Synthesis and Characterization of Hybrid Polymer Composite: An Experimental Approach

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Abstract. Hybrid Polymer composites have recently emerged as one of the most important fields for researchers owing to their weight reduction benefits, corrosion resistance, design flexibility, manufacturing developments, multidiscipline applications, and sustainability. There are many types of hybrid polymer composites, one of which is made up of combining natural polymers and synthetic polymers and the other which is made up of combining natural-natural polymers. Hybrid composites also consist of nanocomposites, molecular composites, nanomaterials, and mesoscopic materials. In present study, hybrid polymer matrix composites reinforced with copper particulate were prepared using polycarbonate (PC), acrylonitrile butadiene styrene (ABS), and polycarbonate plus ABS. Injection moulding process employed to synthesize the hybrid polymer composite. Tensile strength, electrical conductivity and thermal expansion coefficient were measured as per the ASTM D638, ASTM D 257 and ASTM D 696, respectively. 50% Copper + 50% Polycarbonate outperform other combinations in terms of tensile strength, electrical conductivity, and coefficient of thermal expansion. In addition, scanning electron microscopy was also used to understand the homogenous mixture of hybrid polymer composites.

1. Introduction

Polymer composites have in fact become one of the most important areas of study in recent years because of several convincing reasons. This increase in interest can be linked to the special and beneficial qualities that polymer composites provide. The significance of this work is very useful in several areas like enhanced material properties of hybrid polymer composites which exhibit improved properties compared to their individual polymer constituents. By combining different polymers or polymer-based materials, it is possible to achieve synergistic effects and tailor the composite's properties to meet specific application requirements. It is also used in making lightweight and high-strength materials which offer the advantage of high strength-to-weight ratios. By incorporating lightweight and strong reinforcing materials, such as carbon fibers, into the polymer matrix, composites with excellent mechanical properties can be produced. These materials find applications in aerospace, automotive, and sports industries, where weight reduction and high strength are

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Hybrid polymer composites show improved resistance to wear, impact and chemical degradation compared to pure polymers. The study of hybrid polymers matrix composites is done using different process parameters like tensile strength, electrical conductivity, and thermal expansion coefficient of each composite material. The study of copper surface oxidation resistance property using polymeric molecular coating and study of thermal conductivity and thermal resistance using copper nanoparticle-deposited graphite sheets was done in [1-5]. Islam et al [6] used physics-based computational methods to predict the dielectric properties of polymer nanocomposites; and on the electrical conductivity and dielectric permittivity of graphene-polymer nanocomposites, the influence of temperature and graphene concentration was investigated by Weng et al. [7]. Zhang et al [8] looked at how carbon black affected the ability of 3D printed conductive polymer composites to detect strain. Noor et al [9] studied the mechanical and physical characteristics of hybrid composites, Swagatika and Punyapriya [10] studied the characterization and synthesis of hybrid ceramic polymer composites and the review of the effects of low-velocity impacts on polymer composites was studied by Megavannan et al [11]. Review of over molding process for hybrid metal polymer composites was done in [12]. Effect of various parameters on fracture roughness was investigated in kiran et al [13]. Manjeet et al. [14] studied photo actuation in crystal-polymer composites and thermal properties. Rigidity, electromagnetic wave absorption and statistical strength of polymer composites were studied in [15-17]. Low loss BaSrTiO3/ABS ceramic/polymer composite fabrication and dielectric characterization were examined by Athanasios et al [18]. Elssa et al [19] reviewed thermal, frictional, and mechanical performance of ABS sheets. High-performance ABS-based dielectric composites were designed and prepared by Cuilian et al [20]. PC and ABS plastics that have been compatibly blended using solvent-recycled waste from electronic devices [21]. Study of mechanical, thermal, and electromagnetic interference shielding application with high absorption and low reflection characteristics of ABS, PLA and nylon polymers were investigated [22-26]. Merve et al. evaluated bio-based materials utilization in shape memory polymer composites production [27]. Wong et al [28] studied shape-memory polymers' applications in biomedical field. The study of polymer-matrix composites using drilling process parameters [29] and review of recent advancements in particulate-reinforced polymer matrix composites was conducted [30]. Moreover, researchers have explored and conducted experimental studies on machining of hybrid composites and bio composites to see the probable applications. Gulia and Nargundkar [31] prepared hybrid composites and conducted experimental study on abrasive water jet machining process. Nargundkar et al [32] performed experimental and optimization study of nonabrasive assisted abrasive water jet machining on bio composites. In this work, the following key contributions have been experimentally studied. Authors developed and studied a hybrid polymer matrix composite reinforced with copper particulate and tensile, electrical & thermal properties of the composites respectively.

2. Materials and Methods

In the present work, the solution mixing approach was used to generate PC polymer and ABS based composites, which were then hot pressed. Three various compositions of the main material and the metallic powder in terms of weight percentage were chosen as shown below, the compositions have been chosen to explore the impact of metal powder on the mechanical, electrical, and thermal characteristics of composite materials.

- Copper 30% + 70% Polycarbonate+ ABS (acrylonitrile–butadiene–styrene)
- Copper 50% + 50% Polycarbonate+ ABS (acrylonitrile–butadiene–styrene)
- Copper 50% + 50% Polycarbonate
- Copper 30% + 70% ABS (acrylonitrile–butadiene–styrene)
- Copper 30% + 70% Polycarbonate
- Copper 70% + 30% ABS (acrylonitrile–butadiene–styrene)

The covalent bonding and flowability between the ABS and the metallic copper powder are improved in this situation by the addition of the surfactant material. For the preparation of composites, copper reinforcement of 50 μm size was employed.

![Specimen (Dumbbell)](image1)

**Fig. 1. Specimen (Dumbbell)**

Composite specimens were tested on tensile, elongation, thermal & electrical properties and scanning electronic microscopy used to understand the distribution of copper particles in polymer matrix.

Tensile tests measure the amount of stretch or elongation that a plastic sample specimen must undergo to reach its breaking point. One of the most used plastic strength standards, ASTM D638, includes the tensile characteristics of both unreinforced and reinforced polymers. Standard "dumbbell" or "dog bone" shaped specimens are used in this test procedure as shown in figure 1. Tensile test setup is shown in figure 2.

![Tensile test Setup](image2)

**Fig. 2. Tensile test Setup**

Coefficient of thermal expansion by ASTM D 696 is intended to provide a means of determining the coefficient of linear thermal expansion of plastics which are not distorted or indented by the thrust of the dilatometer on the specimen. The rate of expansion of a material as a function of temperature is calculated using linear thermal expansion. This test may be used to check for potential thermal stress failure as well as for design reasons. Refer to figure
3 for the test setup for further information on how crucial it might be to comprehend the relative expansion/contraction properties of two materials in contact.

Fig. 3. Coefficient of thermal expansion test setup

Electrical Conductivity by ASTM D 257 adopted for measuring the resistivity of test samples. A measurement of the current or voltage drop under specified condition is used to estimate the resistance or conductance of a material specimen or capacitor. Surface and volume resistance or conductance may be measured individually using the right electrode setups.

Fig. 4. Electrical conductivity test setup

Once the required specimen and electrode dimensions are determined, the resistivity or conductivity may then be calculated. Refer to figure 4, which shows the electrical conductivity test apparatus. To create test specimens, a vertical hand-operated injection molding machine is used. The specimens were created using a stainless-steel multiple cavity mold, as shown in figure 5.
Fig. 5. Injection Moulding Setup

3. Results and Discussion

3.1 Tensile Strength

The addition of copper (Cu) to a polymer matrix like polycarbonate (PC) or acrylonitrile butadiene styrene (ABS) can enhance the tensile strength of the composite material. Copper is known for its high strength and good mechanical properties, which can contribute to improving the overall strength of the composite. From table 1 it can be seen that 50% Cu + 50% PC tensile strength is higher than the other combination of polymer matrix composite. It is reasonable to expect that a composite with a higher percentage of copper (such as 50% Cu + 50% PC) would generally exhibit higher tensile strength compared to a composite with a lower percentage of copper (such as 30% Cu + 70% PC). This is because a higher copper content would provide more reinforcement to the polymer matrix, leading to increased strength.

<table>
<thead>
<tr>
<th>Material</th>
<th>30% Cu + 70% PC, ABS</th>
<th>50%Cu + 50% PC, ABS</th>
<th>30% Cu + 70% ABS</th>
<th>70% Cu + 30% ABS</th>
<th>30% Cu + 70% PC</th>
<th>50% Cu + 50% PC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength (MPa)</td>
<td>22.8</td>
<td>23.7</td>
<td>29.01</td>
<td>30.21</td>
<td>33.03</td>
<td>36.11</td>
</tr>
</tbody>
</table>

3.2 Electrical Conductivity

A composite material's electrical conductivity tends to rise as the copper content of the polymer matrix rises. Since copper is a superb electrical conductor, adding it as a particulate reinforcement to a polymer matrix composite improves the composite's electrical conductivity. The distribution and presence of conductive filler particles like copper inside the polymer matrix has a significant impact on the composite's conductive characteristics. There are more conductive channels open for the movement of electrons when there is a
larger proportion of copper, leading to improved electrical conductivity. Similar observation can be seen from table 2.

Table 2. Electrical Conductivity

<table>
<thead>
<tr>
<th>Material</th>
<th>Electrical Conductivity (m Ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% Cu + 70% PC, ABS</td>
<td>-500</td>
</tr>
<tr>
<td>50%Cu + 50 % PC, ABS</td>
<td>200</td>
</tr>
<tr>
<td>30% Cu + 70% ABS</td>
<td>-500</td>
</tr>
<tr>
<td>70% Cu + 30% ABS</td>
<td>200</td>
</tr>
<tr>
<td>30% Cu + 70% PC</td>
<td>-500</td>
</tr>
<tr>
<td>50% Cu + 50% PC</td>
<td>200</td>
</tr>
</tbody>
</table>

3.3 Coefficient of Thermal Expansion

The coefficient of thermal expansion (CTE) of a composite material is influenced by the properties and proportions of its constituents. Copper (Cu) and polycarbonate (PC) have different CTE values, and when combined in a composite, the resulting CTE can vary based on their relative percentages. Copper typically has a higher CTE compared to polycarbonate. Therefore, a composite with a higher percentage of copper, such as 50% Cu + 50% polycarbonate, is likely to have a higher overall CTE compared to a composite with a lower percentage of copper, refer table 3.

Table 3. Coefficient of Thermal Expansion

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient of Thermal Expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% Cu + 70% PC, ABS</td>
<td>11.4</td>
</tr>
<tr>
<td>50%Cu + 50 % PC, ABS</td>
<td>14.04</td>
</tr>
<tr>
<td>30% Cu + 70% ABS</td>
<td>8.1</td>
</tr>
<tr>
<td>70% Cu + 30% ABS</td>
<td>10.42</td>
</tr>
<tr>
<td>30% Cu + 70% PC</td>
<td>13.2</td>
</tr>
<tr>
<td>50% Cu + 50% PC</td>
<td>15.73</td>
</tr>
</tbody>
</table>

3.4 Scanning Electron Microscopy (SEM)

The SEM analysis was done on three magnification levels. The following are the SEM images of a few components on which tests were conducted.

Fig 6. a) 50% Copper + 50% ABS with X 3000 b) 50% Copper + 50% ABS with X 6000
It is clearly seen from figure 6 a, b and c with different magnifications, SEM images conclude that the mixture is not homogenously mixed the spherical shapes are seen as copper is present, but it doesn’t specifically conclude that the material with exhibit conductivity as they are not interconnected.

![SEM image](image1)

**Fig 6. c)** 50% Copper + 50% ABS with X 10000

Figure 7 a, b and c represent 50 % polycarbonate and 50 % ABS with X3000, X6000, and X10000 magnification respectively. SEM images justify that the tested component is electrically conductive as the ends of the grains are spherical in nature but as these grains are looking open which means the composite is not homogenously mixed.

![SEM images](images2)

**Fig. 7 a)** 50% PC + 50% ABS with X 3000  
**Fig. 7 b)** 50% PC + 50% ABS with X 6000  
**Fig. 7 c)** 50% PC + 50% ABS with X 10000
Figure 8 a, b and c shows 50% copper and 50% (ABS + PC) with X3000, X6000, and X10000 magnification respectively. SEM image justifies that ABS and PC cannot be mixed with any conductive material as ends are looking pointed in nature, which says that the material is not homogenous in nature.

**Fig 8.** a) 50% Copper + 50% (ABS+PC) with X 3000  b) 50% Copper + 50% (ABS+PC) with X 6000  c) 50% Copper + 50% (ABS+PC) with X 10000

**4. Conclusion and Future Scope**

In this work, an attempt was made to synthesize and characterize hybrid polymer matrix composite reinforced with copper particulates. The performance measures considered in this study were tensile strength, electrical conductivity, and thermal expansion coefficient. Specifically, the key finding of the study is that the hybrid polymer composite, which is 50% Copper + 50% Polycarbonate is the best suited alloy for electrical applications when considering all testing parameters. The parameters results are as follows, values are 36.11 MPa for tensile strength, 200 m Ohm for electrical conductivity, 15.73 as coefficient of thermal expansion (K). In addition to that, SEM analysis also justifies that the tested component is electrically conductive. Authors suggest that continued research can be implemented by making new hybrid polymer composites with modified properties. Further research should be focused on sustainability, industrial and health care applications of polymer hybrid composites.
References


