(Received 30 June 2024, Accepted xxx, Scheduled xxx)

Factorial Analysis on the Preparation of Barium Titanate-Epoxy Resin Composite for Antenna Substrate

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ABSTRACT: This study investigates the preparation and characterization of barium titanate-epoxy resin composites, focusing on main factors influencing the dielectric properties of that composite materials. Using a 2^k factorial design, the effects of heating temperature, stirring speed, stirring time, and hardening process on the permittivity were thoroughly investigated. Sixteen samples were prepared and analyzed using Design-Expert software, with permittivity measurements conducted via the waveguide method and a Vector Network Analyzer (VNA) in the 4–6 GHz range. Results show significant impacts from stirring time and speed, with optimal conditions identified as 50°C heating, 500 rpm stirring speed, three minutes stirring time, and room temperature hardening from two-level factorial analysis (TLFA). These findings provide valuable insights into the best fabrication conditions for barium titanite-epoxy resin composites, contributing to the development of antenna substrate with a permittivity value of 7.0208 and a loss tangent of 0.0238 that is suitable for high-frequency communication applications.

1. INTRODUCTION

For optimizing antenna performance, especially on materials for antenna substrates, achieving high permittivity with minimal loss is important. Other than that, the use of composite material in electronic communication systems is on the rise. It is reported that the usage of the composite materials can contribute to high performance and maintain the low-cost, miniaturization factors [1]. Multiple methods for fabricating antenna substrates from various materials have been explored, including flexible [2–4], textile [5], agricultural waste [6–9], and composite materials [10–13]. This study aims to identify the key factors that influence the dielectric properties of barium titanate-epoxy resin composites, based on the preparation and characterization processes. Barium titanate ($BaTiO_3$) is renowned for its excellent dielectric properties, making it an ideal ceramic filler in composite materials [13, 14]. By combining with epoxy resin, these composites can offer enhanced performance in high-frequency applications such as antennas [13, 14].

The composite material preparation involves precise mixing of barium titanate powder with epoxy resin and a hardener. The interaction between these components, particularly during the stirring and curing phases, significantly impacts the resulting material's permittivity. It is reported that the epoxy resin alone has a low permittivity value around two to five, making it inadequate to be applied for electronic application [15]. The combination of epoxy resin with high-permittivity ceramic nanopowders, such as barium titanate, to enhance the material's permittivity is often observed in several studies [1, 12, 13, 15–18]. Few studies have highlighted the effect of the temperature, concentration level, and processing method in general on the dielectric properties of composites [6, 7, 19]. However, a comprehensive factorial analysis on heating temperature, stirring speed, stirring time, and hardening process effects on permittivity, particularly at 5 GHz, remains underexplored.

This study employs two-level factorial analysis (TLFA) to systematically investigate the impact of four critical factors: heating temperature, stirring speed, stirring time, and hardening process on permittivity of barium titanite-epoxy resin composites. Sixteen experimental runs are presented and analyzed using Design-Expert software to generate experimental conditions and assess their effects on the permittivity of the composites. The goal is to determine the optimal combination of these factors that yields the highest permittivity, making the composite material suitable for antenna substrate applications from TLFA.

Permittivity measurements were conducted using the waveguide method, operating at a range of 4 GHz to 6 GHz. Since this study aims to identify the key factors that influence the dielectric properties of barium titanate-epoxy resin composite and propose potential improvements for future research in this field, the results of this study are expected to contribute to the development of advanced dielectric materials with good performance for high-frequency communication applications.

2. METHODOLOGY

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