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Effect of Titanium Filler in Composite Conductivity with Different Binder

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Abstract. *This study investigates the impact of titanium (Ti) filler on the electrical conductivity of polypropylene (PP)-based composites. The research aims to determine the optimal Ti content to maximize conductivity while maintaining structural integrity. A series of samples were prepared with varying Ti concentrations (10–95 wt%), using controlled weighing, mixing, compression molding, and electrical conductivity testing methods. Results showed that conductivity increased significantly with higher Ti content, reaching a maximum value of 1.05 × 10 S/cm at 90 wt% Ti. This corresponds to the percolation threshold, where Ti particles form a continuous network enabling effective electron transfer. Beyond this threshold, conductivity declined sharply due to reduced binder content, leading to weak particle bonding and brittleness. These findings underscore the critical balance between filler concentration and binder properties for optimal performance. The study concludes that PP+Ti composites with 90 wt% Ti are promising for applications in electronics and energy systems, such as fuel cell bipolar plates, but highlight the need for further research on mechanical optimization. This work advances the understanding of conductive polymer composites and supports their potential in industrial and engineering applications.*

Keywords: *electrical conductivity, titanium filler, polypropylene composites, percolation threshold, polymer engineering*

1. Introduction

The field of metal-filled polymer composites has gained significant traction due to its ability to merge the advantageous properties of metals and polymers. These materials provide electrical conductivity levels comparable to metals while maintaining the mechanical flexibility and cost-effective processing of plastics. This unique combination makes metal-filled polymer composites ideal candidates for a wide range of industrial applications, particularly in electronics, automotive, and energy sectors. A key aspect of these materials is the transfer of electric charge and thermal energy, which depends on the filler materials' dispersion and interaction within the polymer matrix.

The inclusion of conductive fillers such as metals and carbon-based materials has been extensively studied to enhance the electrical conductivity of polymer composites. Conductive pathways are formed when the fillers create a continuous network through the matrix, allowing for effective electron movement. This phenomenon aligns with percolation theory, which posits that a material's electrical conductivity increases significantly when the filler concentration exceeds a critical threshold, enabling the formation of infinite conductive networks. However, achieving an optimal balance between filler concentration, distribution, and composite mechanical integrity remains a challenge.

Titanium, known for its excellent conductivity, corrosion resistance, and

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lightweight properties, has emerged as a promising filler material for polymer composites. When incorporated into a polymer matrix such as polypropylene (PP), titanium enhances the composite's electrical conductivity while contributing to structural durability. Recent studies have demonstrated that titanium's addition to polymer matrices can significantly improve electrical and mechanical properties, making such composites suitable for advanced engineering applications, including bipolar plates in fuel cells.

This study explores the effects of titanium filler on the electrical conductivity of polypropylene composites. By systematically varying the composition of titanium and analyzing its impact on conductivity, the research seeks to identify the optimal filler concentration for maximum performance. The methodology includes a series of controlled processes, such as material weighing, mixing, compression molding, and electrical conductivity testing, ensuring precision in composite fabrication and characterization.

In particular, the focus is on determining the role of titanium's weight percentage in achieving a balance between conductivity and mechanical stability. Preliminary observations indicate that increasing titanium content enhances conductivity up to a certain threshold, beyond which the composite's mechanical properties may deteriorate due to insufficient polymer binder. This phenomenon underscores the importance of achieving an optimal filler-polymer ratio.

The findings of this research contribute to the broader understanding of conductive polymer composites and their applications. With potential implications for renewable energy systems, such as polymer electrolyte membrane fuel cells, and electronic devices, the study emphasizes the value of designing composites with tailored properties. Moreover, the insights gained from this work can serve as a foundation for future innovations in composite material engineering.

2. Method

This study aimed to evaluate the effects of titanium (Ti) filler on the electrical conductivity of polypropylene (PP)-based composites. The methodology included systematic steps to ensure accurate preparation, fabrication, and characterization of the composite materials. The workflow included material weighing, mixing, crushing, molding, and conductivity testing.

a. Weighing Process

   The initial stage involved determining the precise composition of each sample. All materials were weighed using high-precision scales to ensure consistency and reproducibility. The total weight of the mixture was standardized at 20 grams per sample with the composition expressed in weight percentage (wt%). The weight percentage of titanium varied across samples to examine its effect on conductivity, while PP served as the matrix or binder.

b. Mixing Process

   Achieving a homogeneous distribution of materials was crucial for the consistency of test results. Pre-weighed materials were manually blended before being introduced into a Roller Rotor 600R (Haake Rheomix) mixer. The mixing process ensured uniform dispersion of titanium particles within the polypropylene matrix, minimizing the risk of agglomeration which could adversely affect the composite's electrical properties.

c. Crushing and Granulating Process

   The mixed materials were crushed and granulated to facilitate subsequent molding.

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This step involved using a MIM Strong Crusher, Model TSC-5010, located in the Advanced Manufacturing Laboratory. The crushing process transformed the solid mixture into coarse, black granules, which were easier to handle and shape during compression molding.

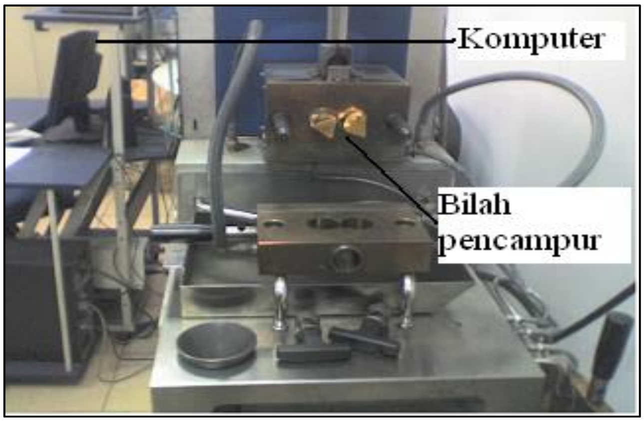

Figure 1. Mixer Roller rotor 600R (Haake Rheomix)

d. Compression Molding Process

The granulated mixture was subjected to compression molding to form composite plate samples. A high-speed, high-precision 50-ton compression molding machine was used. The process involved the following steps:

1) Pre-heating: The molding machine was pre-heated for three minutes to ensure uniform thermal distribution.
2) Pressing: The granulated material was subjected to a temperature of 200°C and a pressure of 75 kg/cm^2 for 180 seconds. This procedure compacted the powder into a rigid plate-like shape, ensuring even density and structural integrity.
3) Binder Coating: Extended pressing times allowed the PP binder to adequately coat the titanium filler particles, reducing inter-particle voids but potentially lowering conductivity.

e. Electrical Conductivity Testing Process:

The final stage involved testing the electrical conductivity of the molded samples. A Four Point Probe system, specifically the Jandel Multi-Height Four Point Probe with an RM3 Testing Device, was employed for this purpose. Key aspects of the testing process included:

1) Current Application: A current of I = 10 mA was applied to PP+G+Ti samples, while a lower current of I = 10 nA was used for PP+Ti samples. This adjustment accounted for the differences in resistance levels and equipment sensitivity.
2) Voltage Measurement: The resulting voltage values were recorded and used to calculate electrical conductivity, incorporating a correction factor (F) to improve measurement accuracy.
3) Repeatability: Multiple readings were taken for each sample to ensure consistency and reliability of results.

3. Results and Discussions

This section presents the results obtained from the electrical conductivity tests and provides a detailed discussion of the findings in relation to percolation theory and material behavior. The focus is on the effects of varying titanium (Ti) filler content on the

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conductivity of polypropylene (PP)-based composites. The conductivity and resistivity graphs for Ti compositions of 80%, 90%, and 95% are shown below.

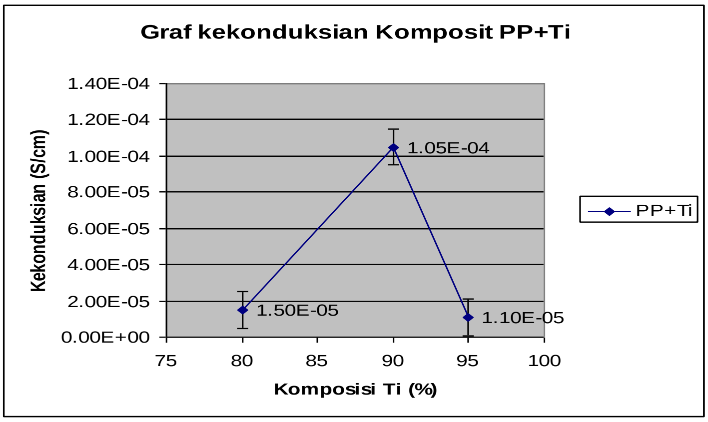

Figure 2. Conductivity Graph of PP+Ti Composite

Electrical Conductivity Measurements

The electrical conductivity of the composite samples was evaluated using a four-point probe method. Initial samples with low titanium content (10% to 70%) exhibited negligible conductivity. This observation aligns with the concept of percolation threshold, where a minimum concentration of conductive filler is required to establish a continuous network for electron transport within the composite. The conductivity values began to register significantly once the titanium content reached 80 wt%. The highest electrical conductivity recorded was 1.05 × 10 S/cm, achieved at a titanium concentration of 90 wt%. This result indicates that at this composition, the titanium particles form an optimal interconnected network, enabling effective electron movement across the composite. The results are graphically presented in Figure 2.

Impact of Titanium Concentration

Low Titanium Content (< 80 wt%): At lower titanium concentrations, the composite's electrical conductivity was minimal due to insufficient contact between filler particles. The titanium particles remained isolated within the PP matrix, preventing the formation of conductive pathways. This behavior underscores the critical role of particle dispersion and spatial distribution in achieving high conductivity.

Optimal Titanium Content (90 wt%): At 90 wt% titanium, the composite demonstrated peak conductivity. This concentration marks the percolation threshold where a sufficient number of titanium particles come into contact to create a continuous conductive network. This result is consistent with the percolation theory, which describes the rapid increase in conductivity once the filler content exceeds the threshold value.

Excessive Titanium Content (95 wt%): Beyond 90 wt%, conductivity decreased sharply. The reduction in conductivity is attributed to the reduced proportion of the PP binder. With less binder, the composite becomes brittle, and the bonding between titanium particles weakens, leading to structural deficiencies. This highlights the importance of maintaining an optimal balance between filler and matrix materials to preserve mechanical integrity while maximizing conductivity.

Comparison with Previous Studies

These results align with existing literature on metal-filled polymer composites.

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Studies by Dweiri and Sahari (2007) observed similar conductivity trends in carbon-based PP composites, emphasizing the significance of filler-matrix interactions. Furthermore, Eze et al. (2018) demonstrated the role of titanium in enhancing conductivity in copper composites, reinforcing titanium's potential as a conductive filler.

Practical Implications

The optimal PP+Ti composite (90 wt% Ti) offers promising applications in fields requiring lightweight and conductive materials. Potential applications include: (a) Bipolar plates for fuel cells: The conductivity and mechanical properties of the composite make it suitable for use in polymer electrolyte membrane fuel cells. (b) Electronic devices: The lightweight and flexible nature of the composite allows integration into electronic components. However, the study also highlights the trade-offs involved in increasing filler content. While higher titanium concentrations improve conductivity, they compromise the composite's mechanical properties, necessitating careful optimization for specific applications.

Limitations and Recommendations

a. Mechanical Properties: The brittleness observed at higher titanium concentrations underscores the need to balance conductivity with mechanical stability. Future studies could explore hybrid fillers or surface treatments to enhance inter-particle bonding.
b. Dispersion Techniques: Improved mixing techniques, such as ultrasonic dispersion, could enhance the uniformity of titanium particle distribution, potentially lowering the percolation threshold.
c. Environmental and Cost Factors: The cost-effectiveness and recyclability of PP+Ti composites should be investigated further, considering the environmental implications of titanium mining and processing.

4. Conclusions

This study investigated the effect of titanium (Ti) filler on the electrical conductivity of polypropylene (PP)-based composites, focusing on identifying the optimal filler concentration for achieving maximum conductivity while preserving the composite's structural integrity. The findings offer valuable insights into the interplay between filler content, composite properties, and material behavior.

The results revealed that electrical conductivity in PP-based composites significantly depends on the concentration of titanium filler. At lower filler concentrations (<80 wt%), the composite exhibited negligible conductivity due to the absence of sufficient conductive pathways. This observation aligns with percolation theory, which emphasizes the need for a critical concentration of conductive filler to form an interconnected network for electron movement.

At a titanium concentration of 90 wt%, the composite achieved its highest electrical conductivity of 1.05 × 10 S/cm. This optimal composition highlights the point at which the titanium particles form a continuous conductive network within the polymer matrix, enabling effective electron transfer. The mechanical integrity of the composite was also maintained at this concentration, making it a promising material for applications requiring both conductivity and structural durability.

However, further increases in titanium content (beyond 90 wt%) resulted in a sharp decline in conductivity. This decline is attributed to the reduced proportion of the PP binder, which compromised the bonding between titanium particles and led to brittleness.

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These findings underscore the critical importance of maintaining a balanced ratio of filler to binder to ensure both electrical and mechanical performance.

The study's results have practical implications for the design and development of advanced composite materials. The PP+Ti composite with 90 wt% titanium shows potential for applications in energy systems, such as bipolar plates in fuel cells, and in the electronics industry, where lightweight, conductive materials are essential. However, the brittleness observed at higher filler concentrations highlights the need for further optimization to enhance mechanical properties without compromising conductivity.

Future research could focus on exploring alternative binders, hybrid filler systems, or advanced mixing techniques to achieve better dispersion and bonding of titanium particles. Additionally, investigating the environmental and economic aspects of producing PP+Ti composites could support their adoption in sustainable manufacturing practices.

In conclusion, this study successfully demonstrated the feasibility of using titanium as an effective conductive filler in PP-based composites. The knowledge gained provide a foundation for future innovations in conductive polymer composites, implementing the way for their broader application in engineering and industrial domains.

5. Acknowlegment

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