Mechanical Characterization of Polymer Matrix Composite For Foot Rest In Automotive Brake Pedals

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ABSTRACT

In this research aim of polymer matrix Composite materials are new generation materials and are mostly utilized for its good surface finish, less weight and high strength. In general polymer matrix composites are widely used in automotive applications like brake pads, brake shoes and clutch pedals. In this project the characterization of polymer matrix composite for foot rest in automotive brake pedal is investigated. E-glass fiber, alumina particles and silicon carbide particles are reinforced with phenolic resin is fabricated. The fabrication of polymer matrix composite is done by using hand layup process. The composite materials are fabricated with different alumina and silicon carbide weight fraction. Mechanical tests such as tensile test, hardness, flexural test and impact test were conducted on the specimen. Thus it was found that when the alumina particle is 10% reinforced with phenolic resin shows the better mechanical properties when compared to other compositions. The material exhibits a good property such that it can be used for footrest application in automotive brake pedal.

Keywords: E-glass fiber, alumina particles and silicon carbide particles, phenolic resin, Tensile and hardness test.

INTRODUCTION

A composite material is a material consisting of two or more physically or chemically distinct phases. The composite generally has superior characteristics than those of each of the individual components. Usually the reinforcing component is distributed in the continuous or matrix component. There is an increasing demand for advanced materials with better properties to meet new requirements or to replace existing materials. Particulate filled fiber reinforced polymers have generated wide interest in various engineering fields.

Polymer matrix composites are the workhorse of the composites industries. They have excellent room temperature properties at a comparatively low cost. Phenolic resins are oldest synthetic polymers used commercially around the beginning of 20th century. These thermoset resins have typically been cured at high temp (140°C-180°C) of usually at high pressures. Commonly phenolic resin is used in a broad range of applications such as paints, adhesives, and composites. The mechanical properties of a material are those properties that involve a reaction to an applied load. The mechanical properties of a composition determine the range of usefulness of a material and establish the service life that can be expected.

In this project E-glass fiber, alumina and silica particles reinforced with phenolic resin are going to be fabricated by hand layup process according to three different compositions. The characterization of the polymer composite is done successfully and the best composition can be used for the application of foot rest in automotive brake pedal.

A.E. Samuel, et al. [10] revealed that development and production of asbestos-free brake pad using palm kernel shell (PKS) was studied with a view to replace the use of asbestos whose dust is carcinogenic. The PKS were sieved into sieve grades.
of 100,350,710μm and 1mm. The sieve PKS was used in production of brake pad in ratio of 20% resin, 10% graphite, 15% steel, 35-55% PKS and 0-20% SiC using compression moulding. They examined the properties like microstructure analysis, hardness, compressive strength, density, flame resistance, water and oil absorption. The microstructure reveals uniform distribution of resin in PKS. The results obtained showed that the finer the sieve size the better the properties. The results obtained in their work were compared with that of commercial brake pad (asbestos based and optimum formulation laboratory brake pad Palm Kernel Shell based (PKS), the results are in close agreement. Hence PKS can be used in production of asbestos-free brake pad.

Amazing Comfortson S, et al. [1] said that energy crisis is the major problem faced widely. Though wide range of researches is being laid in the areas of alternate energy sources, proper management of the available energy sources will contribute in controlling this energy crisis, particularly in high populous countries such as India. Ceiling fan being one of the vital electric appliance, consumes considerable electric power in most domestic and Industrial application. Imparting fiber reinforced composite blade in ceiling fans reduces the weight of the blade, thereby considerably reducing the power consumption. In their work the fabrication of composite fan blade made up of glass fiber reinforced polymer is carried out and the performance of this fan is compared with the conventional fans. Compared to existing ceiling fan blade, the composite blade saves 26% of power, and reduces the cost by 28%. The weight is reduced by 27% thus reducing the power consumption. They also determined that the flow velocity through the composite blade is 15% more than that of the conventional fan.

R. Yunus, et al. investigated the effect of hardener on mechanical properties of carbon reinforced phenolic resin composites. Carbon fiber is one of the most useful reinforcement materials in composites, its major use being the manufacture of components in the aerospace, automotive, and leisure industries. In their study, carbon fibers are hot pressed with phenolic resin with various percentages of carbon fiber and hardener contents that range from 5-15%. Composites with 15% hardener content show an increase in flexural strength, tensile strength and hardness. The ultimate tensile strength (UTS), flexural strength and hardness for 15% hardener are 411.9 MPa, 51.7 MPa and 85.4 HRR respectively.

Ibtihal-Al-Namie, et al. studied about the mechanical properties of polymer composites reinforced with ceramic particulates. The epoxy resin used as a Matrix material is Ep-10 and the reinforcement particulate materials are silica with particle size (53-63) μm and alumina with particle size (106-150) μm, and having weight fraction of 20%, 30% and 40% respectively. They subjected the specimens of the matrix material and the six types of composite materials to tensile, compression, bending, impact and hardness tests. Experimental tests results indicate that the composite materials have significantly higher modulus of elasticity than the matrix material. They found that the enhancement in modulus of elasticity is directly proportional to the weight fraction of reinforcement material and that alumina composites have higher modulus of elasticity than silica composites with equivalent weight fraction. The highest modulus of elasticity is that of the composite with 40% alumina, which is 182% higher than that of the matrix material. The tensile and bending strength of the matrix material were found to be significantly higher than those of the composite material while composites with 30% and 40% weight fraction reinforcement material have marginally higher compressive strength than the matrix material. Test results also indicate that material toughness, fracture toughness and hardness of the composite materials are significantly higher than those of the matrix material. The enhancements in these properties are found to be directly proportional to the weight fraction of reinforcement materials. These properties of composites reinforced with alumina are significantly higher than that of composites reinforced with equitant silica (quartz) content. The highest material toughness, fracture toughness and hardness are that of the composite with 40% alumina.

Harshvardhan Sahu, et al. determined the mechanical characterization of a new class of multi-phase composites consisting of polyester resin reinforced with glass fiber and filled with alumina particulates. Four different composite samples are prepared with 0, 5, 10 and 15wt. % of Al2O3 (alumina). The mechanical properties of these composites are evaluated. They found that the Al2O3 modifies the tensile, flexural and the inter-laminar shear strength of the glass-polyester composites. The hardness and density of the composites are also greatly influenced by the content of these fillers.

Dinesh Pargunde, et al. stated that several technical challenges exist with casting technology yet it can be used to overcome this problem. Achieving a uniform distribution of reinforcement within the matrix is one such challenge, which affects directly on the properties and quality of composite material. In their present study a modest attempt would be made to develop Aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two step-mixing method of stir casting technique has been proposed and subsequent property analysis has been made. Aluminium (98.41%) and SiC (320-grit) has been chosen as matrix and reinforcement material respectively. Experiments are planned for conducting varying
weight fraction of SiC (in the steps of 5%) while keeping all other parameters constant. The results from their work are evaluated by Tensile-Hardness, Impact (including micro-structure) for this 'development method'. The trend of hardness and impact strength with increase in weight percentage of SiC would be observed and recommendation made for the potential applications accordingly. Impact (including micro-structure) for this 'development method'. The trend of hardness and impact strength with increase in weight percentage of SiC would be observed and recommendation made for the potential applications accordingly.

Sandeep Kumar, et al. said that in the past few years the global need for low cost, high performance and good quality materials has caused a shift in research from monolithic to composite materials. In case of MMC’s, aluminum matrix composite due their high strength to weight ratio, low cost and high wear resistance are widely manufactured and used in structural applications along with aerospace and automobile industry. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. Reinforcements like particulate alumina, silicon carbide, graphite, fly ash etc can easily be incorporated in the melt using cheap and widely available stir casting method. This paper presents a review on the mechanical and tribological properties of stir cast aluminium matrix composites containing single and multiple reinforcement. Addition of alumina to aluminum has shown an increase in its mechanical and tribological properties. Organic reinforcement like fly ash, coconut ash also improved the tensile and yield strength. Self-lubricating property of graphite improved the machinability of aluminum. Many authors have also reported about modified stir casting route.

Gaurav Agarwal, et al. investigated the effect of addition of silicon carbide (SiC) filler in different weight percentages on physical properties, mechanical properties, and thermal properties of chopped glass fiber-reinforced epoxy composites. Physical and mechanical properties, i.e., hardness, tensile strength, flexural strength, interlaminar shear strength, and impact strength, are determined with the change in filler content to notice the behavior of composite material subjected to loading. Thermomechanical properties of the material are measured with the help of a dynamic mechanical analyzer. The result shows that the physical and mechanical properties of SiC-filled glass fiber-reinforced epoxy composites are better than unfilled glass fiber-reinforced epoxy composites. Viscoelastic analysis for different compositions indicate that adding too much SiC content results in degradation in energy absorption capacity of the material and hence overall performance of the composites, whereas adding too much (more than 10 wt.%) SiC content increases the elastic behavior of the composite.

### 1.1 Polymer Matrix Composites:

Polymer matrix composites (PMC) and fiber reinforced plastics (FRP) are referred to as Reinforced Plastics. Common fibers used are glass (GFRP), graphite (CFRP), boron, and aramids (Kevlar). These fibers have high specific strength (strength-to-weight ratio) and specific stiffness (stiffness-to-weight ratio). Matrix materials are usually thermoplastics or thermosets; polyester, epoxy (80% of reinforced plastics), fluorocarbon, silicon, phenolic.

### 1.2 Reinforcements:

The reinforcement material is embedded into a matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging, or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD). Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

### 1.3 Matrices:

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

### 1.4 Fiber:

Reinforcement usually adds rigidity and greatly impedes crack propagation. The different forms of fibers are shown in the figure 2.2. Thin fibers can have very high strength, and provided they are mechanically well attached to the matrix they can greatly improve the composite’s overall properties. Fiber-reinforced composite materials can be divided into two main categories normally referred to as short fiber-reinforced materials and continuous fiber-reinforced materials. Continuous reinforced...
materials will often constitute a layered or laminated structure. The woven and continuous fiber styles are typically available in a variety of forms, being pre-impregnated with the given matrix (resin), dry, uni-directional tapes of various widths, plain weave, hardness satins, braided, and stitched.

These come in the form of flakes, chips, and random mate (which can also be made from a continuous fiber laid in random fashion until the desired thickness of the ply / laminate is achieved).

**Fig. 2.2:** Forms of fibers.

Common fibers used for reinforcement include glass fibers, carbon fibers, cellulose (wood/paper fiber and straw) and high strength polymers for example aramid.

### 1.5 Resins:

Polyester resin tends to have yellowish tint, and is suitable for most backyard projects. Its weaknesses are that it is UV sensitive and can tend to degrade over time, and thus generally is also coated to help preserve it. It is often used in the making of surfboards and for marine applications. Its hardener is a peroxide, often MEKP (methyl ethyl ketone peroxide). When the peroxide is mixed with the resin, it decomposes to generate free radicals, which initiate the curing reaction. Hardeners in these systems are commonly called catalysts, but since they do not re-appear unchanged at the end of the reaction, they do not fit the strictest chemical definition of a catalyst.

Vinylester resin tends to have a purplish to bluish to greenish tint. This resin has lower viscosity than polyester resin, and is more transparent. This resin is often billed as being fuel resistant, but will melt in contact with gasoline. This resin tends to be more resistant over time to degradation than polyester resin, and is more flexible. It uses the same hardeners as polyester resin (at a similar mix ratio) and the cost is approximately the same.

Epoxy resin is almost totally transparent when cured. In the aerospace industry, epoxy is used as a structural matrix material or as a structural glue. Shape memory polymer (SMP) resins have varying visual characteristics depending on their formulation. These resins may be epoxy-based, which can be used for auto body and outdoor equipment repairs; cyanate-ester-based, which are used in space applications; and acrylate-based, which can be used in very cold temperature applications, such as for sensors that indicate whether perishable goods have warmed above a certain maximum temperature.

These resins are unique in that their shape can be repeatedly changed by heating above their glass transition temperature \(T_g\). When heated, they become flexible and elastic, allowing for easy configuration. Once they are cooled, they will maintain their new shape. The resins will return to their original shapes when they are reheated above their \(T_g\). The advantage of shape memory polymer resins is that they can be shaped and reshaped repeatedly without losing their material properties. These resins can be used in fabricating shape memory composites.

### 3 Vacuum Bag Moulding Process:

Vacuum bag molding (figure 2.3) uses a flexible film to enclose the part and seal it from outside air. A vacuum is then drawn on the vacuum bag and atmospheric pressure compresses the part during the cure. Vacuum bag material is available in a tube shape or a sheet of material. When a tube shaped bag is used, the entire part can be enclosed within the bag. When using sheet bagging materials, the edges of the vacuum bag are sealed against the edges of the mould surface to enclose the part against an air-tight mould. When bagged in this way, the lower mold is a rigid structure and the upper surface of the part is formed by the flexible membrane vacuum bag. The flexible membrane can be a reusable silicone material or an extruded polymer film. After sealing the part inside the vacuum bag, a vacuum is drawn on the part (and held) during cure. This process can be performed at either ambient or elevated temperature with ambient atmospheric pressure acting upon the vacuum bag. A vacuum pump is typically used to draw a vacuum. An economical method of drawing a vacuum is with a venturi vacuum and air compressor.

A vacuum bag is a bag made of strong rubber-coated fabric or a polymer film used to compress the part during cure or hardening. In some applications the bag encloses the entire material, or in other applications a mold is used to form one face of the laminate with the bag being a single layer to seal to the outer edge of the mold face. When using a tube shaped bag, the ends of the bag are sealed and the air is drawn out of the bag through a nipple using a vacuum pump. As a result, uniform pressure approaching one atmosphere is applied to the surfaces of the object inside the bag, holding parts together while the adhesive cures.

The entire bag may be placed in a temperature-controlled oven, oil bath or water bath and gently heated to accelerate curing. Vacuum bagging is widely used in the composites industry as well. Carbon fiber fabric and fiberglass, along with resins and epoxies are common materials laminated together with a vacuum bag operation.
3.1 Raw Materials:
The materials used in this project are listed below:
1. Alumina
2. Silicon carbide
3. E-glass fiber
4. Phenolic resin
5. Hexamine
6. Cobalt

3.2 Alumina:
The figure 3.2 shows the clear view of alumina. Here the particle size of 80-90 microns alumina is used. The alumina is purchased at Algrain products limited, Hosur. Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al₂O₃. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium (III) oxide. It has high strength and stiffness and it is a wear resistant material.

3.3 Silicon Carbide:
The figure 3.3 shows the structure and appearance of silicon carbide. Here the particle size of 25-60 microns silicon carbide is used. The silicon carbide is purchased at Snam abrasives private limited, Hosur. Silicon carbide (SiC), also known as carborundum, is a compound of silicon and carbon with chemical formula SiC. It has more fatigue resistance and possesses more tensile and fracture properties.

3.4 E-Glass Fiber:
Figure 3.4 shows the diagram for E-glass fiber. It was purchased at RPI industries Bangalore. In this project E-Glass fiber is used as mat type structure. Glass fibers are mainly used for its less corrosion and high strength. Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber.

3.5 Phenolic Resin:
Phenol formaldehyde resins (PF) are synthetic polymers obtained by the reaction of phenol or substituted phenol with formaldehyde. Figure 3.5 shows the appearance of phenolic resin and it was purchased at Aishwarya polymers limited, Coimbatore. Phenolic resins are mainly used in the production of circuit boards. Phenolic resin involves less cracks, with less density. So it was used as an effective binding material.

3.6 Hexamine (Hardener):
Hexamine (figure 3.6) is used as a hardener with phenolic resin in order to increase the high bonding capacity. Hexamethylenetetramine or methenamine is a heterocyclic organic compound with the formula (CH₂)₆N₄. This white crystalline compound is highly soluble in water and polar organic solvents. It was purchased along with phenolic resin at Aishwarya polymers limited, Coimbatore. It is useful in the synthesis of other chemical compounds, e.g. plastics, pharmaceuticals, rubber additives. It sublimes in vacuum at 280 °C.
Figure 3.6: Hexamine.

3.7 Cobalt (Catalyst):

Figure 3.7 cobalt is used as a catalyst with phenolic resin in order to increase the speed of the reaction. Several cobalt compounds are used in chemical reactions as oxidation catalysts. Typical catalysts are the cobalt carboxylates (known as cobalt soaps). They are also used in paints, varnishes, and inks as "drying agents" through the oxidation of drying oils. The same carboxylates are used to improve the adhesion of the steel to rubber in steel-belted radial tires.

Table 3.3: Composition of reinforcement and matrix in weight fraction.

<table>
<thead>
<tr>
<th>Materials</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina (Al₂O₃)</td>
<td>10</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Silicon Carbide (SiC)</td>
<td>10</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>E-Glass Fiber</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Fig. 3.7: Cobalt.

3.8 Reinforcements:

The other phase of composite material is the reinforcements. They exist as discontinuous phase. These reinforcements help to increase the strength of the composite material.

3.9 Matrix:

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

3.10 Fabrication Of Composite Materials:

The composite material is fabricated by the hand layup technique is shown in figure 3.8. The hand layup is done in Reinforced Plastic Industry (RPI), Bangalore. The surface is to be cleaned where the hand-­lay-up process is to be made. Initially the wax is to be applied over the surface in order to avoid the dust and also to remove the fabricated plate easily. The clay is to be mound around the sides of fabrication area for making vacuum. The three different compositions are made according to weight ratio. The phenolic resin, silicon carbide (SiC) and alumina (Al₂O₃) are mixed together according to the compositions made. The mixed substrate is applied for the required size of the fabrication plate (200×120 mm).
Above the substrate the glass fiber of mat type is placed and the substrate is again applied over the glass fiber. The process is repeated till it acquires 4mm of thickness for 3 compositions. After the fabrication is finished, a carry bag is placed above the fabricated plate and the vacuum tube is inserted into the carry bag. The vacuum is made at a suction of 1atm pressure. The fabricated plate allowed curing for a period of 3 to 4 hours. The post curing is made by keeping the fabricated model in over for 12 hours. The fabricated composite plate is taken from the oven and the sides are made to cut. Thus the fabrication of polymer matrix composite is done according to the compositions specified in the table.

4. Experimental Tests:

4.1 Tensile Test:

The specimen was prepared as per ASTM D 638 standards shown in figure 3.11. The experiment is conducted by using universal testing machine shown in figure 3.10. Tensile test is conducted by gripping the test specimen between the upper and lower cross heads, compression, transverse, bending, shear and hardness tests are condition between the lower cross head and the table. The lower cross heads can be raised or lowered rapidly by operating the screwed columns.

4.1.1 Tensile Test Procedure:

1. Measure the length of specimen at several section with a vernier caliper to obtain a mean value. The gauge length is marked off by means of center punch and is measured.
2. Firmly grip one end of the specimen in the fixed head of the testing machine such that the punch marks face the front of the machine.
3. Mount the extensometer on the specimen, the fixing screws being located in punch marks.
4. Set the load dial of the machine to a suitable range and adjust the testing machine and extensometer to read zero.
5. Apply the load at slow speed and make simultaneous observation of load and extensometer readings.
6. When an increment of loads leads to disproportionate extension (yield point) replace the locking bars and remove the extensometer.
7. Continue to load the specimen taking the extension by means of the graduated scale. Record the yield point, maximum load and load at fracture.
8. Remove the broken specimen from the machine. Observe the location and character of the fracture and measure the diameter of the neck. Place two parts together and measure the final gauge length.

4.2 Hardness Test:

The specimen (figure 3.13) was prepared as per ASTM D 785 standards. The Rockwell hardness test is a hardness measurement based on the net increase in depth of impression as a load applied. The hardness was conducted in Wilson wolpert Rockwell machine shown in figure 3.12. Hardness covers several properties resistance to deformation, resistance to friction and abrasion.

The term refers to stiffness or temper or to resistant’s to scratching, abrasion, or cutting. If the
hardness of the material is more, then it will be highly resistant to deformation. By measuring the depth of the indentation, progressive levels of forcing or measurable on the same piece. 

The indenter may either be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120 angle and 0.2mm tip radius. The hardness number is expressed by the symbol HR and the scale designation.

4.2.1 Hardness Test Procedure:
1. The material to be tested is to be held on the anvil of machine and then suitable indenter is to be fixed on the chuck.
2. The test piece is raised by turning the hand wheel, it just touches the tip of the indenter.
3. A minor load of 10kg is applied to seat the specimen. Then the dial indicator is set at zero. Now the major load of 60kgf is applied to the indenter to produce a deeper indentation.

![Fig. 3.12: Wilson wolpert-rockwell.](image1)

**Fig. 3.13:** Hardness specimen.

4.3 Impact Test:

An important test is a dynamic test in which a selected specimen which is usually notched is struck and broken by a single blow in a special machine. Using impact machine energy absorbed while breaking the specimen is measured. In our laboratory, impact test is done on the tinius Olsen impact testing machine and consists of two tests:

1. Charpy test
2. Izod test

4.3.1 Izod Test:

The specimen (figure 3.15) was prepared as per ASTM D 256 standards. The experiment was carried out in impact testing machine shown in figure 3.14. In the izod test, the specimen is held on one end and is free on the other end. This way it forms a cantilever beam. In this case the notch is just at the edge of the supporting vise and facing into the direction of impact. As with the izod test this position places the notch at the location of the maximum tension.

4.4.1 Flexural Test Procedure:

1. The specimen with the given span is supported between two supports as a simply supported beam and the load is applied at the center by the loading nose producing three point bending at a specified rate.
2. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test.
3. These parameters are based on the test specimen thickness and are defined differently by ASTM.
4. Under ASTM D790, the test is stopped when the specimen reaches 5% deflection or the specimen breaks.

![Fig. 3.14: Impact testing machine.](image2)

**Fig. 3.15:** Impact test specimen.

4.3.2 Impact Test Procedure:

1. Specimen is placed in the vise of the anvil.
2. The pendulum hammer is raised to standard height depending on type of specimen.
3. When the pendulum is released its potential energy is converted into kinetic energy.
4. Izod specimen hits above the v-notch and the charpy specimen hits behind the v-notch.
5. Now the energy absorbed is measured from the scale of impact testing machine.
4.4 Flexural Test:

The specimen was prepared as per ASTM D 790 standards shown in figure 3.16. The experiment was done in universal testing machine shown in figure 3.10. The flexural test measures the force required to bend a beam under three point loading situation. The data is often used to select elements for parts that will support loads without inflection. Flexural modulus is used as an indication of materials stiffness when inflection. Since the physical properties of many elements can vary depending on ambient temperature it is appropriate to test materials at temperatures that simulate the intended end use environment.

Fig. 3.16: Flexural test specimen.

RESULTS AND DISCUSSION

Tensile Test Results:
Composition 1 (C1): Al₂O₃ (10%), SiC (10%), glass fibre (50%), phenolic resin (30%).
Breaking load = 11055 N
Area = 60.200 mm²
Tensile strength = breaking load/ area = 11055/60.200 = 184 N/mm²
Elongation = 28%

Fig. 4.1: Stress vs strain curve for composition 1.

Composition 2 (C2): Al₂O₃ (5%), SiC (15%), glass fibre (50%), phenolic resin (30%).
Breaking load = 11250 N
Area = 60.200 mm²
Tensile strength = breaking load/ area = 11250/60.200 = 187 N/mm²
Elongation = 23%

Fig. 4.2: Stress vs strain curve for composition 2.

Composition 3 (C3): Al₂O₃ (15%), SiC (5%), glass fibre (50%), phenolic resin (30%).
Breaking load = 7910 N
Area = 60.200 mm²
Tensile strength = breaking load/ area = 7910/60.200 = 131 N/mm²
Elongation = 18%

Fig. 4.3: Stress vs strain curve for composition 3.

The figure 4.1 shows the tensile test graph for composition-1. In composition-1 alumina and silicon carbide is added in 10%. The obtained ultimate tensile strength value is 184 N/mm². The figure 4.2 shows the tensile test graph for composition-2. In composition-2 alumina is reduced to 5% and silicon carbide is increased to 15%. The attained ultimate tensile strength value is 187 N/mm². The figure 4.3 shows the tensile test graph for composition-3. In this composition alumina is increased to 15% and silicon carbide is reduced to 5%. The obtained ultimate tensile strength is 131 N/mm².

By combining these three graphs it is concluded that the increase in alumina reduces the value of ultimate tensile strength. This is due to alumina has high density and reduces the load carrying capacity of the material. Also increase in alumina increases the bonding surface area and hence the bonding strength decreases.

4.2 Hardness Test Results:

The below tabulation shows the hardness values for three different compositions of the material. The graph for the hardness test result is shown below.
**Fig. 4.4:** Variation of tensile strength for different compositions.

<table>
<thead>
<tr>
<th>S. No/Sample ID</th>
<th>1 Hardness in HR ‘L’ Scale</th>
<th>2 Hardness in HR ‘L’ Scale</th>
<th>3 Hardness in HR ‘L’ Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69.5</td>
<td>73.1</td>
<td>80.0</td>
</tr>
<tr>
<td>2</td>
<td>76.0</td>
<td>90.6</td>
<td>84.0</td>
</tr>
<tr>
<td>3</td>
<td>89.8</td>
<td>96.4</td>
<td>95.9</td>
</tr>
</tbody>
</table>

From the below figure 4.5 it is concluded that when the filler material is increased it forms a strong bonding between the fiber and matrix. This bonding of material helps to form a dense shaped structure.

**Fig. 4.5:** Variation of hardness test for different compositions.

The dense shaped structure makes the hardness to increase. Hence the 15% alumina, 5% silicon carbide composition has the high hardness value compared to the other compositions.

**4.3 Impact Test Results:**

**Fig. 4.6:** Variation of impact strength for different compositions.

The above figure 4.6 shows the effect of impact strength on phenolic resin reinforced with E-glass fiber, alumina and silica particles. The value of impact strength is increased initially in composition 1. There is a fall of level in the graph in composition 2. Further the value of impact strength is increased in composition 3.

The material’s resistance to fracture is known as toughness. It is often expressed in terms of the amount of energy a material can absorb before fracture. A ductile material can absorb a considerable amount of energy before fracture, while a brittle material absorbs very little. The increase in impact strength is due to the weaker bond, i.e., as the bond strength between the glass fiber, SiC filler, alumina filler and the phenolic resin reduces, the impact energy absorbing capacity of the composite increases. Also, a large amount of energy is absorbed by the crack initiated along the fiber/filler/matrix interface during debonding. The energy absorbing capability of composites depends on the properties of the constituents.

**Fig. 4.7:** Variation of flexural strength for different compositions.

**4.4 Flexural Test Results:**

Figure 4.7 shows the flexural strength for phenolic resin reinforced with E-glass fiber, alumina and silica particles. When the specimen is placed on two support points and load is applied from the top of the specimen, then the specimen is subjected to bending and the top layer is subjected to compressive loading, whereas the bottom layer is subjected to tensile loading.

When the bonding between the fiber, filler and the matrix is increased, a flexural strength increases and strong bonding transfer’s loads from one end to another resulting in the increase in flexural strength.
of the specimen. The reason for reduction in flexural strength is that when SiC is added above 10% it disturbs the continuity of matrix and bonding strength between fiber, filler and matrix reduces. This decrease in bonding strength eventually decreases the value of flexural strength.

Conclusions:
E-glass, silicon carbide and alumina fibre reinforced with phenolic resin polymer matrix composites have been fabricated. Tensile test, hardness test have been conducted on fabricated composite and the following conclusions are drawn.

The increase in the percentage of alumina particle to 15% shows the better hardness of 96.4 RHN when compared to other compositions. The increase in the percentage of silicon carbide to 15% shows the better results in tensile strength, impact strength and flexural strength. These materials exhibit better properties and it is used as a suitable material for the footrest application in automotive brake pedal.

References


