OPTIMIZATION OF ELECTRICAL CONDUCTIVITY IN POLYPROPYLENE-TI COMPOSITES FOR PEMFC BIPOLAR PLATE APPLICATIONS

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ABSTRACT: This study aims to determine the optimal quantity of Ti powder mixture to achieve the highest electrical conductivity for composite materials based on PP, and to investigate the electrical conductivity values of PP composites with Ti filler. PP serves as the matrix while Ti powder is the additive. To assess the effect of adding Ti powder to PP-based composites, 10 wt%, 20 wt%, and 30 wt% of Ti powder will be blended with PP. Samples undergo mixing, crushing, compression molding, and electrical conductivity testing. Test results indicate that the highest electrical conductivity of 0.4 S/cm is achieved with a composition of 90 wt% Ti and 10 wt% PP for the PP-Ti composite. However, the electrical conductivity decreases with increasing weight percentage of Ti powder in the composite, reaching 0.23 S/cm and 0.18 S/cm for 20 wt% and 30 wt% Ti mixtures, respectively. This decrease is attributed to the low electrical conductivity of Ti powder at 2.07 S/cm, possibly due to oxidation of the Ti powder.

KEYWORDS: *Titanium (Ti) powder, Polypropylene (PP), electrical conductivity, percolation theory, bipolar plate, four-point probe method, Proton Exchange Membrane Fuel Cells (PEMFC).*

1.0 INTRODUCTION
Polymer composites with metal fillers have attracted considerable attention in diverse technical disciplines. Their electrical conductivity characteristics are similar to those of metals, while nevertheless retaining the mechanical features and processing methods of plastics. Additional research on these polymer composites has resulted in the advancement of proton exchange membrane fuel cells (PEMFCs), which are also referred to as polymer electrolyte membrane fuel cells.

1.1 Problem Statement and Research Focus
The challenge faced by polymer composite PP/Ti as an electrical conductor lies in achieving high electrical conductivity for its use as bipolar plates in Proton Exchange Membrane Fuel Cells (PEMFCs).

1.2 Research Objectives
The objectives of this study to determine the optimal PP and Ti mixing ratio for the composite to achieve the highest electrical conductivity.

2.0 LITERATURE REVIEW
Proton Exchange Membrane Fuel Cells (PEMFCs), also known as Polymer Electrolyte Membrane Fuel Cells, utilize hydrogen to generate electrical energy. This technology serves as an electric power source for vehicles, buildings, and portable electronic devices.

The operation principle of PEMFC is based on the chemical reaction between hydrogen and oxygen. This reaction produces water, which is an environmentally friendly process. The reaction between hydrogen and oxygen also generates electricity.

Bipolar plates serve multiple functions in a PEMFC. They supply reactant gases, remove water, support the membrane, conduct electrons, and house cooling channels. Most current fuel cells use bipolar plates made from graphite due to several favorable properties for PEMFC operation. Graphite is electrically conductive, corrosion-resistant, withstands high temperatures, and is inert to gas reactions.

2.1 Electrical Conductivity in Composites

The percolation theory (Figure 1) has provided insights into explaining the electrical conductivity dependence on the volume fraction of fillers through the relationship:

$$\sigma \sim (\phi - \phi_c)^t$$

where:

- σ = conductivity value
- ϕ = filler volume fraction
- ϕ_c = critical filler volume fraction
- t = rate of change of conductivity

Figure 1: Percolation Theory Analysis of Electrical Conductivity in Composite Materials

Typical electrical conductivity values for filler materials are approximately 10 S/cm for graphite, 10 S/cm for carbon black, and 10 S/cm for aluminum. The concentration of fillers conducting electricity must exceed the critical value of 60 wt%, as determined by percolation theory, to enable composite materials to conduct electricity effectively.

2.2 Factors Influencing Electrical Conductivity

The characteristics of filler materials play a crucial role in determining the conductivity of a composite. Using carbon as a filler material, ranging from small carbon particles to graphite fibers, yields varying conductivity values. The conductivity of filler materials sets a limit for composite conductivity. Additionally, particle size affects electrical conductivity; finer particles have been shown to lower the percolation threshold (Qingzhong Xue, 2003). Studies indicate that filler orientation during sample molding processes also influences composite conductivity (Huang, J. Baird, D.G, 2005). Drawing or injection molding aligns filler materials, resulting in multi-phase ratios in various directions due to flow out from the mold's sprue and gate.

2.3 Methods for Measuring Plate Conductivity

Several methods are employed to measure the conductivity of composite samples, including four-point probe, pressure method, and four-point probe scan method. The most commonly used method is the four-point probe scan method because contact resistance can be neglected; it measures voltage drop and is not dependent on contact resistance (Miccoli, 2015).

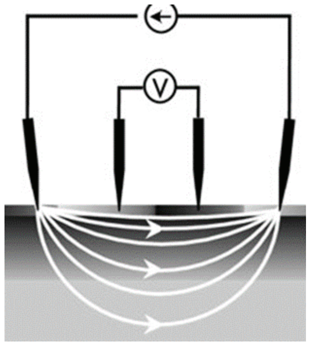

Figure 2: Figure: Four-Point Probe Method (Miccoli, 2015).

This method is highly suitable for measuring the conductivity of thin plates up to 2mm thick. The probe needles are spaced a fixed distance apart, typically 2mm. Current is supplied to the outer needles, and the voltage drop is measured across the inner needles. This voltage drop is then used to calculate the resistance value. Once the resistance value is obtained, the conductivity of the sample can be determined by reciprocal calculation of the plate resistance.

3.0 METHODOLOGY

The research methodology outlines the systematic processes and techniques employed to prepare and evaluate the polypropylene (PP) and titanium (Ti) composite samples. The primary objective is to determine the optimal composite formulation that yields the highest electrical conductivity for use in Proton Exchange Membrane Fuel Cells (PEMFC). The methodology includes four main processes: mixing, crushing and granulation, compression molding, and electrical conductivity testing.

3.1 Mixing Process

The mixing process is crucial for achieving a homogeneous sample mixture. All the weighed materials, including polypropylene and titanium powder, are initially mixed randomly to ensure an even distribution of components. This preliminary manual mixing step helps to break any large agglomerates and promote uniformity before mechanical mixing. The mechanically aided mixing is performed using a Roller Rotor 600R (Haake Rheomix) mixer. This equipment is designed to handle the specific viscosities and properties of the materials involved, ensuring thorough and consistent mixing. The Roller Rotor mixer operates by rotating the sample within a confined chamber, utilizing shear forces to disperse the titanium powder uniformly throughout the polypropylene matrix.

3.2 Crushing and Granulation Process

Following the mixing process, the composite material undergoes crushing and granulation. This step is essential to prepare the material for compression molding by reducing it to a manageable and consistent particle size. The crushing process breaks down any remaining agglomerates, while granulation ensures that the material is in the appropriate form for the molding process. By converting the mixed material into granules, the process facilitates better flow and packing during the subsequent molding stage. This step is critical to ensure that the final molded samples are free of defects and have uniform properties throughout.

3.3 Compression Molding Process

Compression molding is selected as the technique for producing composite plate samples due to its effectiveness in shaping composite materials into precise forms. This process involves placing the granulated composite material into a mold cavity, where it is subjected to heat and pressure. According to Huang J. (2005), this method ensures that the composite powder melts, flows, and fills the mold cavity uniformly. The applied pressure compacts the material, enhancing the density and mechanical integrity of the final sample. The mold is then cooled to solidify the composite into a rigid plate. The precise control of temperature and pressure parameters during this process is crucial to achieve the desired shape of the composite plates.

3.4 Electrical Conductivity Testing Process

The final step in the methodology is the assessment of the electrical conductivity of the molded composite samples. This is performed using a Four Point Probe device, specifically the Jandel Multi Height Four Point Probe and RM3 Test Instrument. The Four Point Probe method is a widely accepted technique for measuring the electrical conductivity of thin samples. It involves placing four equally spaced probes on the sample surface. A current is applied through the outer probes, and the resulting voltage drop is measured across the inner probes. This setup allows for accurate determination of the sample's resistivity, which can then be converted to conductivity. The Four Point Probe method is advantageous as it minimizes the contact resistance, providing a more accurate measurement of the sample's intrinsic electrical properties.

4.0 RESEARCH FINDINGS

The research findings section provides an in-depth analysis of the empirical outcomes derived from the experimental procedures outlined earlier in the methodology. The purpose of this part is to provide a comprehensive analysis and interpretation of the data pertaining to the electrical conductivity of PP/Ti composite samples. The main focus is to examine how different amounts of titanium (Ti) powder affect the total conductivity of the samples.

4.1 Sample Conductivity Testing Process

The final step in the research involved measuring the electrical conductivity of the samples using the JANDEL RM3 Multi Height Probe testing instrument. The samples were supplied with a current, and the voltage readings were recorded. It was observed that at 95 wt% Ti composition, conductivity drastically dropped to 1.10x10 S/cm. This decrease is attributed to the reduced polypropylene binder content, leading to insufficient bonding of the Ti particles and resulting in brittle samples. According to percolation theory, the electrical conductivity increases with the addition of conductive material but plateaus after reaching a maximum conductivity threshold.

4.2 Electrical Conductivity Analysis with Ti Powder Mixing in PP/Ti Composites

Figure 3 illustrates the effect of adding Ti powder on the electrical conductivity of PP/Ti samples. It was noted that conductivity decreased with increasing Ti powder addition. The highest conductivity observed was 0.4 S/cm at a 10 wt% Ti powder mixture. A study by Clingerman (2001) indicated that materials like nylon 6.6 with high conductivity, surface energy, and crystallinity levels have better conductivity compared to amorphous polycarbonate. Comparisons were made with previous research (Dweri R., 2007) to assess the effectiveness of processing parameters and materials used in producing composites with two fillers.

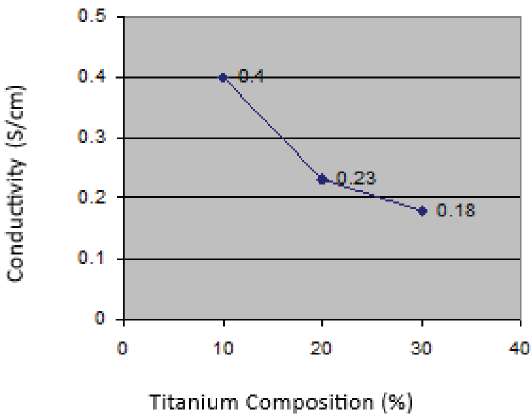

Figure 3: Graph of Conductivity vs. Titanium Composition at 20 wt% PP.

Due to the high density of Ti powder (4540 kg/cm^3), it can be inferred that Ti powder sediments during the compression process, resulting in uneven conductivity between the sample's upper and lower parts. The size of the materials used also contributed to the decrease in electrical conductivity observed in the study. The addition of a small amount of carbon black (CB) to the composite created a synergistic effect, resulting in higher electrical conductivity (Dweri, R., Sahari, J., 2007). The conductivity continued to decrease with increasing Ti powder addition, reaching 0.18 S/cm at a 30% Ti powder mixture. The conductivity value for the 10% Ti powder mixture, which produced the highest conductivity, aligns with findings (Dweri, R., Sahari, J., 2007) stating that adding 10% to 25% CB to PP/Ti composites yields optimal conductivity.

5.0 CONCLUSIONS

This investigation has yielded useful information regarding the influence of titanium powder composition on the electrical conductivity of polypropylene/titanium composites. The findings demonstrated that the use of a reasonable quantity of Ti powder, specifically at a weight percentage of 10%, greatly improves the conductivity of the composite material. This formulation achieves a perfect balance between the conductive qualities of Ti and the binding features of polypropylene, leading to a synergistic effect that maximises electrical performance.

In conclusion, the research goals were effectively completed by identifying the Ti composition that resulted in the maximum conductivity for the PP/Ti composite samples. The maximum conductivity attained was 0.4 S/cm with a titanium content of 10 wt%.

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