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Determination of Microwave Properties of Sodium Lime Glass Polycaprolactone (SLG/PCL) Composites Using Open Ended Coaxial Sensor

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ABSTRACT
The use of electronic devices operating in the microwave frequency range has led to a significant increase in electromagnetic interference (EMI) causing increased interest on materials that may absorb EMI and improve performance of electronic devices. A potential solution is the reuse of sodium lime glass (SLG) bottle waste from drink containers, which can be repurposed into composite materials for microwave applications. This approach may addresses EMI issues and also contributes to sustainable waste management practices and environmental conservation. The research focuses on microwave characterization of SLG/polymer composites for microwave applications while demonstrating the potential of SLG to enhance dielectric properties of polymeric materials.This paperdetermined the dielectric constant, loss factor and loss tangent of the SLG/PCL composite using open ended coaxial probe (OECP). Four different composite of SLG/ PCL were considered in this paper with varying ratio of SLG and PCL. Results from measurement indicated that dielectric constant increased with frequency from 8 GHz to 13 GHz, indicating an enhanced ability to store electrical energy at higher frequencies. The addition of different amounts of glass powder influenced the energy dissipation properties of the materials. Increasing the amount of SLG powder led to higher loss factors with the highest value of 0.26for the pure SLG inclusion. Whereas, increasing SLG particles led to decreasing loss tangent, stabilizing around 10 GHz. The results obtained hold considerable promise for the production of microwave absorbers, paving the way for the utilization of SLG/PCL composites in the production of efficient microwave absorbers and equipment with enhanced electromagnetic properties.

Keywords: Loss tangent, Loss factor, Dielectric Constant, Open ended coaxial probe, composite

I. INTRODUCTION

Usage of working electronic devices in the frequency band of microwave has grown rapidly over the years, whereas electromagnetic interference (EMI) has immensely increased. Therefore, there are perturbations of large degree produced in electronic systems of military and civil telecommunication. In the civil domain, the shelf life is reduced and disrupted by electromagnetic interferences and the electronic systems efficiency fitted to automobiles or planes (Idris et al., 2016).

Protection of electronic equipment against electromagnetic aggression is needed to avoid these problems, and one way to do that is repressing the electronic circuits in a shielding package that allows the reduction of the impact of the incident waves and electromagnetic coupling (Belaabedet al., 2013). Extensive studies have been carried out about developing new and high effective shielding materials that can increase the electronic devices shelf life and also reducing the effect of the EMI. Recent developments in microwave absorber technology have resulted in composite mixed materials, by mixing two or more different materials together in a single matrix or hybrid matrix, which can be used on whether they are appropriate for narrow or broadband absorption and for low or high-frequency (Kang et al., 2015).

Yakubu et al. (2022), reported the use of agricultural waste (corn husk powder) in the production of microwave shielding composites. In their work they reported that a dielectric property of 3.42 was obtained for the 30 % corn husk filler with a loss factor of 0.47. They concluded that the corn husk powder played a significant role in the values of shielding effectiveness (SE) obtained, where the highest filler was able to shield radiation by up to -4.21 dB at the frequency range measured.

Reduction of reflection of electromagnetic signals is achieved effectively by composite mixed materials and the physical performance, on the other hand, is good with also lower production cost (Nayak et al 2014). The composite mixed materials possess interesting functions through the mixture of important properties from both components and optimized to achieve a particular balance of properties for a given range of applications (Patil et al., 2011). The metal oxide is one of the important components that is utilized to form improved composites materials with advanced properties. Their large variety of structural geometries with an electronic structure have made them advanced candidates for biological sensing, optoelectronic applications, and electronics (Dragan &Carlone, 2015).

Meanwhile, the cost of the raw materials, the weight of resulting composites, and the metal corrosion may be considered as drawbacks or disadvantages on these candidates (Shao et al., 2004; Li et al., 2001). Thus, to overcome these disadvantages, researchers used compounds that were mixed with other materials, such as carbon compounds and polymers.

Glass is a non-crystalline inert material, non-porous and fragile and is considered as a thermal insulator. By presenting these features and being impermeable to the passage of oxygen or carbon dioxide, the use of glass debris as filler in the manufacture of Polyurethane Resin (PUR) can offer a number of advantages, such as reduction of collection costs, reducing environmental pollution, improving the economy and reducing the consumption of natural resources (Santos, 2009). On the other hand, there are also many applications for waste glass. Glasses are widely used in a wide range of technological applications, from chemically resistant containers and piping to fiber composites, and from pharmaceutical, and sealing glasses to nuclear waste immobilization.

The controlled heat treatment of borosilicate glasses especially those which have domain sizes in sub-optical scale is interesting in controlling and designing the physical properties such as chemical durability, crystal nucleation rates, and high-temperature strength, and is of interest in some natural magmatic systems as well. Due to these interesting physical properties, borosilicate glasses can be used as laser host matrices after doping with rare earth oxides (Saddeeket al., 2010). Herein, soda lime glass (SLG) will be utilized due to its promising properties along with its potential applications for use in microwave absorbers. The SLG material will be combined with PCL as a polymeric matrix due to its flexibility and easy to process to provide the carrier template.

II. MATERIALS AND METHOD

The methods used in this paper are melt-blend method for sample preparation, open ended coaxial probe for determining the dielectric properties. The collected glass was soaked in acetone for two days. After which it washed and dried for 24 hours. The dried glass was pounded and grind using mortar and pestle to micrometer sizes as shown in Figure 1.

Figure1: Grinded Sodium Lime Glass

The PCL was melted by heating in a beaker and mixed with the grinded glass. Four different mixtures with different proportions of Sodium Lime glass and PCL were prepared. Shown in Table 1 is the Material composition for the composites.

Table 1: Composites Nominal Ratio

S/N	SLG (g)	PCL (g)	Total
1.	20.0	5.0	25.0
2.	15.0	10.0	25.0
3.	10.0	15.0	25.0
4.	5.0	20.0	25.0

The melt blend techniques was used to synthesize the sodium lime glass powder/polycaprolactone composites involve heating the two components to a temperature between 70 - 100°C. The prepared composites was then prepared into pellets for further characterization. For the dielectric measurements, Agilent N5230A PNA.L Vector Network Analyzer was used at room temperature with the frequency variation ranging from 8 to 12.9 GHz. Figure 2 is the set up for dielectric measurement using VNA.

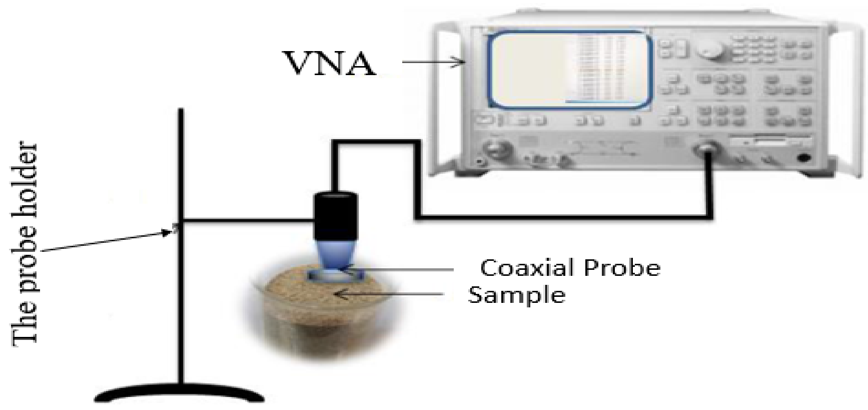

Figure 2: Experimental set up for Dielectric measurement

III. RESULT AND DISCUSSION

Dielectric Constants

The result of dielectric constant for the different ration of sample is shown in Figure3. PCL, careful observation shows that sample shows dielectric constant ranges from 3.0143 to 3.1856. The dielectric constant increases with frequency, indicating an enhanced ability to store electrical energy and an increased electrical response at higher frequencies.

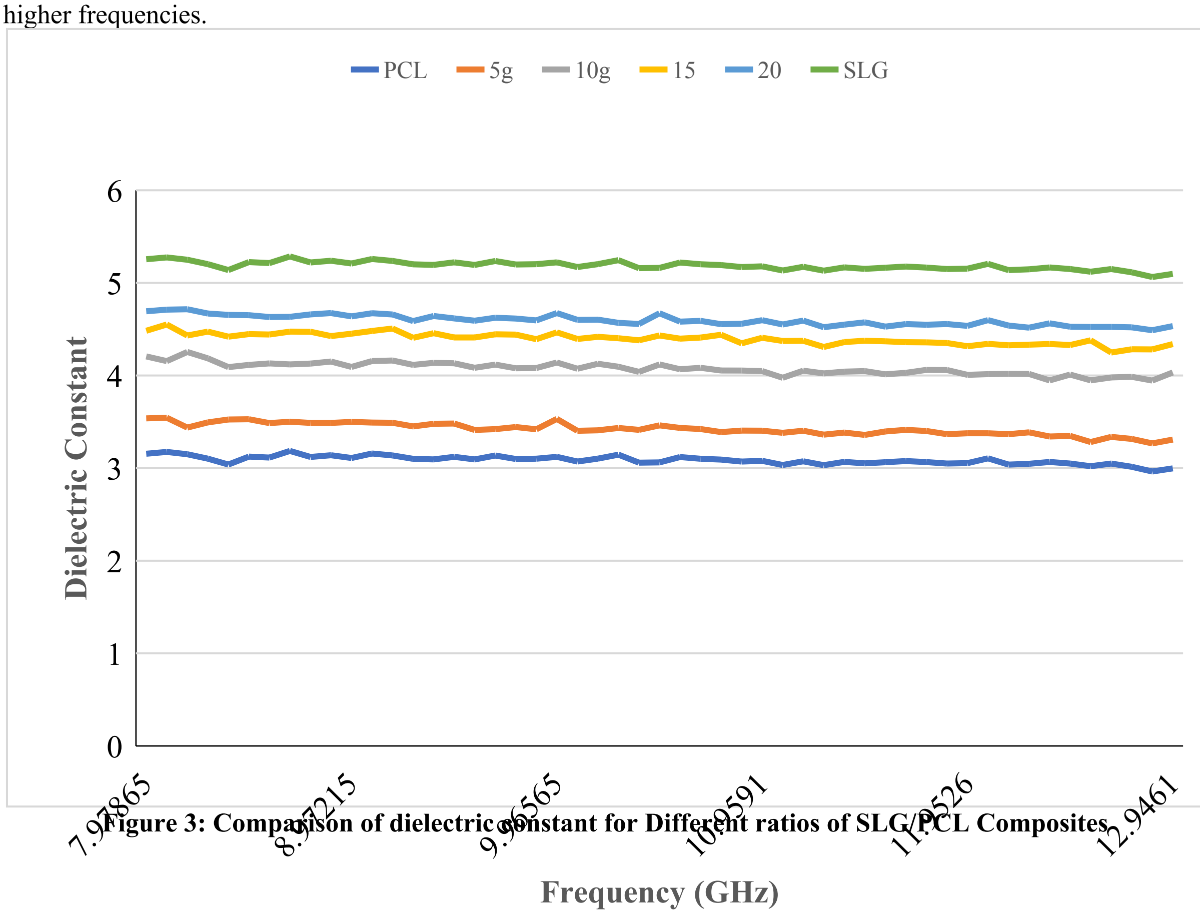

Figure 3: Comparison of dielectric constant for Different ratios of SLG/PCL Composites

5g sample exhibits a dielectric constant ranging from 3.2816 to 3.5442. Compared to PCL, 5g generally has higher dielectric constant values, suggesting a greater ability to store electrical energy and a higher responsiveness to electric fields.

10g the dielectric constant for this sample ranges from 3.947 to 4.2831. 10g shows a further increase in dielectric constant compared to 5g, indicating an even higher ability to store electrical energy and an increased electrical response at higher frequencies. 15g sample has a dielectric constant ranging from 4.2483 to 4.5507. 15g exhibits higher dielectric constant values compared to 10g, indicating a greater ability to store electrical energy and a higher responsiveness to electric fields.

20g the dielectric constant for this sample ranges from 4.5165 to 4.711. The 20g shows a further increase in dielectric constant compared to 15g, indicating an even higher ability to store electrical energy and a greater electrical response at higher frequencies. SLG sample has a dielectric constant ranging from 5.0636 to 5.2748. SLG exhibits higher dielectric constant values compared to 20g, indicating a greater ability to store electrical energy and a higher responsiveness to electric fields.

The samples demonstrate an increasing trend in dielectric constant with increasing sample number, indicating that the materials or compositions represented by these samples become more polarizable or exhibit higher electrical response as the SLG increases. The data allows for a comparison of the dielectric behavior among different samples, highlighting their varying abilities to store electrical energy and respond to electric fields at different frequencies. Overall, the trend among the samples is an increasing dielectric constant with increasing sample number. This trend agreed with Arshad et al., 2020 who reported that the materials or compositions represented by samples become more polarizable or exhibit higher electrical response as the sample number increases.

5.4 Loss Factor

The addition of 5 grams of glass powder to PCL reduces the energy dissipation capacity, resulting in a lower and stable loss factor ranging from 0.18 to 0.20. Increasing the glass powder concentration to 10 grams 10g shows a similar effect, with a stable loss factor between approximately 0.19 and 0.20. The presence of 15 grams of glass powder slightly increases the loss factor compared to 10g, indicating enhanced energy dissipation, with a stable loss factor ranging from 0.20 to 0.21.

Further increasing the glass powder concentration to 20 gramsleads to a higher loss factor, suggesting greater energy dissipation, with a stable loss factor ranging from 0.22 to 0.23. Pure glass powder (SLG) exhibits the highest loss factor among all samples, ranging from 0.24 to 0.26, indicating excellent energy dissipation capabilities.

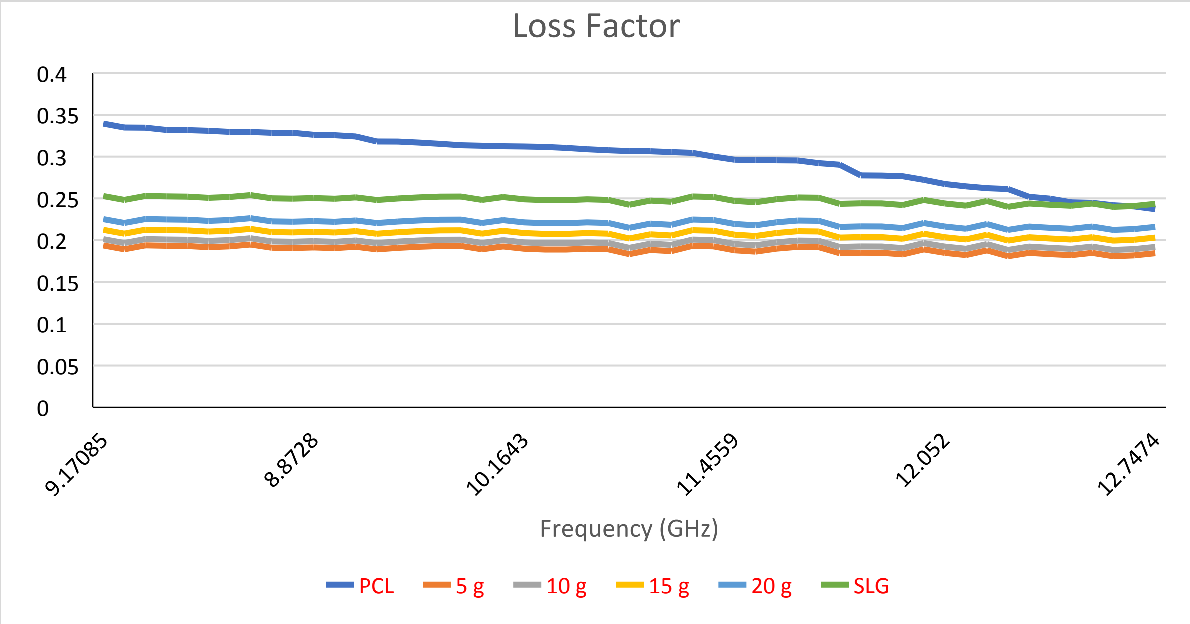

Figure 4: Comparison of loss factor for Different ratios of SLG/PCL Composites

The addition of glass powder to the PCL matrix affects the energy dissipation properties of the material this is in agreement with the work of Shahin-Shamsabadiet al., (2018). Higher concentrations of sodium lime glass powder tend to increase the loss factor, indicating improved energy dissipation. Notably, demonstrates the highest loss factor, and the trends in loss factors across all samples indicate consistent energy dissipation behavior within the tested frequency range.

5.5 Loss Tangents

The analysis of various materials' loss tangent behavior reveals distinct characteristics as shown in figure 4 . In the case of PCL, it demonstrates the common trend of decreasing loss tangent with increasing frequency, with stabilization around 10 GHz.

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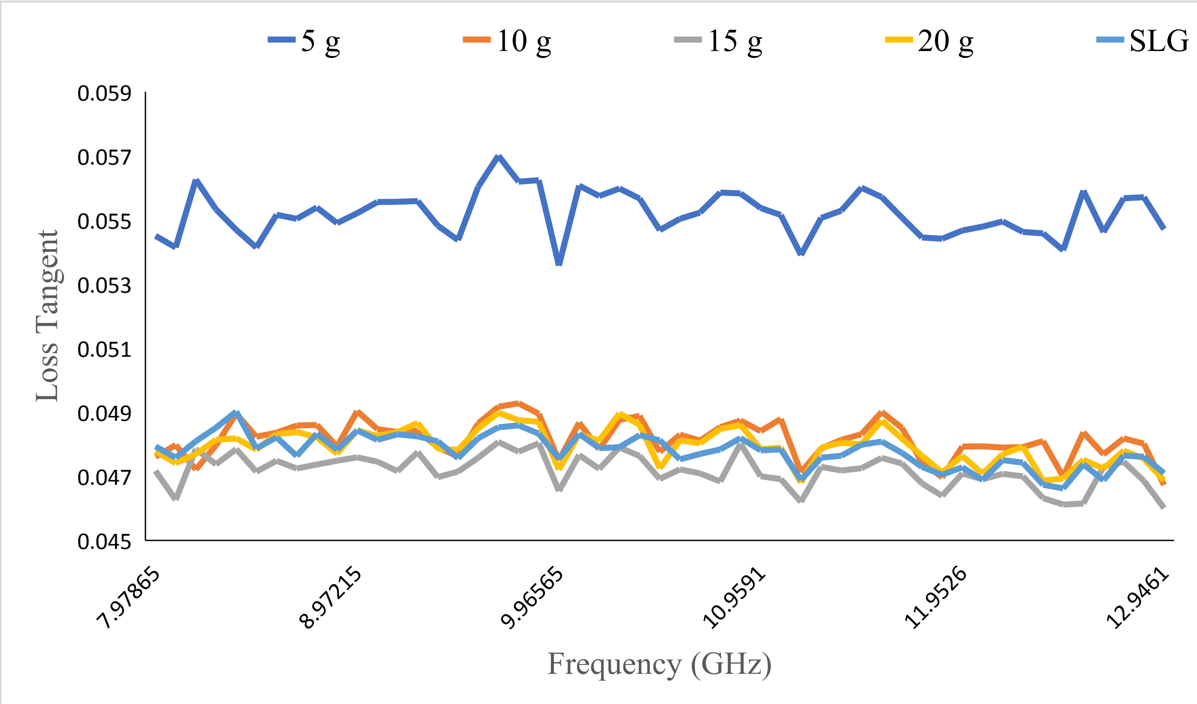

Figure 5: Comparison of loss tangent for Different ratios of SLG/PCL Composites

This suggests that PCL has the potential for tailored energy dissipation in diverse applications. exhibits consistently low energy dissipation within the range, displaying stable behavior with minimal variations. (10g) sees an increase in loss tangent as frequency rises, ultimately stabilizing at a relatively higher level. 15 g maintains low energy dissipation with minor fluctuations and a temporary dip around 11.7575 GHz, indicating no significant frequency-dependent trends.20gshows low energy dissipation at lower frequencies, with intermittent peaks and subsequent decreases, suggesting stable properties with some frequency-dependent variations. The SLG material maintains low energy dissipation, featuring a notable peak in loss tangent around 9.6676 GHz, highlighting potential frequency-dependent variations in its energy dissipation behavior. The result provide valuable information for material selection in applications requiring specific energy dissipation characteristics. The decreases with increase in frequency might be due to decreased polarization at high frequency ranges. Loss tangent decreased strongly as frequency increased for both high purity and low purity materials as agrees by Silakaewet al. (2021). It was noticed that the various composite maintains low energy dissipation.

IV. CONCLUSION

This study successfully accomplished the synthesis of sodium lime glassand polycaprolactone (PCL) composites using a straightforward melt blending technique. A comprehensive examination was conducted to assess electromagnetics shielding properties employing the OpenEnded Coaxial Probe (OECP).

Findings show the potential of SLG to function as a filler for enhancing parameters such as dielectric constant, loss factor, and loss tangent when combined with PCL as a matrix. Additionally, the composite exhibits the capability to serve as a valuable component in the construction of equipment with notable microwave and infrared absorption attributes. Furthermore, the research observed a trend where, as the frequency increased, the dielectric properties decreased. In essence, the research not only successfully achieved its objectives but also unveiled a range of valuable findings, paving the way for the utilization of SLG/PCL composites in the production of efficient microwave absorbers and equipment with enhanced electromagnetic properties.

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