Mechanical and Tribological Analysis of Polymer Matrix Composites

Ajit Kumar Senapati, Subham Choudhury, Snehansu Sekhar Mishra, Ravi Roushan, Subhashis Nanda, Amit Kumar Mohanta

Abstract: ***Polymer matrix composites are very popular in the applications of lightweight aircraft, marine and automobile structures. Particularly, epoxy resin based reinforced composites are the prepared choice because of the superior physical, thermal, electrical and mechanical properties, ease of processing, excellent wettability with various reinforcements, less moisture pick up, low density, and ductile nature of the epoxy resin. In accordance with that, the present work is aimed to study the mechanical and tribological properties of pariculate filled fibre reinforced glass Epoxy resin polymer matrix composite. At first glass Epoxy resin polymer matrix composite was prepared by filling varying wt% of Fly Ash(240 mesh size) and Carbon Powder(240 mesh size) using hand lay up technique. While preparation of the polymer matrix composite a brief study on the process of preparation and composition was studied. After that tests for mechanical and tribological properties was carried out. The mechanical property tests such as density and hardness was investigated in accordance with ASTM standards. Tribological properties i.e. two body abrasive wear study was carried out using a pin-on-disc wear tester. According to the observations the concentration of filler material best suited for different purposes was determined. Finally we have compared the properties of Fly Ash and Carbon Powder filled fibre reinforced glass Epoxy resin polymer matrix composite with each other and other polymer matrix composites. It also highlights the current application and future potential of particulate filled glass fiber reinforced polymer matrix composites in aerospace, automotive, marine and other construction industries.***

Keywords: ***Polymer Matrix Composites (PMCs), Fly ash, Carbon Powder, Abrasive wear, Micro Hardness, Density.***

I. INTRODUCTION

1.1 Overview of Composites

Metals, Ceramics and high polymers have their own characteristics in pure state. They are being used in various fields of operations. In case of complicated situations dealt by modern technologies, e.g. gas turbines, supersonics, Spacecraft and missile technology a combinations of specific properties are required of material which may only be obtained from different materials, but not from a single substance. For Example, aeronautics require lightness, low density, high strength, stiffness and resistance to abrasion, corrosion and impact which is neither available from aluminium, magnesium, or steel but a combined form and solve this problem. Technology needs development of a new class of material to take care of such increasing demands and such materials which are called 'composite materials'. Composite material consists of two or more materials in a different phase. In traditional engineering impurities in metal can be represented in different phase and by definition considered as a composite, but are not considered as a composite due to modulus of strength is nearly same as that of pure metal. Oldest known composites were natural composites, wood consist of cellulose fiber in lignin composites, human bone can be considered as a osteons embedded in an interstitial bone matrix.

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1.2 Definitions of Composite

Composites are materials consisting of two or more chemically distinct constituents, on a macro-scale, having a distinct interface separating them. One or more discontinuous phases are embedded in a continuous phase to form a composite. Composite mainly formed from two distinguished material one of which is in the particle or fiber or in sheet form are combined with other material known as a matrix. Fiber in the composites acts as a principle load carrying member due to its high strength modules while matrix in the composites acts as a load transfer medium between the fibers. Due to more ductility of the composite it gives matrix high toughness.

1.3 Types of Composites

1.3.1 On the basis of Matrix Material:

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 composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

Composites material formed from two different materials, matrix and fibrous system. And on the basis of matrix used composites may be categories into three different categories.

1.3.1.1 Metal matrix composites
1.3.1.2 Ceramic matrix composites
1.3.1.3 Polymer matrix composite

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1.3.1.1 Metal matrix composites:

A Metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to-weight ratios of resulting composites can be higher than most alloys. Metal matrix composites, at present, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli. Due to above mentioned reason it is used in the combustion chamber nozzle (in the rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

1.3.1.2 Ceramic matrix composites:

Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. Ceramic matrix composites (CMCs) are a subgroup of composite materials as well as a subgroup of technical ceramics. They consist of ceramic fibres embedded in a ceramic matrix, thus forming a ceramic fibre reinforced ceramic material. The matrix and fibres can consist of any ceramic material, whereby carbon and carbon fibres can also be considered a ceramic material.

1.3.1.3 Polymer matrix composites:

When different types of polymeric material use as a matrix material to make composite it is known as the polymer matrix composites. Polymers are the macromolecule formed by the linking together of a large number of smaller units know as monomers. It shows high tensile strength, high stiffness, fracture toughness, good abrasion resistance, puncher resistant, corrosion resistant and low cost. It shows low thermal resistance and has high co-efficient of thermal expansion. It is used in the field of automobile where we need damping and good shock absorbing function. The most common types of reinforcement used for PMC are strong and brittle fibers incorporated into a soft and ductile polymeric matrix. In this case, PMC are referred to as fiber reinforced plastics (FRP). Capital letters G, C and A are placed before the acronym FRP to specify the nature of the reinforcing fibers: glass, carbon or aramid fibers. The fibers can be long (continuous) or short (discontinuous). Long fibers can be unidirectional (all fibers parallel to each other) or woven into a fabric or cloth. Unidirectional fibers provide for the highest mechanical properties in a composite. Glass fiber reinforced plastics (GFRP) are by far the most commonly used materials in view of their high specific mechanical properties and low cost. Carbon fiber reinforced plastics (CFRP) and aramid fiber reinforced plastics (AFRP) provide higher specific strength, higher specific stiffness and lighter weight. They are, however, expensive and are used only for those applications where performance and not cost is the major consideration. AFRP is used instead of CFRP where strength, lightness and toughness are major considerations, and stiffness and high temperature performance are not. It cannot be used in high temperature application due to its high CTE. It is further divided into two types.

i. Thermosetting polymer matrix composites.

ii. Thermoplastic polymer matrix composites.

i. Thermosetting polymer matrix composites: Usually thermostats are the material usually liquid or malleable prior to curing and designed to mold into their final form. Once it gets its final form it will not melt due to its well-developed 3D bonded structure. Generally used thermosetting polymers are epoxy and cyanate ester. Thermosetting polymer matrix composites have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Thermoset polymers remain rigid when heated and consist of a highly cross-linked three dimensional network; they are quite strong and stiff and have poor ductility.

Epoxy (Epoxide):

Epoxy is used widely in numerous formulations and forms in the aircraft-aerospace industry. It is called "the work horse of modern day composites". Standard epoxies (90%) are based on bisphenol A diglycidyl ether formula.In recent years, the epoxy formulations used in composite prepregs have been finetuned to improve their toughness, impact strength and moisture absorption resistance. Maximum properties have been realized for this polymer.

This is not only used in aircraft-aerospace demand. It is used in military and commercial applications and is also used in construction. Epoxy-reinforced concrete and glass-reinforced and carbon-reinforced epoxy structures are used in building and bridge structures.

ii. Thermoplastics polymer matrix composites:

Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of conventional compress techniques to mould the compounds. Thermoplastic polymers consists of flexible linear molecular chains that are tangled together and, as the name indicates, soften when heated; they have lower strength and modulus but quite high ductility. The advantage of thermoplastics systems over thermosets are that there are no chemical reactions involved, which often result in release of gases or heat. Manufacturing is limited by the time required for heating, shaping and cooling the structures. However,

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their redeeming qualities like rigidity, toughness and ability to repudiate creep, place thermoplastics in the important composite materials bracket. They are used in automotive control panels, electronic products encasement etc.

1.3.2 On the basis of Reinforcement:

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

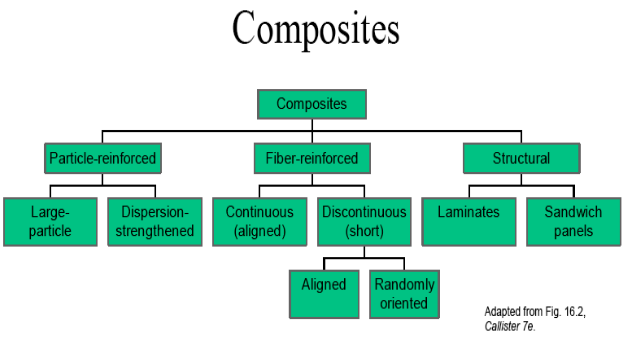

Figure 1: Classification of Composites

Reinforcements: A strong, inert woven and nonwoven fibrous material incorporated into the matrix to improve its metal glass and physical properties. Typical reinforcements are asbestos, boron, carbon, metal glass and ceramic fibers, flock, graphite, jute, sisal and whiskers, as well as chopped paper, macerated fabrics, and synthetic fibers. The primary difference between reinforcement and filler is the reinforcement markedly improves tensile and flexural strength, whereas filler usually does not. Also to be effective, reinforcement must form a strong adhesive bond with the resin.

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. All of the different fibers used in composites have different properties and so affect the properties of the composite in different ways .However, individual fibers or fiber bundles can only be used on their own in a few processes such as filament winding. For most other applications, the fibers need to be arranged into some form of sheet, known as a fabric, to make handling possible. Different ways for assembling fibers into sheets and the variety of fiber orientations possible lead to there being many different types of fabrics, each of which has its own characteristics.

i. Fly Ash as reinforcement:

Fly ash is an industrial waste, which is a byproduct of coal combustion collected from electrostatic precipitators and bottom ash at the bottom of furnaces. It is a finegrained, powder material and comprises the fine particles that rise with the flue gases and usually collected by means of electrostatic precipitators, bag housings, or mechanical collection devices such as cyclones. Fly ash obtained from electrostatic precipitators varies in size from 5µm to 75 µm. A typical composition of fly ash is as shown in the table below.

Reinforcements for the composites can be fibers, fabrics particles or whiskers. Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does their shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibers. Figure shows types of reinforcements in composites.

Reinforcing constituents in composites, as the word indicates, provide the strength that makes the composite what it is. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements.

A reinforcement that embellishes the matrix strength must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite. This means that the ductility should be minimal or even nil the composite must behave as brittle as possible.

1.4 Glass Fiber:

Glass fiber is a material consisting of numerous extremely fine fibers of glass. Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as strong or as rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites. Glass fibers are therefore used as a reinforcing agent for many polymer products; to form a very strong and relatively lightweight fiber-reinforced polymer (FRP) composite material called glass-reinforced plastic (GRP), also popularly known as "fiberglass". This structural material product contains little or no air or gas, is more dense, and is a much poorer thermal insulator than is glasswool.

Properties Of Glass Fiber :

1. **Thermal**

Glass fibers are useful thermal insulators because of their high ratio of surface area to weight. However, the increased surface area makes them much more susceptible to chemical attack. By trapping air within them, blocks of glass fiber make good thermal insulation, with a thermal conductivity of the order of 0.05 W/(m·K).

2. **Tensile**

Table 1: Properties of Glass Fiber

Fiber type	Tensile strength (MPa)	Compressive strength (MPa)	Density (g/cm^3)	Thermal expansion (µm/m·°C)	Softening T (°C)
E-glass	3445	1080	2.58	5.4	846
S-2 glass	4890	1600	2.46	2.9	1056

The strength of glass is usually tested and reported for "virgin" or pristine fibers—those that have just been manufactured. The freshest, thinnest fibers are the strongest because the thinner fibers are more ductile. The more the surface is scratched, the less the resulting tenacity. Because glass has an amorphous structure,

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Its properties are the same along the fiber and across the fiber. Humidity is an important factor in the tensile strength. Moisture is easily adsorbed and can worsen microscopic cracks and surface defects, and lessen tenacity.In contrast to carbon fiber, glass can undergo more elongation before it breaks. There is a correlation between bending diameter of the filament and the filament diameter. The viscosity of the molten glass is very important for manufacturing success. During drawing (pulling of the glass to reduce fiber circumference), the viscosity must be relatively low. If it is too high, the fiber will break during drawing. However, if it is too low, the glass will form droplets rather than drawing out into fiber.

1.5 Advantages of PMC over MMC

- High specific strength
- Better Tribological properties
- Lower specific gravity
- Low electrical and thermal conductivity.
- Better suitability over ageing and weathering.
- Flexible in design
- Wide varieties of availability

1.6 Effect of Addition of Filler Materials

Filler materials we are using are Fly Ash & Carbon Powder. Following are the effects of addition of fillers

- Fillers improve the wear resistance of the composites.
- Fillers reduce the shrinkage of polymer matrix composite.
- Fillers reduces the cost of composite by reducing the quantity of costlier resin and reinforcement fibers.
- Fillers enhance the mechanical properties of the composites by transferring stresses and by improving the bonding between the reinforcement and matrix.
- Fillers influence the fire resistance of composites.

1.7 Future Scope of PMCs

- Many modern light aircraft are being increasingly designed to contain as much lightweight composite material as possible.Concord's disk brakes use this material, rocket nozzles and re-entry shields have been fashioned from it, and there are other possibilities for its use as static components in jet engines. A particularly interesting (and important) application of composites is in its development in Australia as a means of repairing battle damage (patching) in metal aircraft structures. Space applications offer many opportunities for employing light-weight, high-rigidity structures for structural purposes.
- Marine applications include surface vessels, offshore structures and underwater applications. A vast range of pleasure craft has long been produced in GRP, but much serious use is also made of the same materials for hull and superstructure construction of passenger transport vessels, fishing boats and military (mine-countermeasures) vessels. Sea-water cooling circuits may also be made of GRP as well as hulls and other structures. Off-shore structures such as oil rigs also make use of reinforced plastics, especially if they can be shown to improve on the safety of steel structures, for fire protection piping circuits, walkways, flooring, ladders, tanks and storage vessels, blast panels,

II. LITERATURE REVIEW

2.1 Literature Survey

This literature review provides background information on the issues to be considered in this project and emphasizes the relevance of the present study. This treatise embraces some related aspects of polymer composites with special reference to their mechanical and tribological properties.

- Epoxy resin has been significantly important to the engineering community for many years. Components made of epoxy-based materials have been providing outstanding mechanical, thermal, and electrical properties.Using an additional phase (e.g.inorganic fillers) to strengthen the properties of epoxy resins has become common practice **(Zheng et al 2003).** It has been established in the recent years that polymer-based composites reinforced with a small percentage of strong fillers can significantly improve the mechanical, thermal, and barrier properties of the pure polymer matrix.
- **Dr. K.A. Rameshkumar** conducted a study on investigation of Mechanical Properties on Epoxy, Fly Ash and E -Glass Fiber Reinforcement Composite Material and reported that that addition of fly ash significantly improves ultimate tensile strength along with compressive strengthened hardness properties.
- **B. Suresha, G. Chandramohan, J. N. Prakash, V. Balusamy and K. Sankaranarayanasamy(2006)** investigated the role of Fillers on Friction and Slide Wear Characteristics in Glass-Epoxy Composite Systems and reported that Inclusion of Graphite and SiC particulate fillers contributed significantly in reducing friction and exhibited better wear resistant properties. Silicon carbide filled G-E composite shows higher resistance to slide wear compared to plain G-E composites. Graphite filled G-E composite shows lower coefficient of friction compared to the other two samples.
- **Mohan et al (2011)** investigated the effects of silicon carbide fillers on two-body abrasive wear behavior of glass fabric-epoxy (G-E) composites.They reported that increase of abrading distance increases the weal loss linearly. The addition of SiC particles with the G-E composites increases wear resistance. This is due to the incorporation of SiC particles, led to less matrix and less fiber damage during the abrasion.
- **K. Devendra and T. Rangaswamy(2012)** studied Mechanical behaviour of E-Glass Fiber reinforced Epoxy composite filled with varying concentration of AL2O3, Mg(OH)2 and SiC. They reported that composites filled by (10% vol.).Mg(OH)2 exhibited maximum ultimate tensile strength and SiC filled composite exhibited maximum impact strength, flexural strength and Hardness.

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- **Suresha et al (2007)** investigated the role of SiC fillers in glassepoxy (G-E) composites on mechanical and dry sliding wear behavior. They reported that the mechanical properties such as tensile strength, tensile modulus, and elongation at break, flexural strength, and hardness improved due to the inclusion of SiC filler. Also, the dry slide wear test results of SiC-G-E composite showed a lower slide wear loss irrespective of the load/sliding velocity when compared to G-E composite.
- The use of graphite as a filler material was known to improve the mechanical and tribological properties of polymer matrix composites.The mechanical and tribological properties of the particulate-filled bi-directional carbon/glass fabric-reinforced epoxy composite material were evaluated by **Suresha et al [2006, 2007 and 2009]**.They concluded that the incorporation of particulate fillers improved the mechanical and tribological properties of polymer composites.
- **Biswas and Satapathy (2010)** conducted the tribological and mechanical investigation on alumina filled glass-epoxy composites. The results revealed that alumina filled glass-epoxy composite exhibited lower mechanical properties even though it showed a superior wear performance when compared to other materials.
- **Basavarajappa et al (2010)** investigated the effect of SiC filler material on three-body abrasive wear behavior of glass-epoxy composites under the parameters of abrading distance, applied load and sliding speed.They reported that the weight loss increases with an increase in load, sliding speed and abrading distance; even though SiC filled glass-epoxy composite exhibit a significant wear resistance by the loading of SiC when compared to the unfilled glass-epoxy composites.
- **Sudarshan Rao K , Y.S Varadarajan and N Rajendra(2011)** investigated the abrasive wear behaviour of graphite filled carbon fabric reinforcement epoxy composite and reported that abrasive wear of the composites depend on the applied load, as well as on the weight fraction of fillers. Among the control parameters, normal load has the highest physical properties as well as statistical influence on the abrasive wear of the composites, followed by sliding distance and filler content.
- **Sujesh and Ganesan (2012)** investigated the tensile behavior of bidirectional woven Glass Fiber Reinforced Epoxy Polymer (GFRP) composites filled with nano silica. He reported that reinforcement of nano silica with the composite increases the stiffness with damage free range. Thus the silica compensates for the weak mechanical properties of GFRP composite, even though the tensile result showed a slight decrement in ultimate tensile strength and tensile modulus of the composites.
- **R.Satheesh Raja, K.Manisekar, V.Manikandan(2013)** conducted a study on Effect of fly ash filler size on mechanical properties of polymer matrix composites and found that the size reduction of fly ash particle enhances the strength of PMC.
- **Weikang Li, Anthony Dichiara, Junwei Zha, Zhongqing Su, Jinbo Bai (2014)** conducted a study on improvement of mechanical and thermo-mechanical properties of glass fabric/epoxy composites by incorporating CNT–Al2O3 hybrids and found the potential of CNT–Al2O3 hybrids as structural reinforcements in fibrous composites.
- **Md Nadeem M, K Chandrashekaran,Yathisha N , Rudramurthy(2014)** conducted a study on the effects of Carbon and glass fibre reinforcement and other fillers on elevated temperature resistant properties of ER matrix composites and reported that Tensile strength, Hardness and impact energy were improved with increase in fillers content. Wear resistance also improved with increase in percentage of fillers substantially.
- **Aditi Kaul Shah & Sandeep K. Sodhi (2015)** studied about Effect of epoxy modifiers on the Tensile Strength of epoxy/glass fibre hybrid composites and found that the mechanical behaviour of Hybrid GFRP composites is improved by the addition of filler abrasive particles.
- **Iskender Ozsoy,Askin Demirkol, Abdullah Mimaroglu, Huseyin Unal, Zafer Demir(2015)** investigated the Influence of Micro- and Nano-Filler Content on the Mechanical Properties of Epoxy Composites and reported that tensile strength, flexural strength and elongation at the break values of composites decreased while the tensile modulus and flexural modulus increased with the increasing micro- and nano-filler content ratio.
- **Vijay D. Karande, Prof. P.R.Kale(2015)** investigated the effect of Fly Ash as Filler on Glass Fiber Reinforced Epoxy Composites and reported that by increasing the percentage of filler content the tensile strength is decreases. It Is concluded that pure composite material showed significant strength when compare to filler content of 10%, 30%and 40%.
- **Prasad Galande, S. E. Zarekar(2016)** investigated the effect of Various Fillers on Mechanical Properties of Glass Fiber Reinforced Polymer Composites and Stiffness, friction coefficient and antiwear abilities of GFRP composites were improved with single incorporation of ceramic whisker while the strength properties were slightly reduced after whisker addition. But after the addition of solid lubricant as secondary filler it improved both mechanical and tribological properties of composites
- **Mr.Chavan V.B. , Prof. Gaikwad M.U.** conducted a study on review on development of Glass Fiber/Epoxy Composite Material and its Characterizations and reported that Ultimate tensile strength and flexural strength of the fiber glass polyester composite increased with increase in the fiber glass Volume fraction of fiber weight fractions. The Young's modulus of elasticity of the composite increased with the fiber glass Volume fraction.

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- **T RAM PRABHU, S BASAVARAJAPPA,R B SANTHOSH and S M ASHWINI(2016)** conducted a study on tribological and mechanical behaviour of dual-particle (nanoclay and CaSiO3)-reinforced E-glass-reinforced epoxy nano-composites and found that the wear loss increases.
  With increasing nanoclay amount due to the particle agglomeration effects. Tensile and flexural test results showed that a good dispersion of nanoclay is achieved with 2 wt% amount in epoxy-based nanocomposites.
- **Halil Burak, Kaybal1, Hasan Ulus1, Ahmet Avcı (2016)** studied about Characterization of Tensile Properties And Toughness Mechanisms on Nano-Al2O3 Epoxy Nano-composites and concluded that using nano-Al2O3 particle would be a new approach to increase tensile properties due to strong matrix-fiber interface adhesion of carbon fiber reinforced nano-Al2O3 epoxy.

2.2 Objectives of the present research work

The knowledge gap in the existing literature review has helped to set the objectives of this research work which are outlined as follows:

- Fabrication of fly Ash and Carbon Powder reinforced glass fiber epoxy resin composites.
- Evaluation of mechanical properties such as density and hardness of composites.
- To study the tribological behaviour of particle reinforced glass epoxy resin polymer matrix composites.

III. EXPERIMENTAL WORK

3.1. RAW MATERIALS:

The raw materials we have taken for conducting the tests are:

PMC = Glass Epoxy Resin Polymer Matrix Composite
Epoxy Resin = AW4858
Hardener = HW 4858
Reinforcement = E-Glass Fiber
Filler Materials = 1. Fly Ash (240 mesh Size)
2. Activated carbon powder(240 mesh size)
3. Carbon powder + Fly Ash(240 mesh size)

We have used E-glass fiber as reinforcement and by varying % concentration of different filler materials we have prepared samples for carrying out tests.

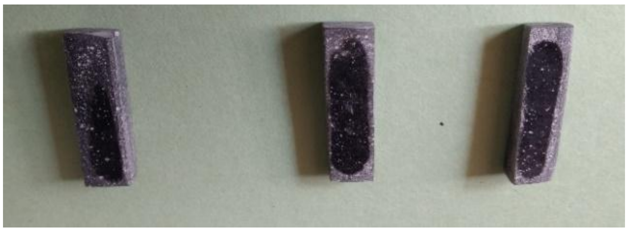

Figure 2 : Raw Samples of Epoxy Resin with Filler Materials

3.2. Fabrication technique:

In our experiment we have used Hand Lay-up method for the preparation of polymer matrix composite.

3.2.1: Hand Lay-Up Method

Hand lay-up technique is the simplest method of composite processing. The infrastructural Requirement for this method is also minimal. The processing steps are quite simple. First of all, a release gel(vacuum grease, wax) is sprayed on the mould surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mould plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats are cut as per the mould size and placed at the surface of mould. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardener (curing agent) and poured onto the surface of mat already placed in the mould. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mould plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mould is opened and the developed composite part is taken out and further processed. The time of curing depends on type of polymer used for composite processing. For example, for epoxy based system, normal curing time at room temperature is 24-48 hours. This method is mainly suitable for thermosetting polymer based composites. Capital and infrastructural requirement is less as compared to other methods. Production rate is less and high volume fraction of reinforcement is difficult to achieve in the processed composites. Generally, the materials used to develop composites through hand lay-up method are given in table.

Materials Used	
Matrix	Epoxy, polyester, polyvinyl ester, phenolic resin, unsaturated polyester, polyurethane resin
Reinforcement	Glass fiber, carbon fiber, aramid fiber, natural plant fibers (sisal, banana, nettle, hemp, flax etc.) (all these fibers are in the form of unidirectional mat, bidirectional (woven) mat, stitched into a fabric form, mat of randomly oriented fibers)

3.3 Fabrication Procedure:

All laminates used in this study were manufactured by hand lay up technique. At first, mould was prepared in accordance with the required sample size. Now, a release gel(vacuum grease, wax) is sprayed on the mould surface to avoid the sticking of polymer to the surface. E-glass plain weave roving fabric, which is compatible to epoxy resin, is used as the reinforcement. The epoxy resin(AW 4858) is mixed with the hardener(HW 4858) in the ratio 5:1 by weight. Reinforcement in the form of woven mats or chopped strand mats are cut as per the mould size and placed at the surface of mould. Then epoxy resin having mixed with hardener (curing agent) is poured onto the surface of mat (glass fiber) already placed in the mould.

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The polymer is uniformly spread with the help of brush. Second layer of glass fiber is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. To prepare the filled G-E composites, fillers (Fly Ash and activated carbon powder) is mixed with a known amount of epoxy resin and glass fiber in varying % concentration. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mould plate which is then kept on the stacked layers and the pressure is applied. After curing at room temperature for 36 hours, mould is opened and the developed composite part is taken out. Now the ready specimen is cut into required sample size 40x8x8mm. Atlast, using sand paper the samples were polished to give it exact dimension.

3.4 Mechanical Property Observation:

3.4.1 Hardness Test:

Hardness test was carried out using Brinnell cum Rockwell hardness tester. The samples were prepared and polished to provide a scratch free test surface. Steel ball indenter of 5mm diameter tip was used for Brinnell Hardness Test.

Figure 3: Brinell cum Rockwell hardness tester

3.5 Physical Property Observation:

Density is one of the basic properties of matter. Density is defined as the mass of an object divided by the volume of the same object. This yields a density of mass per unit volume. If two objects have same volume, but different densities, the object with the higher density will weigh more than identical looking object of lower density. Density of materials can be measured in a no .of ways but in this experiment we used two different methods namely direct measurement of volume using vernier callipers and Archimedes principle to determine the volume to determine the density of the materials and then the results were compared to get the deviation.

3.5.1 Density Test:

A) Weighing the object: An electronic weighing machine which is in accordance with ASTM standard was being used to measure the weight of the sample. While weighing the object it was taken care that the specimen was completely dry in order to avoid any error in measurement.

B) Determining the volume of the regular shaped specimen by measurement: Measurement of the length and the diameter of the cylindrical shaped object were being done using vernier callipers and using the standard mathematical formulae's the results were obtained.

Volume of Cuboid = Length x Breadth x Height

C) Finding the volume of specimen by displacement method: This method is generally being used to measure the volume of irregular shaped object whose volume cannot be measured by direct measurement using vernier calipers. The displacement vessel was being prepared. The beaker of water was being placed on the pan of weighing machine. It was ensured that there was enough water in the beaker to cover the object to be measured and also ensured it wasn't overfilled which lead to the spillage of water and ultimately ruin the measurement. The end of the object was tied to a light string such that it was fully submerged and the new water level in the beaker was recorded. The apparent change in volume was found out and the increase was multiplied with the surface area of the water in order to obtain the volume added into the beaker by the introduction of the objects. This added volume is the volume of the object.

D) Calculating the density: The volume using both the methods were obtained and by dividing mass with that of the volume the density was being obtained.

Density= Mass/Volume.

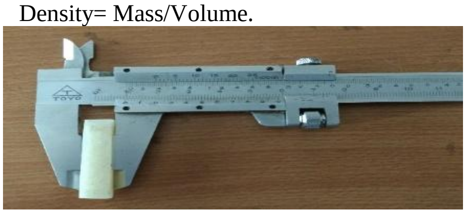

Figure 4: Vernier Calliper Showing the reading

3.6 Tribological Property Observation: Wear Test

This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Materials are tested in pairs under nominaly non-abrasive conditions. For the pin-on-disk wear test, two specimens are required. One, a pin with a radiused tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk centre. In either case, the sliding path is a circle on the disk surface. The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. Linear measures of wear are converted to wear volume (in cubic millimetres) by using appropriate geometric relations. If loss of mass is measured, the mass loss value is converted to volume loss (in cubic millimetres) using an appropriate value for the specimen density. Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load and speed. In the present experiment we are using the sample size of 40x8x8mm and above mentioned steps are carried out to get the desired result.

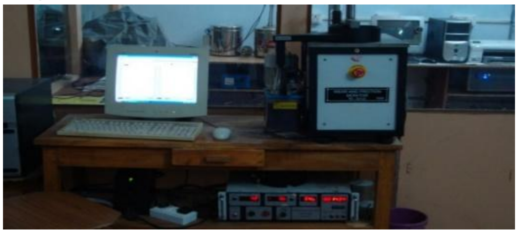

Figure 5 : A pin-on-disc type machine

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IV. RESULT AND DISCUSSION

In this chapter, different test like Wear Test, Micro hardness test, density test were carried out on the newly developed Polymer matrix composites (PMC's). from the glass Epoxy Resin and reinforced particles like Fly ash and Activated Carbon Powder. The results thus obtained from the above mention test were reported, analysed and discussed later in this chapter.

Table 2: Composition of Samples Prepared

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
(Wt. %)	63.34	24.6	4.97	1.23	0.56	0.11	0.64

4.1 Reinforced Particles Analysis:

4.1.1 Fly Ash Analysis:

Table 4: Chemical composition of Fly Ash

We have taken the above reinforced particle (Fly Ash) from the industry which present near to our college. The major components of fly ash as received from the sources and used for reinforcement are listed in Table-4.1 in wt%. The Fly Ash contain mainly of two components SiO2 (63.34 wt%) and AL2O3 (24.60 wt%).

4.2 Mechanical Properties Determination:

Various Mechanical properties such as Hardness, Density and Wear Test has been analysed and the results are as discussed in the following contexts:

4.2.1 Micro Hardness Test:

Micro hardness testing is a method of determining a material's hardness or resistance to penetration when test samples are very small or thin, or when small regions in a composite sample or plating are to be measured. Brinnell cum Rockwell Hardness tester was used for determining the hardness of the material was done. The samples were prepared and polished to provide a scratch free test surface. Steel ball indenter of 5 mm Diameter tip was used for Brinnell Hardness Test**.**The experiment was conducted and the observation was recorded and studied.

Figure 6: Brinnell cum Rockwell Hardness tester

Table 3: Micro Hardness of Glass Epoxy Resin ,Fly Ash and Activated Carbon

Sample Number	Micro Hardness Measurements			Mean (in Kgf)
	Trail - 01	Trail - 02	Trail - 03	
1	57.5	55.5	56	56.33
2	69.5	74.5	65	69.66
3	71.5	73	78.5	74.33
4	61	55	59.5	58.5
5	83.5	89	87	86.5

Major Load During the Test: 250 Kgf, Minor Load During the Test: 10 Kgf

S. No.	Matrix (M)	Reinforcement (R)	FillerMaterials (F)	%age of Matrix (M)	%age of Reinforcement (R)	%age of Filler Materials (F)
1	Epoxy Resin	Glass Fiber	NA	40 %	60%	NA
2	Epoxy Resin	Glass Fiber	Fly Ash (240 M)	40 %	48.16%	11.84%
3	Epoxy Resin	Glass Fiber	Fly Ash (240 M)	40 %	35.48%	24.52%
4	Epoxy Resin	Glass Fiber	Fly Ash	40 %	20.3%	39.7%
5	Epoxy Resin	Glass Fiber	Fly Ash (240 M) +	40 %	15.56%	22.22 % Flyash + 22.22% Carbon

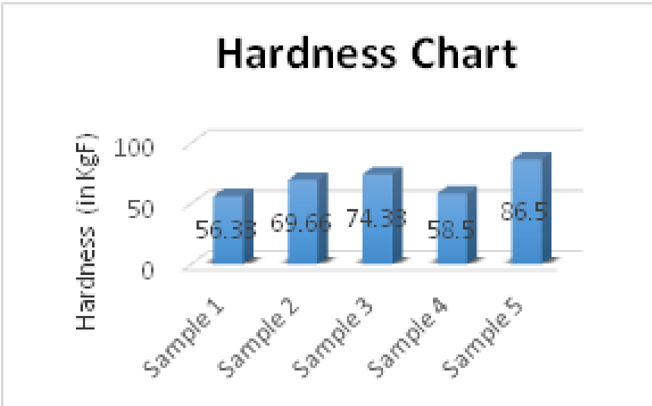

Figure 7: Graphical Representation of Micro Hardness of Glass Epoxy Resin, Fly Ash and Activated Carbon

Figure 8: Sample Before Test

Figure 9: Sample After Test

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4.3 Physical Properties Determination:

Physical properties like density has been analysed and the results are as discussed in the following contexts:

4.3.1 Density:

Density is the mass of an object divided by its volume. There are no. of ways to calculate density of a material but here we used two method to determine the density of the specimen, they are direct measurement of volume using vernier calliper and measurement of volume using Archimedes' principle. The deviation in the result from both the methods were compared to get the accurate value.


Figure 10: Vernier Calliper Figure 11: Weighing Machine

Table 4: Density of Glass Epoxy Resin, Fly Ash and Activated carbon

Sample Number	Mass (gm)	Volume (cm^3)	Density (gm/cm^3)
1	3.007	2.03	1.48
2	3.462	2.43	1.42
3	3.396	2.49	1.36
4	3.142	2.38	1.32
5	2.814	2.039	1.38

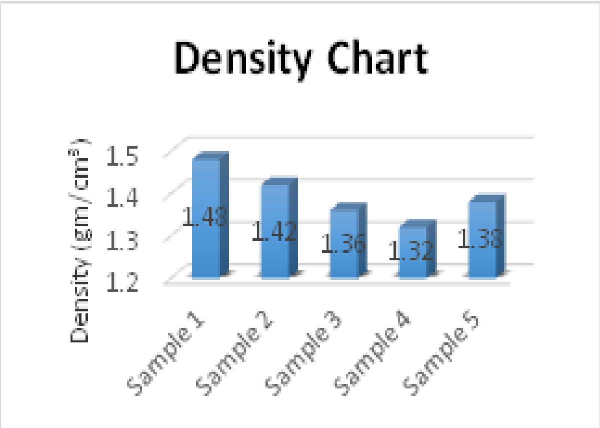

Figure 12: Graphical Representation of Density of Glass Epoxy Resin, Fly Ash and Activated carbon

4.4 Tribological Property Observation

4.4.1 WEAR TEST

Wear tests are carried out on a pin-on-disc type machine (TR201LE) under atmospheric condition. The test samples having the dimensions of 8 mm diameter and 40 m length are slide against the low alloy steel disc (material EN-31-HRS 60 W 61 equal to 4340) of dia 215 mm, and Hardness R¬c 62. Weight loss is measured with electric sensor weighing machine. This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Materials are tested in pairs under nominaly non-abrasive conditions. For the pin-on-disk wear test, two specimens are required. One, a pin with a radiused tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk centre. In either case, the sliding path is a circle on the disk surface. The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. Linear measures of wear are converted to wear volume (in cubic millimetres) by using appropriate geometric relations. If loss of mass is measured, the mass loss value is converted to volume loss (in cubic millimetres) using an appropriate value for the specimen density. Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load and speed. In the present experiment we are using the sample size of 40x8x8mm and above mentioned steps are carried out to get the desired result. Coefficient of friction and wear are measured continuously with an electric sensor attached to the machine and are recorded. The worn out samples are cleaned and are weighed in the balance.


Figure 13 : Wear Test Machine Figure 14: Wear Test Sample

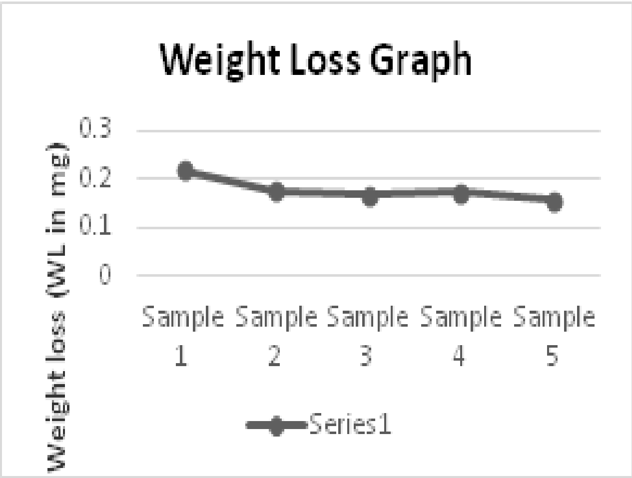

Figure 15: Graphical Representation of Weight Loss in Wear Test

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Table 5: Reading of Wear Test conducted with Samples

S. No.	Sliding Time	Sliding Speed	Load	Weight loss (WL in mg)				
	(T in Sec)	(S in m/sec)	(L in N)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1	1000	1	10	0.228	0.178	0.169	0.173	0.157
2	1000	1	10	0.216	0.172	0.171	0.176	0.159
3	1000	1	10	0.221	0.181	0.168	0.174	0.162
Average				0.221	0.177	0.169	0.174	0.159

V. CONCLUSION

The hand lay-up method used for the preparation of polymer matrix composites is easy, efficient and most economical method. It also helps in the uniform distribution of Fly ash and activated carbon powder particles in the matrix phase. After carrying out experiment we concluded that the hardness value increases with an increase in %concentration of Fly ash but after a definite %concentration hardness value decreases. The observed increase in hardness might be due to hard fly ash particles acting as a barrier for the movement of dislocations within the matrix and exhibit greater resistance to indentation, but after a definite proportion due to large proportion of fly ash in matrix porosity increases and as a result hardness decreases. Hardness value is maximum for activated carbon powder-Fly ash filled PMC due to combined properties of Fly ash and activated carbon powder. The Coefficient of friction as obtained from pin-on-wear disc method is lowest for activated carbon powder- Fly ash filled composites and highest for virgin PMCs with Fly ash filled composites in between. Presence of carbon helps to reduce the coefficient of friction. Weight loss due to wear is maximum for Virgin PMC and minimum for activated carbon powder- Fly ash filled PMC with Fly ash filled PMC in between. Carbon helps in improving the abrasion resistance. However the density value of activated carbon powder- Fly ash filled composite(1.38 g/cm3) is more than Fly ash(39.7%) filled composite i.e 1.32 g/cm3 but it is still less than virgin PMC(1.48 g/cm3).

This is due to the presence of aluminium oxide, calcium oxide and activated carbon in activated carbon-Fly ash filled PMC which makes it better reinforcement than others due to combined properties of all constituent particles. The experimental data shows that the selection of filler material when mechanical and tribological properties are considered as one of the major aspect for the production of polymer matrix composite.

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