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Waste-glass recycling: A step toward microwave applications

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ABSTRACT

This study deals with microwave properties of glass foams prepared from glass industrial waste. Two types of cullets (one from soda-lime silicate glasses and the other from cathodic ray tubes – CRT) have been combined with different foaming agents (C, SiC, AlN). Glass foams electromagnetic properties are primarily determined by their apparent density as well as by the nature of the foaming agent. Foams, blown with carbon as foaming agent, present high dielectric loss and could be used as green electromagnetic absorbent in building industry.

1. Introduction

In times of growing energy and products consumption worldwide, the availability of raw materials becomes core to business and management processes. Waste recycling restricts the negative impact of human industrial activities on the planet by reducing industrial raw material needs. In the past few decades, numerous recycling processes have developed with the full support of the European Union [1]. Waste recycling is yet a standard practice and has become a fully-fledged segment of the industrial economy.

Among the different types of raw materials, the packaging glass recycling chain has proven to be an effective model. From 1974, driven by the glass industry, container glass recycling (bottles, jars . . .) has been a great success. Recycling rates of this kind of hollow glass now achieve an efficiency of more than 70%. Other types of glass compositions, often polluted with heavy metals, pose a tougher problem. This is particularly the case of cathode ray tubes (CRT) found in TV screens and monitors or soda lime silicate glass (SLS) from the automotive industries.

Over a number of years, recycling processes have been developed to produce glass foams [2,3]. While these materials are mostly marketed for thermal and/or acoustic insulation, recent works have shown that those foams could be used in innovative applications (photocatalyst support for hydrocarbon degradation) [2]. In this study, we will focus on the microwave properties of those recycled glass foams for potential new uses in the telecommunication area.

2. Synthesis of glass foams

The expansion of the glass foams is performed through off-gassing (CO_2 or N_2) within the glassy matrix for temperatures above the littleton point ($T > 800\,^\circ C$). The pre-introduced foaming agent (or a combination of agents) is partially degraded, producing a gas, close to the softening temperature of the glass. Bubbles trapped within the viscous glass lead to a cellular material having a density that depends from the nature and the amount of the foaming agent(s), the glass composition and the operating temperature.

The cullet (CRT and/or SLS), pre-dried at 150 °C for 12 h, is milled together with the foaming agent (carbon C, Silicon Carbide SiC, Aluminum Nitride AlN or a combination thereof). The resulting mixture is transferred to a heat resistant steel mold and heated at the operating temperature ($T = 850\,^\circ C$) during 30 min.

Table 1 summarizes the synthesis parameters (cullet type and foaming agent) and apparent density of the elaborated foams. Two sets of experiments were conducted; the first one (sample 01–06) to determine the impact of the waste glass type and the second one (sample 06–11) to measure the influence of the foaming agent nature. In every case, the mass fraction percentage of the blowing agent (pure or combined) does not exceed 4 wt% of the batch.

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Table 1
Synthesis parameters (cullet type and foaming agent) and apparent density. The different cullet proportions are calculated as the percentage by weight.

Samples	Cullet	Foaming agent	d_{app} ($g\,cm^{-3}$)
Smp-01	SLS (100%) – CRT (0%)	AlN	0.47
Smp-02	(70%) – (30%)		0.43
Smp-03	(50%) – (50%)		0.37
Smp-04	(30%) – (70%)		0.34
Smp-05	(0%) – (100%)		0.36
Smp-06	SLS (100%)	AlN (50%) – SiC (50%)	0.77
Smp-07	CRT (100%)	AlN	0.35
Smp-08		C	0.85
Smp-09		SiC	0.49
Smp-10		C (50%) – SiC (50%)	0.60
Smp-11		AlN (50%) – SiC (50%)	0.47

Resulting glass foams can be described as a composite with a matrix consisting of glass and with reinforcing particles consisting of the unreacted remaining part of the foaming agent(s). In fact, in that process, only 20–30% of the pre-introduced foaming agent react and is involved, by decomposition and subsequent gas development, in the expansion process [2]. The unreacted part of the powder particles (C, AlN, SiC) remains dispersed in the glassy walls of the cell material. For specific glass compositions (lead glass), a reduction of the modifier cation soccurs and leads to metallic droplets precipitation [4].

3. Method of microwave characterization

The electromagnetic characterization of the foam glass samples (Fig. 1a) is done in the X-band frequency range (8–12 GHz). Microwave measurements are carried out with an Agilent PNA E8664A network analyzer. A rectangular waveguide is used for the characterization of the foam samples.

Prior to taking measurements, a TRL (Through-Reflect-Line) calibration is performed to put the reference planes at the beginning of the waveguide section. A first measurement of vacuum is performed to take into account losses of the empty waveguide. The glass foam sample is cut to the dimension of the waveguide ($22.86 \times 10.16 \times 20\,mm^3$), and then inserted into the waveguide section for the characterization (Fig. 1b).

Measured *S*-parameters of the samples, enable us to extract the microwave dielectric properties of the foam glasses (i.e., relative permittivity ε_r and loss tangent $\tan\delta$) [5–7].

4. Physical and microwave properties of the glass foams

Since no chemical component used possesses magnetic properties ($\mu^* = 1$), only dielectric results will be discussed. In this study, we will focus on the influence of the nature of the cullet (CRT or SLS) as well as that of the foaming agents (C, SiC ou AlN) used in this process.

Fig. 2 shows the glass foams dielectric constant (imaginary and real parts) as a function of the percentage by weight of CRT glass (foam blown with AlN as a foaming agent – samples 01–05). Whatever the soda–lime–silica glass to CRT lead glass ratio in the batch, no significant changes in their dielectric performance have been noted.

Furthermore, apparent foams densities result from the cullet composition and the type of the foaming agent (Table 1). The

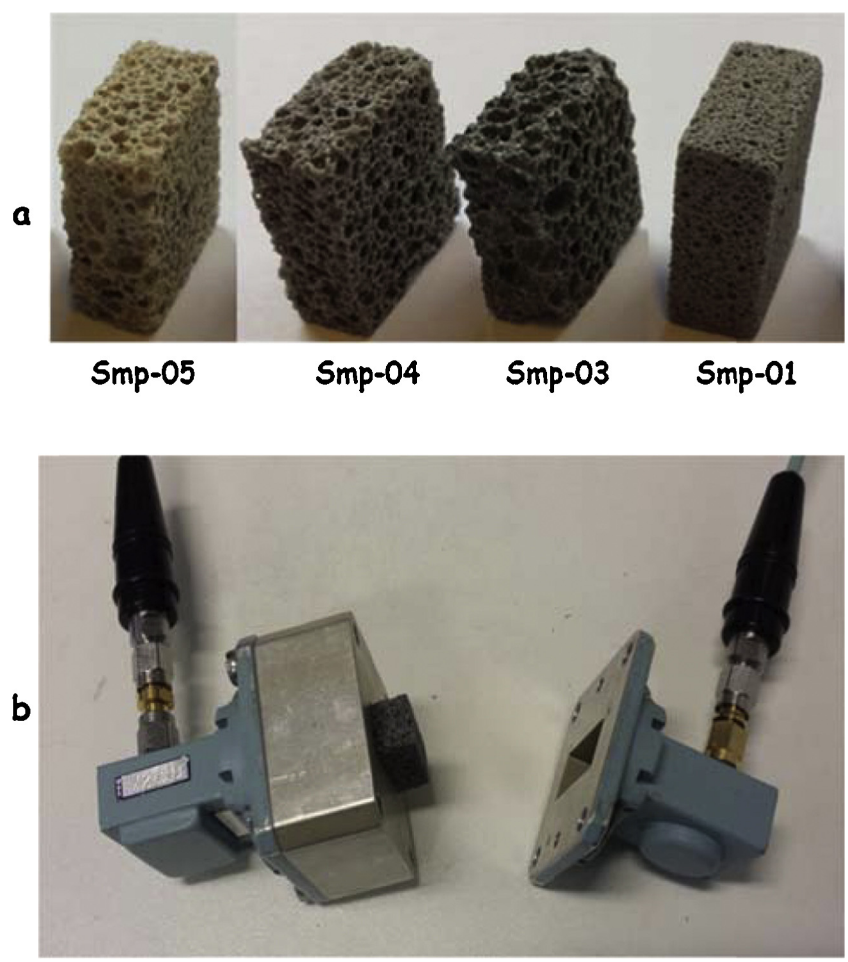

Fig. 1. Foam glass samples with different %wt of CRT waste glass (a) and microwave cell characterization (b).