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Composite absorbing electromagnetic waves based on cullet from recycled glass waste

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***Abstract*— Glass foam composites were developed using recycled glass cullet and tested for electromagnetic wave absorption. Rubber powder and carbon fibers were added as carbon fillers in varying amounts. The resulting composites exhibited a homogeneous porous structure with low density (213–347 kg/m³). SEM analysis revealed significant degradation of rubber powder, unlike carbon fibers. Thermogravimetric analysis showed mass losses of 62.06% for rubber and 1.71% for carbon fibers. Dielectric measurements indicated that composites with carbon fibers had higher permittivity (1.78–3.72) and dielectric losses (0.32–0.46 at 10 GHz), whereas those with rubber powder showed lower dielectric performance.**

***Keywords*— glass foam composites, recycled glass cullet, carbon fillers, electromagnetic wave absorption, dielectric properties**

I. INTRODUCTION

The increasing use of electromagnetic (EM) waves in telecommunications and modern electronic technologies has led to concerning levels of EM pollution [1,2]. In response, the development of materials capable of effectively absorbing these waves has become an active area of research [3,4]. The effectiveness of an absorbing material depends on its physical properties, such as permittivity, permeability, and dielectric losses [5,6]. Depending on their attenuation mechanisms, absorbing materials can be dielectric, magnetic, or a combination of both [7,8]. Generally, a dielectric matrix is used to reduce unwanted EM wave reflection [9,10]. Carbon-based fillers such as graphite [11,12], graphene [13], carbon nanotubes [14,15], and carbon fibers [16,17] are commonly added to enhance dielectric losses. Magnetic absorbers, on the other hand, often contain metal oxides [18,19] or carbonyls [20,21]. At the same time, solid waste recovery especially glass waste (cullet) has become a major environmental issue [22,23]. Cullet is widely used to produce glass foam, known for its acoustic and thermal insulation properties [24,25], and has recently been explored for its potential in EM wave absorption [17,25]. In this study, glass foams produced from waste glass were combined with two types of carbon fillers: carbon fibers (CF) and rubber powder (RP). The aim is to assess the absorption performance of each filler.

II. MATERIALS AND METHODS

A. Sample preparation

Glass foams were produced from soda-lime glass waste supplied by Mediterranean Float Glass (Algeria). The glass, mainly composed of SiO_2, Na_2O, and CaO, was ground to a particle size of 100 µm. The glass powder was mixed with 1 wt.% of calcium carbonate ($CaCO_3$) as a foaming agent, along with varying proportions of carbon fillers: carbon fibers (CF) and rubber powder (RP), measuring 1 mm and 2 mm

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respectively. The mixtures were heated at 800 °C for 30 minutes. During the heat treatment, $CaCO_3$ decomposed into CO_2 and CaO, leading to the formation of foam within the softened glass matrix. Nine samples were prepared with different CF and RP contents, and their apparent density was measured to evaluate the effect of the fillers on the foam structure.

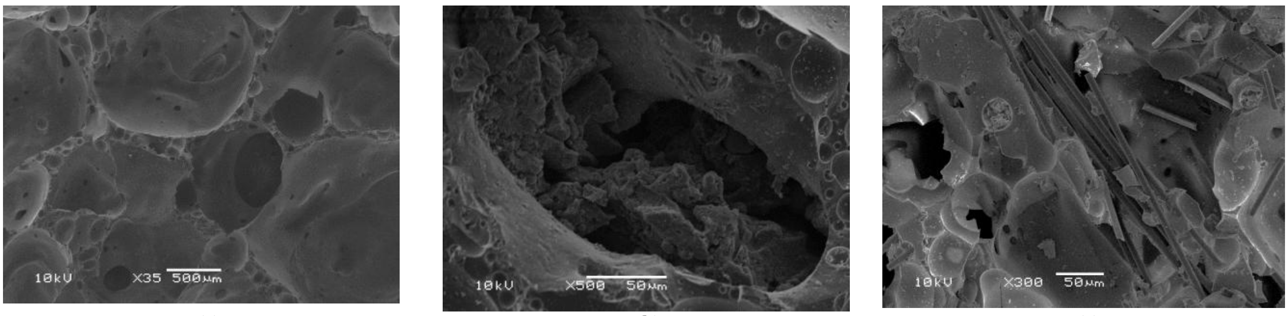
B. Caracterization

The characterization of the glass foams was carried out using various techniques. The morphology of the samples was observed using a scanning electron microscope (SEM). The apparent density was determined by calculating the mass-to-volume ratio, based on the average of three measurements for improved accuracy. Thermogravimetric (TGA) and differential thermal analyses (DTA) were performed using an SDT Q600 device. Dielectric properties were measured over a frequency range from 2 to 18 GHz. For this, a coaxial probe connected to a vector network analyzer was used. The measured values included the real permittivity (ε'), imaginary permittivity (ε''), and dielectric loss ($\tan\delta$). Prior to measurements, samples were carefully polished to ensure good contact with the probe. Eight tests were conducted for each sample to ensure reliable data. The average values were then presented in graphical form.

III. RESULTS AND DISCUSSIONS

A. Structure and morphology

All paragraphs must be indented. All paragraphs must be Glass foams were produced with varying amounts of carbon fibres (CF) from 2 to 8 wt.% and rubber powder (RP) from 4 to 16 wt.%, all containing 1 wt.% foaming agent ($CaCO_3$). The reference foam (UL) had a density of 279 kg/m³, consistent with literature values. Foam densities varied between 221–368 kg/m³ for RP-filled samples and 213–347 kg/m³ for CF-filled ones. The RP content was generally twice that of CF in the samples. No clear correlation was found between filler percentage and foam density, likely due to structural variability and measurement errors. SEM images showed that the unfilled foam had a typical porous structure with both open and closed pores ranging from micrometers to millimeters in size. Foams with 8% RP showed filler localized within pores but with some degradation, likely caused by heat during preparation. Foams with 4% CF also exhibited porous structures with well-distributed fibres and minimal degradation, attributed to carbon fibres heat resistance.



(a) (b) (c)

Fig. 1 Scanning electron microscope images of the unfilled foam (a), the foam loaded with 8% RP (b), and the foam loaded with 4% CF (c).

B. Thermal charaterization

The thermal behavior of rubber powder (RP) and carbon fibers (CF) fillers was analyzed using GTA-DTA from room temperature to 1000°C, focusing on 800°C, the sample preparation temperature. RP showed a significant mass loss of 62.06% between 200°C and 800°C due to the decomposition of elastomeric compounds, releasing gases like CO and CO_2. This mass loss aligns with the degraded structure observed in SEM images. In contrast, CF exhibited only a minor mass loss of 1.71% between 600°C and 800°C, indicating strong thermal stability. The high temperature resistance of CF explains the minimal degradation seen in SEM observations. These results highlight the differing thermal stabilities of RP and CF in glass foam composites.

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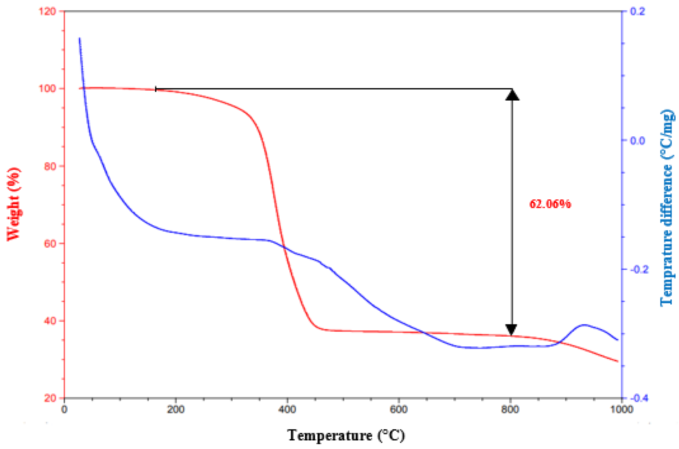

Fig. 2 Gravimetric Thermal Analysis (GTA) and Differential Thermal Analysis (DTA) of RP

C. Dielectric characterization

Figure 4 shows the variations in real permittivity (ε') and dielectric losses (tanδ) of glass foams at 10 GHz, depending on the load of carbon fibers (CF) and rubber powder (RP). The unfilled foam displays a real permittivity of 0.40 and dielectric losses of 0.10. With CF loads of 2%, 4%, and 6%, the permittivity significantly increases to 1.78, 2.61, and 3.72 respectively, while dielectric losses rise from 0.32 to 0.46. In contrast, foams loaded with 4%, 8%, and 12% RP exhibit lower permittivity values between 0.55 and 1.74, and limited losses ranging from 0.13 to 0.15. These results clearly indicate that CF-loaded foams have much better dielectric properties than those with rubber powder. To design an efficient electromagnetic absorber, it is essential to maintain a low real permittivity close to air while achieving high dielectric losses, ideally between 0.2 and 1. Carbon fibers provide better absorption efficiency due to their conductivity, which induces a short-circuit effect under electromagnetic fields, increasing losses. Conversely, rubber powder, being non-conductive and heavily degraded during heat treatment, does not achieve the necessary losses for effective electromagnetic absorption.

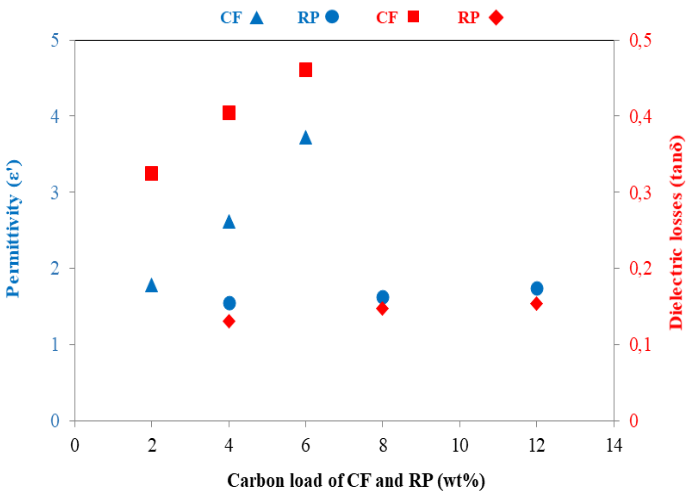

Fig. 3 Variation of real permittivity and dielectric losses of foams as a function
of CF and RP load at 10 GHz frequency

IV. CONCLUSIONS

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This study focused on preparing and analyzing foam composites made from recycled glass cullet, rubber powders, and carbon fibers to create cost-effective materials for electromagnetic wave absorption. Calcium carbonate was used as a foaming agent, while rubber powders and carbon fibers served as absorbers. The composites were produced with rubber powder contents ranging from 4 to 16 wt.% and carbon fibers between 2 and 8 wt.%. The resulting foams exhibited a porous and relatively uniform structure. Thermal treatment caused significant degradation and over 60% weight loss in rubber powder-filled foams, whereas carbon fiber-filled foams showed high thermal resistance with only 1.71% weight loss. Dielectric properties, including permittivity and losses, increased linearly with the amount of filler. Foams loaded with carbon fibers showed much higher dielectric losses compared to those with rubber powder; for example, at 10 GHz, a foam with 6% carbon fiber had a dielectric loss (tanδ) of 0.46, three times higher than that of a 12% rubber powder foam. These results demonstrate that glass foam composites using recycled cullet and carbon fibers are promising materials for efficient electromagnetic wave absorption, outperforming similar foams reported in the literature.

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