements.

6. **Ibrahim Sabry, Amir Hussain, Idirsi** have studied a tribological and mechanical properties on Stir casted SiC-Gr/Al6061 hybrid composite.

In this work, hybrid aluminum matrix composites fabricated using the stir casting technique. Silicon carbide and graphite used as reinforcement to improve the mechanical properties. AMCs produced by adding various volume fraction of SiC .The fabricated AMC samples were tested to determine the tensile strength, hardness, and wear rate. The wear rate was determined under the different loads and sliding velocities. Finally, they concluded that the tensile strength and hardness of aluminum improved with the increase of SiC particles, but the plasticity and malleability of the composites decrease significantly and decrease in hardness with an increase in percentage reinforcement of graphite (Gr) in Al/Gr composites.

7. **G.B. Veeresh Kumar, Selvaraj** has conducted the experiment of Studies on Al6061-SiC Metal Matrix Composite.

In this paper it is aimed to present the experimental results of the studies conducted regarding hardness, tensile strength and wear resistance properties of Al6061- Sic composites. The composites are prepared using the liquid metallurgy technique, in which 2-6 wt. %’age of particulates were dispersed in the base matrix in steps of 2. The obtained cast composites of Al6061-SiC the castings of the base alloys were carefully machined to prepare the test specimens for density, hardness, mechanical, tribological tests and as well as for microstructural studies as per ASTM standards. The SiC and Al2O3 resulted in improving the hardness and density of their respective composites. Further, the increased %’age of these reinforcements contributed in increased hardness and density of the composites.

8. **Arvind Chandrasekhar, N.Radika, Gopalakrishnan** have Investigating the Adhesive Wear Properties of Aluminum Hybrid Metal Matrix Composites at Elevated Temperatures Using RSM Technique.

Fabrication of Aluminum LM13/MoS2/TiO2 hybrid metal matrix composite via stir casting technique was carried out to analyze the wear characteristics at an elevated temperature of 150° C using pin on disc tribometer. The parameters namely load, sliding velocity and sliding distance were varied for five levels as per the run order generated from Response Surface Methodology. From experiments, it was observed that the wear rate decreased with reduced sliding velocity initially due to mechanically mixed layer formation and then increases. Also, the results showed a reduction in wear rate with low loading and sliding distance conditions.

9. **Muhammad Wira Akira, Anne Zulfia, Ekavianti Prajatelistia** have conducted a test on Al2co3 with some other alloys.

Nano-Al2O3 particles were incorporated into ADC12 alloy with the addition of Al-5Ti-B, Al-Sr, and Mg to achieve high performance in mechanical and tribological properties. In this study, varied nano-Al2O3 was used from 0.25 vf-% to 0.5 vf-% through stir casting methods to discover the optimum amount to obtain high performance. Besides, the inclusion of grain refiner Al-5Ti-B and microstructure modifier Al-Sr is expected to improve performance to the next level. However, porosity and agglomeration still be a concern in Aluminum alloy matrix composite fabrication. The presence of spinel phase MgAl2O4 in the interface area between nano-Al2O3 particles and ADC12 alloy is relied upon to minimize this porosity and agglomeration issue. The optimum of tensile strength and hardness was found at 0.35 vf-% Al2O3 and wear rate at 0.4 vf%. Although, the optimum point of wear found at 0.4 vf%, porosity began to increase at 0.4 vf% as well. As a result, 0.35 vf% addition of the nano-Al2O3 gives the best performance for the composite.

10. **Pavitran Boopathy and Swathanandhan** have Studied Mechanical and Tribological Properties Ofal-6061 Reinforced with Silicon Carbide and Graphite Particles.

The matrix material used for study is Al-6061.The Stir casting is a simple and economic process for fabrication of MMC and HMMC in large quantities up to 30% reinforcement volume fraction. In this process aluminium-6061 is melted in a furnace and stirred vigorously, after effective degassing with solid hexachloroethane predetermined mass of reinforcements are added into the vortex in three stage mixing process. The reinforcements are mixed thoroughly before adding it into the molten aluminium for uniform dispersion. And they concluded. The tensile strength of the composite increases linearly with the addition of both SiC & graphite reinforcements, whereas hardness improves with the SiC addition and shows decreasing trend with the graphite particle reinforcement. II. Wear rate of the developed HMMC has decreased with the addition of both SiC and graphite reinforcement.

3 EXPERIMENTAL DETAILS

3.1 Matrix Material (Al-6061):

6061 (Unified Numbering System (UNS) designation A96061) is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935.It has good mechanical properties, exhibits good weldability, and is very commonly extruded (second in popularity only to 6063). It is one of the most common alloys of aluminium for general-purpose use.

Aluminium / Aluminium alloys are sensitive to high temperatures. They tend to lose some of their strength when exposed to high temperatures of about 200-250°C. However, their strength can be increased at sub-zero temperatures. They also have good corrosion resistance. Aluminium / Aluminium 6061 alloy is the most commonly available and heat treatable alloy.

3.1.1 CHEMICAL COMPOSITION:

Table 3.1 CHEMICAL COMPOSITION OF Al-6061

ELEMENT	AMOUNT (wt.%)
ALUMINIUM	96.85
MAGNESIUM	0.9
SILICON	0.7
IRON	0.6
COPPER	0.30
CHROMIUM	0.25
ZINC	0.20
TITANIUM	0.10
MANGANESE	0.05

OTHERS	0.05

3.1.2 PHYSICAL PROPERTIES:

Table 3.2 PHYSICAL PROPERTIES OF Al-6061

PROPERTIES	METRIC	IMPERIAL
DENSITY	2.7g/cm^3	0.0975lb/in^3
MELTING POINT	588^0 C	1090 F

3.1.3 MECHANICAL PROPERTIES:

Table 1.3 MECHANICAL PROPERTIES OF Al-6061

PROPERTIES	METRIC	IMPERIAL
TENSILE STRENGTH	310MPa	45000psi
YIELD STRENGTH	276MPa	40000psi
SHEAR STRENGTH	207MPa	30000psi
FATIGUE STRENGTH	96.5MPa	14000psi
ELATIC STRENGTH	68.9GPa	10000ksi
POISSON’S RATIO	0.33	0.33
ELONGATION	12-17%	12-17%
BRINELL HARDNESS	95	95

3.1.4 THERMAL PROPERTIES:

Table3.2 THERMAL PROPERTIES OF Al-6061

PROPERTIES	VALUES	T (^{0}C)
THERMAL EXPANSION COEFFICIENT	23.2 * 10^6	20-10
THERMAL CONDUCTIVITY	167 W/mK	25

3.1.5 APPLICATIONS:

6061 is commonly used for the following:-

- construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft. 2024 alloy is somewhat stronger, but 6061 is more easily worked and remains resistant to corrosion even when the surface is abraded, which is not the case for 2024, which is usually used with a thin Alclad coating for corrosion resistance.
- yacht construction, including small utility boats.
- automotive parts, such as the chassis of the Audi A8 and the Plymouth Prowler.
- Flashlights
- aluminium cans for the packaging of food and beverages.
- Scuba tanks and other high pressure gas storage cylinders (post 1995)

3.2 **SILICON CARBIDE (SiC):**

Silicon Carbide (SiC) is highly worn resistant and has good mechanical properties, including high temperature strength and thermal shock resistance. Silicon Carbide (SiC), as a technical ceramic, is produced in two main ways.

Reaction bonded SiC is made by infiltrating compacts made of mixtures of

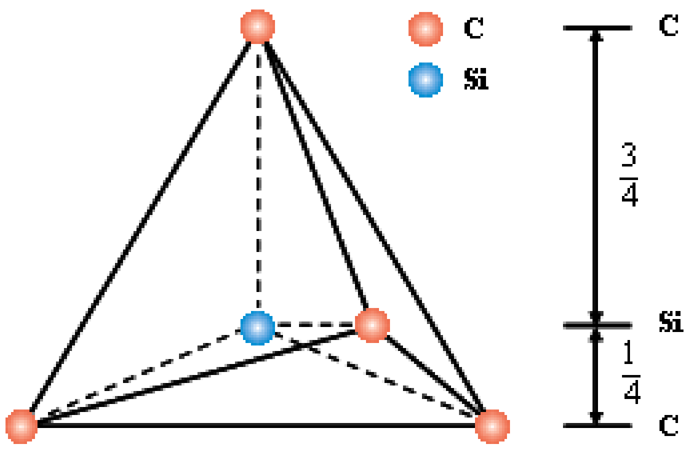

Fig 3.1 STRUCTURE OF SILICON CARBIDE

Silicon Carbide (SiC) and Carbon with liquid Silicon.

3.2.1 PROPERTIES OF SILICON CARBIDE:

Table 3.3 GENERAL PROPERTIES OF SILICON CARBIDE

PROPERTIES	UNITS	SILICON CARBIDE 105	SILICON CARBIDE 106
DENSITY	g/cm^3	3.15-3.20	3.17-3.20
ELASTIC MODULUS	GPa	400-430	400-450
WEIBULL MODULUS	-	12-15	12-18
HARDNESS	$HV(0.3)Kg/mm^2$	2300-2600	2300-2850
FRACTURE TOUGHNESS	$M.Pa.m^{1/2}$	3.5-4.1	4.1-4.3
THERMAL EXPANSION COEFFICIENT	$10^{-6}/^{O}C$	60-120	115-120
THERMAL CONDUCTIVITY	W/m.K	60-120	60-120
THERMAL SHOCK PARAMETER	^{O}C	164-180	164-240
ELECTRICAL RESISTIVITY	Ohm-cm	10^0 -10^6	10^7

3.2.2 APPLICATIONS OF SILICON CARBIDE

- sandblasting injectors
- automotive water pump seals
- bearings
- pump components
- extrusion dies that use high hardness, abrasion resistance, and corrosion resistance of carbide of silicon.
- High-temperature structural uses extend from the rocket injector grooves to the furnace rollers and the combination of high thermal conductivity, hardness and high temperature stability makes the components of the exchanger tubes of silicon carbide heat.

3.3 ALUMINIUM OXIDE (Al_2O_3):

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium (III) oxide. It is commonly called alumina and may also be called aloxide, aloxite, or alundum depending on particular forms or applications. It occurs naturally in its crystalline polymorphic phase α-Al_2O_3 as the mineral corundum, varieties of which form the precious gemstones ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.

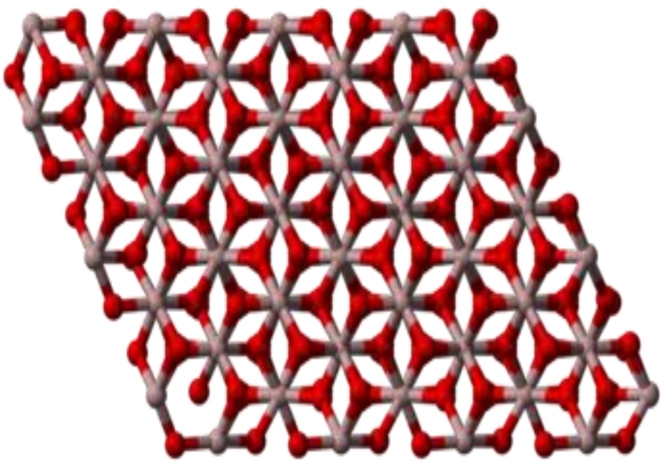

Fig 3.2 STRUCTURE OF ALUMINIUM OXIDE

Aluminium oxide is a thermally unstable and insoluble compound that occurs naturally in various minerals such as corundum, a crystalline variant of the oxide, and bauxite, which is considered as its principal aluminium ore.

3.3.1 PRODUCTION OF ALUMINIUM OXIDE:

Aluminium hydroxide minerals are the main component of bauxite, the principal ore of aluminium. A mixture of the minerals comprises bauxite ore, including gibbsite ($Al(OH)_3$), boehmite (γ-$AlO(OH)$), and diaspore (α-$AlO(OH)$), along with impurities of iron oxides and hydroxides, quartz and clay minerals. Bauxites are found in laterites. Bauxite is purified by the Bayer process:

$$Al_2O_3 + H_2O + NaOH \rightarrow NaAl(OH)_4$$

$$Al(OH)_3 + NaOH \rightarrow NaAl(OH)_4$$

Except for SiO_2, the other components of bauxite do not dissolve in base. Upon filtering the basic mixture, Fe_2O_3 is removed. When the Bayer liquor is cooled, $Al(OH)_3$ precipitates, leaving the silicates in solution.

$$NaAl(OH)_4 \rightarrow NaOH + Al(OH)_3$$

The solid $Al(OH)_3$ Gibbsite is then calcined (heated to over 1100 °C) to give aluminium oxide:

$$2\ Al(OH)_3 \rightarrow Al_2O_3 + 3\ H_2O$$

The product aluminium oxide tends to be multi-phase, i.e., consisting of several phases of aluminium oxide rather than solely corundum. The production process can therefore be optimized to produce a tailored product. The type of phases present affects, for example, the solubility and pore structure of the aluminium oxide product which, in turn, affects the cost of aluminium production and pollution control.

3.3.2 PROPERTIES OF ALUMINIUM OXIDE:

Due to its excellent mechanical, chemical and thermal qualities, alumina stands out from many comparable materials by delivering equal or better solutions for low-cost production and manufacturing.

Table 3.4 GENERAL PROPERTIES OF ALUMINIUM OXIDE

PROPERTY	VALUE
MELTING POINT	2072 ^{O} C
BOILING POINT	2977 ^{0}C
HARDNESS	15-19GPa
ELECTRICAL RESISTIVITY	1012-1013 ohm-m
MECHANICAL STRENGTH	300-630 MPa
COMPRESSIVE STRENGTH	2000-4000 MPa
THERMAL CONDUCTIVITY	20-30 W/mK
MOLECULAR MASS	101.96 g/mol
DENSITY	3.95 g/cm^3
APPEARANCE	SOLID

3.3.3 APPLICATIONS OF ALUMINIUM OXIDE:

- In lighting, translucent aluminium oxide is used in some sodium vapor lamps. Aluminium oxide is also used in preparation of coating suspensions in compact fluorescent lamps.
- In chemistry laboratories, aluminium oxide is a medium for chromatography, available in basic (pH 9.5), acidic (pH 4.5 when in water) and neutral formulations.

- Health and medical applications include it as a material in hip replacements and birth control pills.
- It is used as a scintillator and dosimeter for radiation protection and therapy applications for its optically stimulated luminescence properties.[citation needed]
- Insulation for high-temperature furnaces is often manufactured from aluminium oxide. Sometimes the insulation has varying percentages of silica depending on the temperature rating of the material. The insulation can be made in blanket, board, brick and loose fiber forms for various application requirements.
- Small pieces of aluminium oxide are often used as boiling chips in chemistry.
- It is also used to make spark plug insulators.
- Using a plasma spray process and mixed with titania, it is coated onto the braking surface of some bicycle rims to provide abrasion and wear resistance.[citation needed]
- Most ceramic eyes on fishing rods are circular rings made from aluminium oxide.[citation needed]
- In its finest powdered (white) form, called Diamantine, aluminium oxide is used as a superior polishing abrasive in watchmaking and clockmaking.
- Aluminium oxide is also used in the coating of stanchions in the motocross and mountain bike industry. This coating is combined with molybdenum disulfate to provide long term lubrication of the surface.

4 METHODOLOGY

4.1 STIR CASTING:

Composites were made using the star casting method. This experiment employed 20um silicon carbide particles to make AL-Sic with varied compositions. Initially, aluminium 6061 alloy ingots are stored in a graphite crucible and melted at 700 degrees Celsius in an electric resistance furnace. Silicon carbide is preheated at 300 degrees Celsius in a Muffle furnace. The stirring equipment is moved closer to the furnace, the starter is dipped inside the crucible, and the crucible is stirred at 100rpm. The impeller spins, creating a vortex that drags the reinforcing particle from the surface into the melt. It took around 45 minutes to whisk everything together.

Fig 4.2 STIR CASTING EQUIPMENT

Fig 4.1 CRUCIBLE

Adding different amounts of SiC and Al2O3 reinforcement to melted aluminium 6061 (0, 0.5, 1, 1.5 percent).

After removing the stirring setup, the mixed melt is poured into the appropriate preheated metallic Die at 200°C to form a cylindrical rod with the requisite dimensions. By air quenching, the molten metal is allowed to cool and solidify.

The casted composites were machined and converted into tensile, hardness, and wear testing specimens in accordance with requirements.

4.2 COMPOSITIONS OF SAMPLE:

Table 4.1 COMPOSITION OF MATRIX AND REINFORCEMENT

SAMPLE	MATRIX(Al-6061)	SiC(%)	Al2O3(%)
1	100	0	0
2	99	0.5	0.5
3	98	1	1
4	97	1.5	1.5

Fig 4.3 MOULD

Fig 4.4 FINAL PRODUCT

4.3 WEAR TEST ON PIN-ON-DISC APPARATUS:

Wear samples are made in the shape of pins (length 30 mm, diameter 5 mm, as per the manufacturer's specifications. Standards (ASTM G99-95). Grinding 600-grit silicon carbide paper and washing with alcohol were used to prepare the contact surfaces. Experiments were carried out using a Pin-on-disc type Friction and Wear monitor (DUCOM; TL-20) with a data recording system to examine the wear properties of the composite against a hardened ground steel disc (En-32) with a

Fig 4.5 PIN-ON-DISC APPARATUS

hardness of 65 HRC and a surface roughness of 0.5 m. It's a versatile piece of equipment used to investigate wear in sliding situations. Between a stationary Pin and a rotating disc, sliding usually occurs. A D.C. motor with a speed range of 0-2000 rev/min rotates the disc, which has a worn track diameter of 50 mm, with a sliding speed of 0 to 10 m/sec. Dead weight will be used to provide load on the pin (specimen) using a pulley string arrangement.

5 RESULTS AND DISCUSSIONS

By using Pin-on-disc apparatus we have calculated the weight loss of the composition at various loads(20N, 30N, 40N). These results are also shown in form of graphs as follows.

5.1 WEIGHT LOSS WITH RESPECT TO LOAD APPLIED:

Table 5.1 WEIGHT LOSS AT 20N

	Speed (m/sec)		
	2	3	4
Composition %	Weight loss	Weight loss	Weight loss
1	0.020	0.023	0.026
2	0.019	0.022	0.025
3	0.018	0.021	0.023

Table 5.2 WEIGHT LOSS AT 30N

	Speed (m/sec)		
	2	3	4
Composition %	Weight loss	Weight loss	Weight loss
1	0.024	0.029	0.033
2	0.023	0.027	0.032
3	0.021	0.024	0.029

Table 5.3 WEIGHT LOSS AT 40N

	Speed (m/sec)		
	2	3	4
Composition %	Weight loss	Weight loss	Weight loss
1	0.020	0.023	0.026
2	0.019	0.022	0.025
3	0.018	0.021	0.023

5.2 WEIGHT LOSS(Y-AXIS) vs % OF COMPOSITION(X-AXIS):

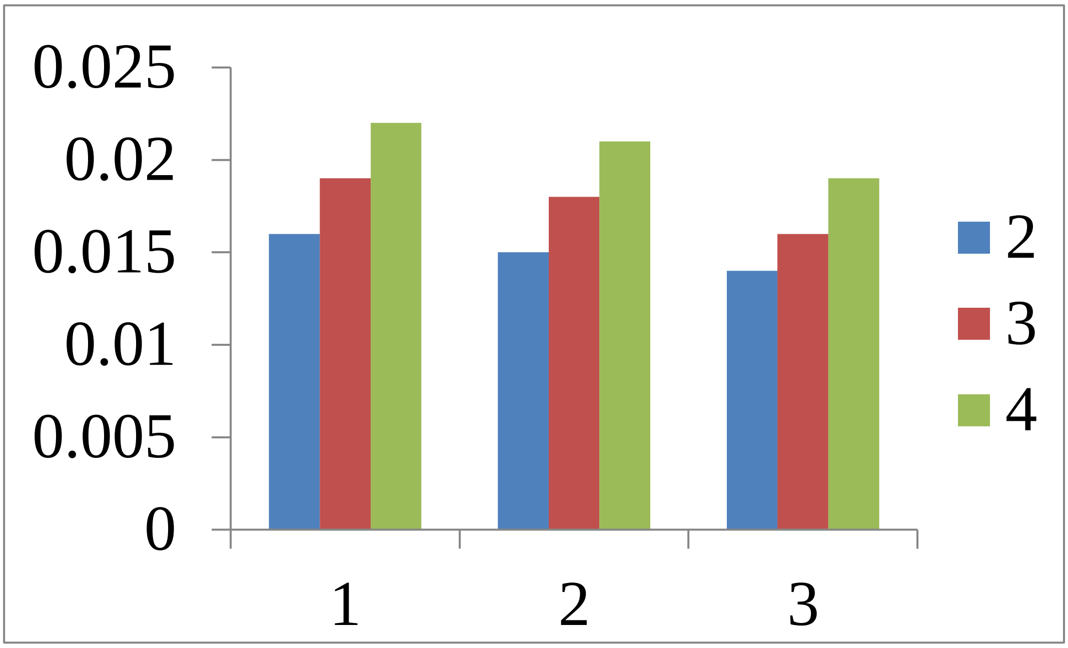

Fig 5.1 WEIGHT LOSS AT 20N

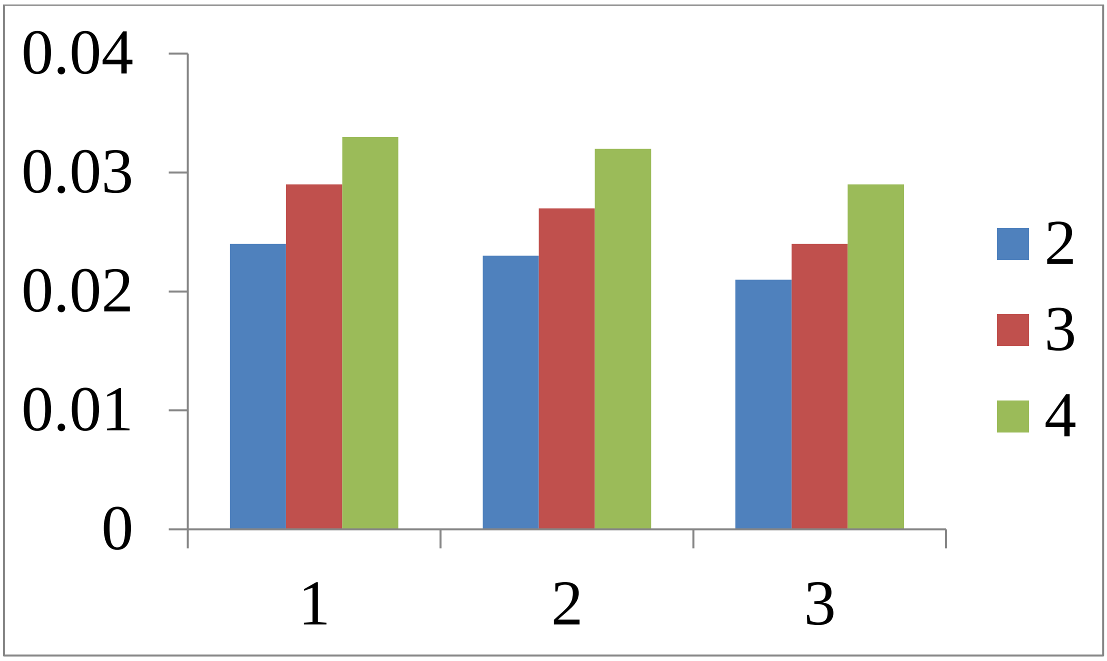

Fig 5.2 WEIGHT LOSS AT 30N

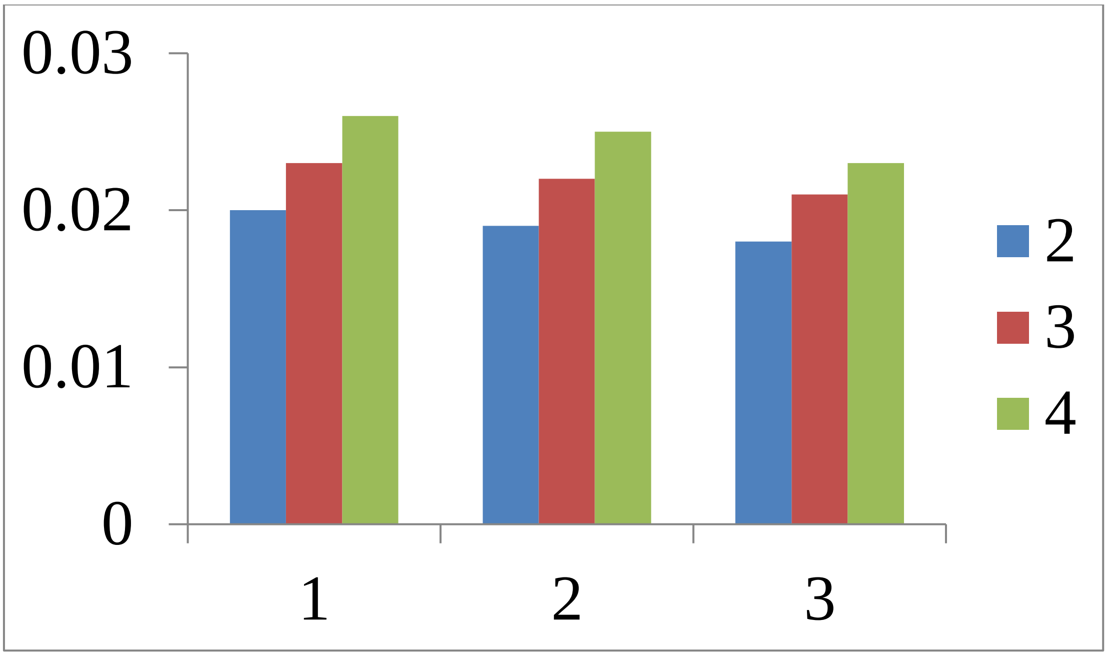

Fig 5.3 WEIGHT LOSS AT 40N

5.3 L9 ORTHOGONAL ARRAY:

As process parameters, the experiment defines three main wear testing conditions: % of composition, sliding speed, and applied load. The trials were carried out to see how the following parameter affected MMC dry sliding wear. Table shows the control elements and their levels. The L9 (3)4 orthogonal array is shown in the table. There would be 3^4 = 81 runs if the complete factorial design was used. Only 9 iterations are required for the L9 (3^4) array, which is a quarter of the whole factorial design. Based on the degree of freedom, the typical Taguchi experimental design L9 $(3)^4$ was adopted. The orthogonal array's degrees of freedom should be larger than or at least equal to those of the process parameters.

Table 5.4 PROCESS PARAMETERS AND THEIR LEVELS

Parameter	**Level-1**	**Level-2**	**Level-3**
% Composition	1	2	3
Load (N)	20	30	40
Speed (m/sec)	2	3	4

Table 5.5 L9 ORTHOGONAL ARRAY

S.No.	% Composition	Load	Speed
1	1	20	2
2	1	30	3
3	1	40	4
4	2	20	3
5	2	30	4
6	2	40	2

7	3	20	4
8	3	30	2
9	3	40	3

Table 5.6 EXPERIMENTAL RESULTS

S.No.	Wear rate (mm3/min)*10-3	Coefficient of Friction
1	3.9	0.345
2	4.6	0.356
3	6.0	0.362
4	3.2	0.328
5	4.4	0.336
6	5.8	0.354
7	2.8	0.322
8	4.1	0.330
9	5.2	0.341

5.4 TAGUCHI RESULTS:

The Taguchi method optimizes design parameters to minimize variation before optimizing design to hit mean target values for output parameters. The Taguchi method uses special orthogonal arrays to study all the design factors with minimum of experiments.

Table 5.7 S/N RATIOS OF RESPONSES

S.No.	Wear rate	Coefficient of Friction
1	-11.8213	9.2436
2	-13.2552	8.9710
3	-15.5630	8.8258
4	-10.1030	9.6825
5	-12.8691	9.4732
6	-15.2686	9.0199
7	-8.9432	9.8428
8	-12.2557	9.6297
9	-14.3201	9.3449

Table 5.8 TAGUCHI RESULTS OF WEAR TESTS

Level	% Composition	Load	Speed
1	-13.55	-10.29	-13.12
2	-12.75	-12.79	-12.56
3	-11.84	-15.05	-12.46
Delta	1.71	4.76	0.66
Rank	2	1	3

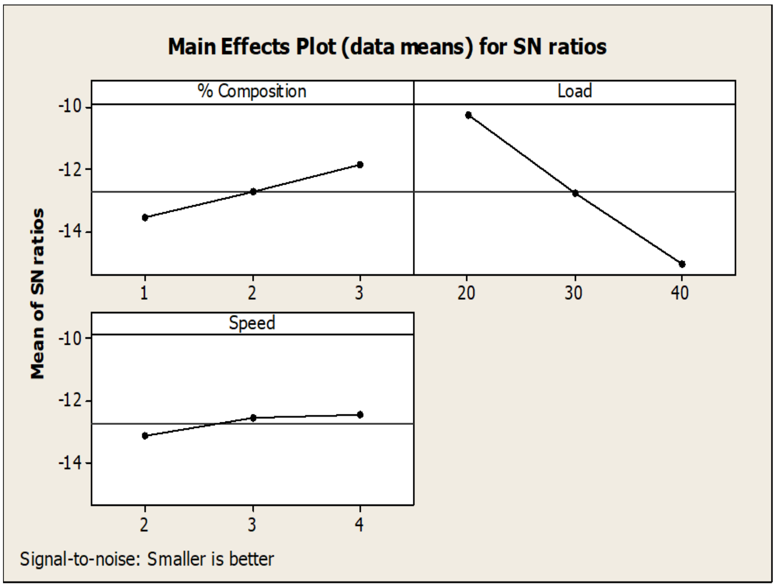

Fig 5.4 MAIN EFFECTS PLOT FOR S/N RATIO FOR WEAR TESTS

Table 5.9 TAGUCHI RESULTS OF COEFFICIENT OF FRICTION

Level	% Composition	Load	Speed
1	9.013	9.590	9.298
2	9.392	9.358	9.333
3	9.606	9.064	9.381
Delta	0.592	0.526	0.083
Rank	1	2	3

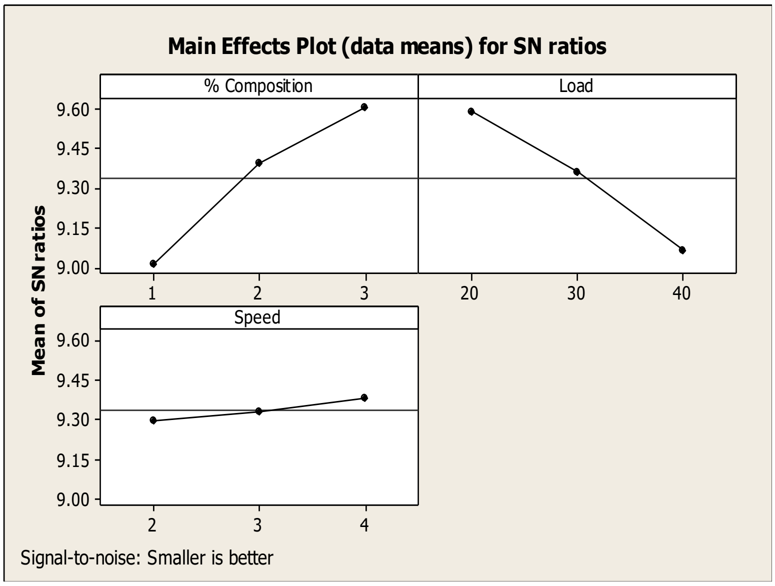

Fig 5.5 MAIN EFFECTS PLOT FOR S/N RATIO FOR COEFFICIENT OF FRICTION

5.5 MICROSTRUCTURAL ANALYSIS:

Figure shows the wear track patterns (i.e., worn surfaces) of the HAMMCs that were studied using scanning electron microscope (SEM) for the optimal parameters L1-S3-D3 (20N, 4.5m/s, 3000m). The presence of pits or prows is clearly observed in the worn surfaces, which is an indication of adhesive wear. As the percentage of reinforcement increases, the volume of prows also decreases

Fig 5.6 MICROSTRUCTURE AT 1% COMPOSITION

Fig 5.7 MICROSTRUCTURE AT 2% COMPOSITION

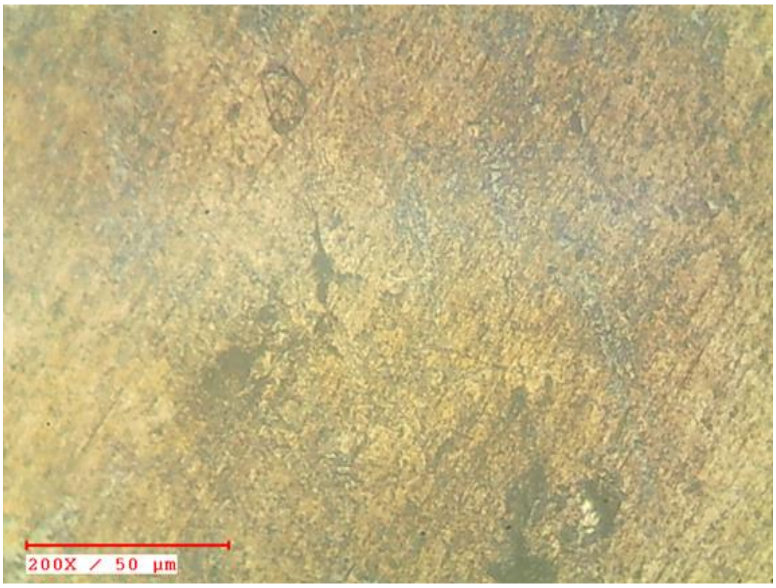

Fig 5.8 MICROSTRUCTURE AT 3% COMPOSITION

5.6 ANOVA RESULTS:

5.6.1 FOR WEAR TEST:

Table 5.10 ANOVA Results for Wear Rate S=0.0881917, R2=99.84%, R2(adj)=99.35%

Source	DF	Seq SS	Adj SS	Adj MS	F	P
% Composition	2	0.9622	0.9622	0.4811	61.86	0.016
Load	2	8.4289	8.4289	4.2144	541.86	0.002
Speed	2	0.1156	0.1156	0.0578	7.43	0.119
Error	2	0.0156	0.0156	0.0078		
Total	8	9.5222				

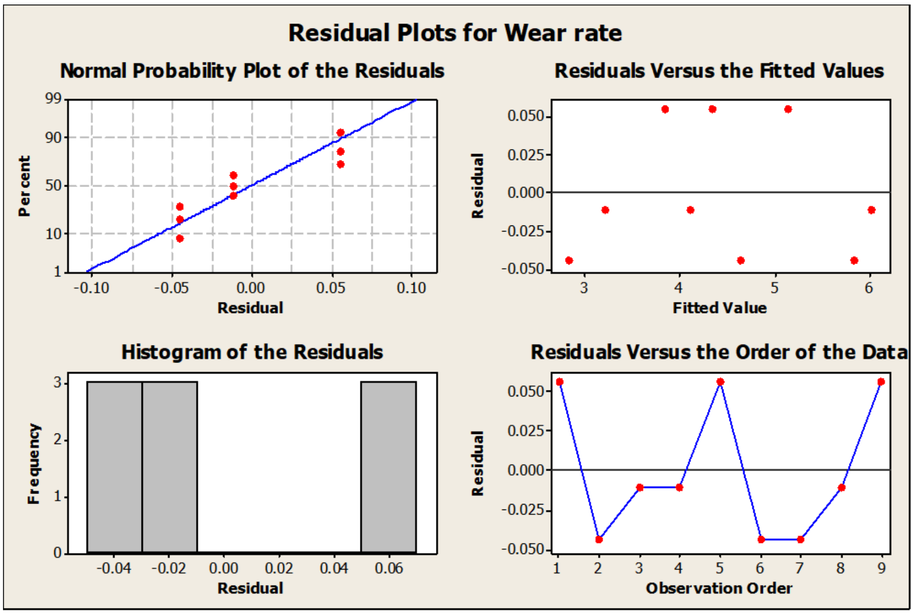

Fig 5.9 RESIDUAL PLOTS FOR WEAR RATE

Table 5.11 ANOVA Results for Coefficient of Friction S=0.00371184, R2=98.19%, R2(adj)=92.77%

Source	DF	Seq SS	Adj SS	Adj MS	F	P
% Composition	2	0.0008389	0.0008389	0.0004194	30.44	0.032
Load	2	0.0006442	0.0006442	0.0003221	23.38	0.041
Speed	2	0.0000136	0.0000136	0.0000068	0.49	0.670
Error	2	0.0000276	0.0000276	0.0000138		
Total	8	0.0015242				

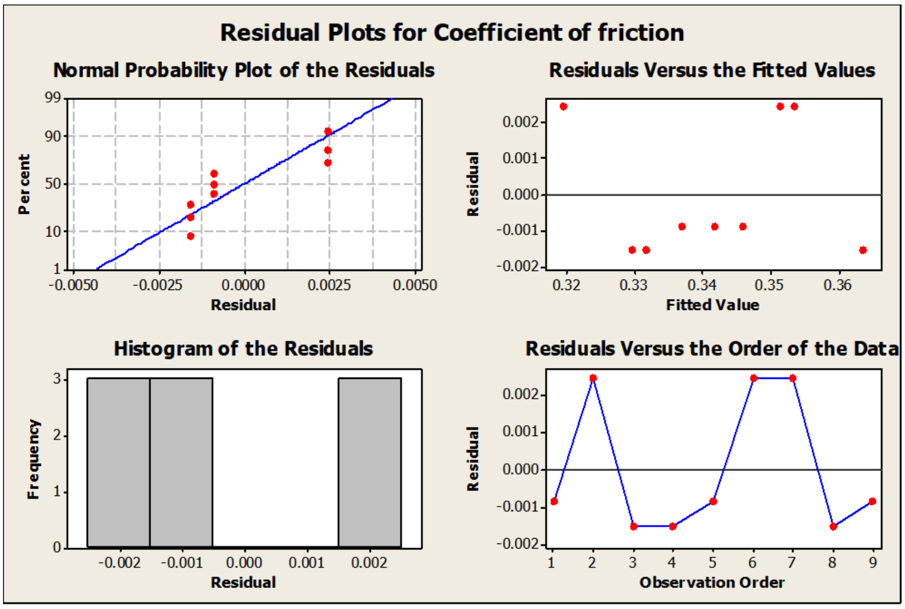

Fig 5.10 RESIDUAL PLOTS FOR COEFFICIENT OF FRICTION

6 CONCLUSIONS

From the experimental results the following conclusions can be made

- **From Pin-on-disc results:**

The weight loss has been reduced with the increase in the reinforcement compositions.

- **From Taguchi's results:**

Both Wear rate and coefficient of friction are optimized at 3% of composition, 20N load and 4m/sec speed respectively.

- **From ANOVA results:**

Load and % of composition are found as the predominant factors for the responses respectively.

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