Mechanical Properties of Particulate Filled Polymer Composites
Prabha Shankar Tiwari¹ Pushpraj Singh² Abhilash Shukla³

1,2,3Department of Mechanical Engineering
1,2Rewa Institute of Technology, Rewa (M.P.), India 3SIRTE, Bhopal, India

Abstract—The present work aims at developing a class of polymer composites consisting of thermostet polymer i.e. epoxy as a matrix material with a micro-size aluminium oxide as a filler material. A set of composites with varying loading of filler content ranging up to 50 wt. % has been fabricated using simple hand lay-up technique. The effect of filler content on various mechanical properties of such fabricated samples is investigated and presented in this work. The various mechanical property evaluated are tensile strength, compressive strength, flexural strength and hardness. The values obtained under controlled laboratory conditions are analyzed to identify its behavior under different loading conditions. From the experimental results, it is found that aluminium oxide filled epoxy composites possess high compressive strength, flexural strength and hardness. Through, tensile strength of the composite decreases with increase in filler content in the fabricated composites.

Keywords: Polymer Matrix Composites, Epoxy, Aluminium Oxide, Mechanical Properties

I. INTRODUCTION

The most common matrix materials for composites are considered to be polymeric. The reasons for this are twofold. Firstly, in general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared with other matrix materials i.e. metals and ceramics. This means that there is a considerable benefit to be gained by reinforcing polymers, and that the reinforcement does not have to have exceptional properties. Secondly, and most importantly, the processing of polymer matrix composites (PMCs) need not involve high pressures and does not require high temperatures. It follows that problems associated with the degradation of the reinforcement during manufacture are less significant for PMCs than for composites with other matrices. Also the equipment required for PMCs may be simpler.

The amount of filler that is incorporated inside the matrix is considered to be the most significant factor which can alter the performance of composite system. It has been shown by many researchers that dramatic improvement in mechanical properties can be achieved by incorporation of either micro or nano-particles, since rigid inorganic particles generally have a much higher stiffness than polymer matrices [1]. The effect of CaCO3 volume fraction on the notched Izod impact toughness of high density polyethylene (HDPE)/CaCO3 composites is shown by Liu et al. [2]. Cho et al. [3] underlined the interest of replacing micro-scale particles by its nano-scale counterparts smaller particle size yields higher fracture toughness.

As far as tribological behaviour is concerned, it has been seen that the incorporation of certain particles enhances the wear resistance of polymers. Wetzel et al. [4] study the effect of micro and nano-sized ceramic particulates into an epoxy resin. They study the effect of SiC and TiO2 particles for different particle loading and particle size as well as with surface modification of particles and observed that with increase in filler loading and decrease in particle size, the specific wear rate decreases whereas modification of particles has only a little effect on the wear performance. However, Zang et al. [5] reported that grafting of PAAM onto nanosilica increases the interfacial interaction between the particles and the matrix through chemical bonding. Antunes et al. [6] found that increasing average particle dimension tends to decrease the volume removed by wear in the composite and increase it in the antagonist body. Recently, Anjum et al. [7] studied specific wear rate of SiO2 filled glass-epoxy composite. Likewise, the incorporation of hard particles i.e. SiC, ZrO, Ti3SiC2 has led to enhancement in wear resistance [8-10].

Many investigations are reported on optically transparent polymer composites because of their wide industrial applications, such as optical fiber sensors, packaging products and medical devices [11]. Other than difference in refractive indices of both the phases, supplementary parameters like filler concentration, particle size and affinity between filler-matrix also influence the composite transparency [12]. Zhou and Burkhart [13] studied the effect of inclusion of SiO2 on three different polymers i.e. polycarbonate (PC), polystyrene (PS) and PMMA, which are all amorphous thermoplastics and are often used as an alternative to glass. Yuan et al. [14] studied the effect of particle size of LaB6 particles on optical properties of LaB6/PMMA composites. They further reported that modification of LaB6 by adding silane coupling agent enhanced the property to a great extent by increasing the light absorption strength of composites. Li et al. [15] evaluated dynamic mechanical properties of particulate composites using high-precision ultrasonic testing technology. Against this background, an attempt has been made in this research work to develop aluminium oxide based epoxy composites using simple hand lay-up technique and to study their mechanical behavior under controlled laboratory conditions.

II. MATERIALS AND METHODS

A. Material Considered

The most popular epoxy monomers are those derived from the reaction of bis(4-hydroxy phenylene) - 2,2 propane (called bisphenol A) and 1 - chloroprene 2 - oxide (called epichlorohydrin), in the presence of sodium hydroxide is used as matrix material in present study. It provides a solvent free room temperature curing system when it is combined with the hardener tri-ethylene-tetramine (TETA) which is an aliphatic primary amine with commercial designation K-6. The epoxy resin with its corresponding hardener is procured from M/s Atul Limited, Bhopal. Aluminium oxide (Al2O3) is aluminium based ceramic material that has been used as a filler in the present work. It is an inorganic material. It can exist in several stable crystalline phase. Among the various stable phase available, the most stable is hexagonal alpha phase which will remain stable at elevated temperature as
well. It also possesses high strength and stiffness. It is therefore chosen as the primary filler material with an average size of 90-100 micron which is procured from Rankem Corporation Limited located at New Delhi, India.

B. Composite Fabrication

In the present investigation, particulate filled polymer composite is fabricated using simple hand lay-up technique. The fabrication of composite involves following steps:

1) The room temperature curing epoxy resin (L-12) and corresponding hardener (K-6) are mixed in a ratio 10:1 by weight as recommended.
2) Micro-size aluminium oxide will then added to the epoxy-hardener combination and mixed thoroughly by hand stirring.
3) Before pouring the epoxy/filler mixture in the mould, a silicon spray is done over the mold so as to get specimens of size as per ASTM standards.
4) The cast is than cured for 12 hours before it was removed from the mould.

Composites were fabricated with different weight fraction of filler ranging from 0 to 50 wt. %. The list of fabricated composite in present work is presented in table 1.

C. Mechanical Characterization

The tensile strength of the composites is measured with a computerized Tinius Olsen universal testing machine in accordance with ASTM D638 procedure by applying uni-axial load through both the ends at a cross head speed of 0.5 mm/min. Static uniaxial compression tests and flexural test on specimens are carried out using the same computerized Tinius Olsen universal testing machine. The method by which the compression test is conducted is in accordance with ASTM D695. The flexural strength is measured by three point bend test was carried out in accordance with ASTM D2344-84. The entire specimens were of rectangular cross section of (150x20x3) mm. A span of 100 mm was used for the test specimen. The specimens were tested at a crosshead speed of 0.5mm/min. Affri LD250 hardness measuring instrument is used to determine the micro-hardness of the fabricated composite. The tests are in accordance with ASTM E384.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Epoxy + 5 % by weight Al₂O₃</td>
</tr>
<tr>
<td>2</td>
<td>Epoxy + 10 % by weight Al₂O₃</td>
</tr>
<tr>
<td>3</td>
<td>Epoxy + 15 % by weight Al₂O₃</td>
</tr>
<tr>
<td>4</td>
<td>Epoxy + 20 % by weight Al₂O₃</td>
</tr>
<tr>
<td>5</td>
<td>Epoxy + 25 % by weight Al₂O₃</td>
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<tr>
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<td>7</td>
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<tr>
<td>8</td>
<td>Epoxy + 40 % by weight Al₂O₃</td>
</tr>
<tr>
<td>9</td>
<td>Epoxy + 45 % by weight Al₂O₃</td>
</tr>
<tr>
<td>10</td>
<td>Epoxy + 50 % by weight Al₂O₃</td>
</tr>
</tbody>
</table>

Table 1: Epoxy Composites Filled With Aluminium Oxide

III. RESULTS AND DISCUSSION

A. Micro-hardness

Surface hardness of the composites is one of the most important factors that directly concerned with the detachment of particles when it undergoes different service condition. The results obtained during the experimentation of are shown in figure 1. From the figure it is clear that, with the increase in the content of micro-size aluminium oxide in epoxy matrix, hardness of the composites increases and reaches its maximum value of 0.462 GPa for 50 wt. % of filler loading. It is evident that with addition of aluminium oxide particles, micro-hardness of the composites is improved and this improvement is a function of the filler content. This improvement is primarily because of the high hardness value of aluminium oxide. This increment is attributed to around 431 %.

![Fig. 1: Micro-hardness of epoxy/aluminium oxide composites](image)

B. Tensile Strength

The tensile strength of all the fabricated samples is measured by universal testing machine and is shown in figure 2. Measuring tensile strength means applying axial loading on the specimen until it breaks. Tensile strength means breaking strength of the material i.e. upto maximum limit a material can sustained tensile loading. From the figure it is observed that the tensile strength of composite decreases with increase in filler content. The result obtained is quite surprising because strength of filler in greater than strength of matrix in present case. The minimum tensile strength among the various fabricated samples was of sample with 50 wt. % of aluminium oxide. Its values were reported to be of 32.5 MPa which was a decrement of around 27.7 %. The decline in strength can be attributed to the presence of pores at the interface between the filler particles and the matrix, the interfacial adhesion may be too weak to transfer the tensile stress. Also this pore gets open up when the tensile load applied on it and reduces the overall strength of the composite body.
C. Compressive Strength

The compressive strength of all the fabricated samples is measured by universal testing machine and is shown in figure 3. From the figure it can be seen that with addition of micro-size aluminium oxide, compressive strength of epoxy increases and this improvement is found to be more for increased filler content. The maximum value obtained is 109 MPa which is an increment of 36.25%. This improvement is mainly because of the high compressive strength of filler material. Also, the increase in compressive strength with increased filler content is due to the auspicious deformation developments assisted by the presence of fillers in the matrix. Under a compressive loading situation, the fillers ostensibly aid the load demeanor ability of a composite, rather than acting as stress raiser as is the case in tensile loading. Further, the fact is that, in a compression test, any crash or defect introduced by dispersion of the filler will, if at all, get restored and made ineffective, contrary to the crack opening mechanism occurring in a tensile loading situation.

D. Flexural Strength

The flexural strength of all the fabricated composite samples were measured by universal testing machine in accordance with ASTM D2344-84 is shown in figure 4.

Fig. 2: Tensile strength of epoxy/ aluminium oxide composites

Fig. 3: Compressive strength of epoxy/ aluminium oxide composites

Fig. 4: Flexural energy of epoxy/ aluminium oxide composites

IV. CONCLUSIONS

This experimental investigation has led to the following specific conclusions:

1) With the increase in the content of aluminium oxide in epoxy matrix, hardness of the composites increases and reaches its maximum value of 0.462 GPa for 50 wt. % of filler loading. This increment is around 431%.

2) Tensile strength of composite decreases with increase in filler content. The minimum tensile strength among the various fabricated samples was of sample with 50 wt. % of Al₂O₃. Its values were reported to be of 32.5 MPa which was a decrement of around 27.7%.

3) Compressive strength of epoxy increases and this improvement is found to be more for increased filler content. The maximum value obtained is 109 MPa which is an increment of 36.25%.

4) Flexural strength of epoxy increases with increase in aluminium oxide content. The maximum value obtained is 151.2 MPa with 50 wt. % of filler content and this is an increment of 16.3%.

REFERENCES


