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Green foams for microwave absorbing applications: Synthesis and characterization

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ABSTRACT

This study deals with the dielectric properties of recycled glass foams and their use as microwave absorbers. Glass wastes from Cathode Ray Tube have been used to produce foams by heating a mixture consisting of glass cullet and foaming agents (carbon or a combination of carbon, TiO_2, MnO_2 and AlN). As only part of the carbon introduced into the initial load oxidizes and contributes to the foaming process, the residual fraction acts as an electromagnetic absorber. The effect of the carbon load rate on the foams density and microwave properties was studied. These materials present a low permittivity and high dielectric losses in X-band. Foams density mainly controls the dielectric properties. Carbon-based glass foams show a great potential as microwave absorbers with a shielding effectiveness of 20 dB/cm at 12 GHz. Moreover, a tradeoff between the density and shielding efficiency can be achieved by controlling the load rate of carbon.

1. Introduction

Recycling materials is a burning issue in our modern societies. Indeed, with the continuous improvement of people's living standard, the needs in raw materials increase whereas resources drastically decrease. Moreover the reintroduction of end-of-life materials in the production chain also reduces global energy consumption, which directly reduces greenhouse gas emissions. In this context, since early seventies, recycling chains of glass wastes were developed with a great success and glass containers (bottles) are now widely recycled. That way, the cullet resulting from the collection of used liquid-food packaging in the form of bottles and jars covers 70% of the glass industry needs in terms of raw materials. As the melting temperature of the cullet (1000 °C) is lower than that of the raw materials (1500 °C), the glass industry's carbon balance is significantly improved [1,2]. Other types of glass compositions, often polluted with heavy metals, pose a tougher problem. Indeed, as hazardous materials, glass wastes from electronic industry (e-wastes) should be treated in specific recycling process [3]. This is particularly the case of cathode ray tubes (CRT) found in older style TV screens and monitors that can be neither recycled in a closed loop production process due to the termination of this technology nor reintroduced as a cullet in the production line of conventional hollow glasses due to their high heavy metal content (Pb, Ba, Sr) [4]. Foam glass manufacture is a promising mode for re-using CRT glasses: depending on the foaming process, this cellular material combines low density, low thermal conductivity, excellent thermal stability and high rigidity [1–8]. As it has been demonstrated by leaching tests that the fraction of lead released, in end-use conditions, from foam glass was lower than the statutory limit [4], this material can be inserted in a commercial device. As the primary function of those leaded glasses was to block electromagnetic (EM) radiation in CRTs, we focused our attention on EM absorptive properties of those glass foams based on cathode ray tube cullet. Inorganic additives (powders or fibers) can be used to reinforce the shielding properties in a specific spectral range [3,9–11]. Indeed, when Aluminum Nitride (AlN) or Silicon Carbide (SiC) are used to initiate the foaming process, part of those adds do not chemically react with the glassy matrix and, as a result, glass foams present a low permittivity together with low dielectric losses [7]. In the same way, when Carbon (C) is used as the foaming agent, high dielectric

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losses are observed making of these foams a good candidate for microwave absorbing applications [7,11].

In this paper, we studied the microwave behavior of glass foams for different load rates of carbon. In a first part, the process of elaboration will be presented. We especially focused on the impact of the load rate and nature of the foaming agent on the density of the foams. Indeed, an original combination of foaming agent based on the results of previous studies [8,12,13] has been tested to reach a low-density C-doped foam glass. Then, the microwave properties of these foams will be presented and their potentiality for microwave absorbing applications will be discussed.

2. Materials and foam manufacturing

The elaboration process of the foams is illustrated in Fig. 1 and the synthesis parameters are summarized in Table 1. As a first step, the cullet and the foaming agent (C for example) are thoroughly mixed and grinded to produce an homogeneous batch (Fig. 1a). When this mixture reaches a temperature close to the softening temperature of the glass, the foaming agent reacts to release gaseous products that is the key factor of the expansion (Fig. 1b). A short chemical reaction time results in a partial consumption of the foaming agent [8] and the unreacted part (Fig. 1c), after cooling down to room temperature, acts as EM-absorbent dispersed in a light matrix.

In this study, the CRT cullet is a mixture of panel (front part) and funnel (rear part) glasses. The weight ratio of the mixture is near 2/3 (panel) and1/3 (funnel). Front glass is typically a SiO_2 based glass containing barium and strontium oxide, while funnel glass is also a SiO_2 based glass but containing around 20% in lead oxide. So, the CRT cullet is a mixture of silicate glasses containing between 5 and 7 wt% in lead oxide. This CRT glass cullet is supplied by Environment Recycling, a French company expert in WEEE dismantlement. A crushing step is achieved on CRT mixture with a Gabrielli Fast-Mill planetar mortar with alumina balls, to obtain a fine powder whose granulometry is lower than 125 μm. The CRT cullet pre-dried at 150 °C for 12 h is milled together with the carbon foaming agent (from Ventron Alfa Produdkte with a granulometry of 325 meshes/44 μm) or a combination of Carbon (C), Manganese dioxide (MnO_2), Aluminum nitride (AlN) and

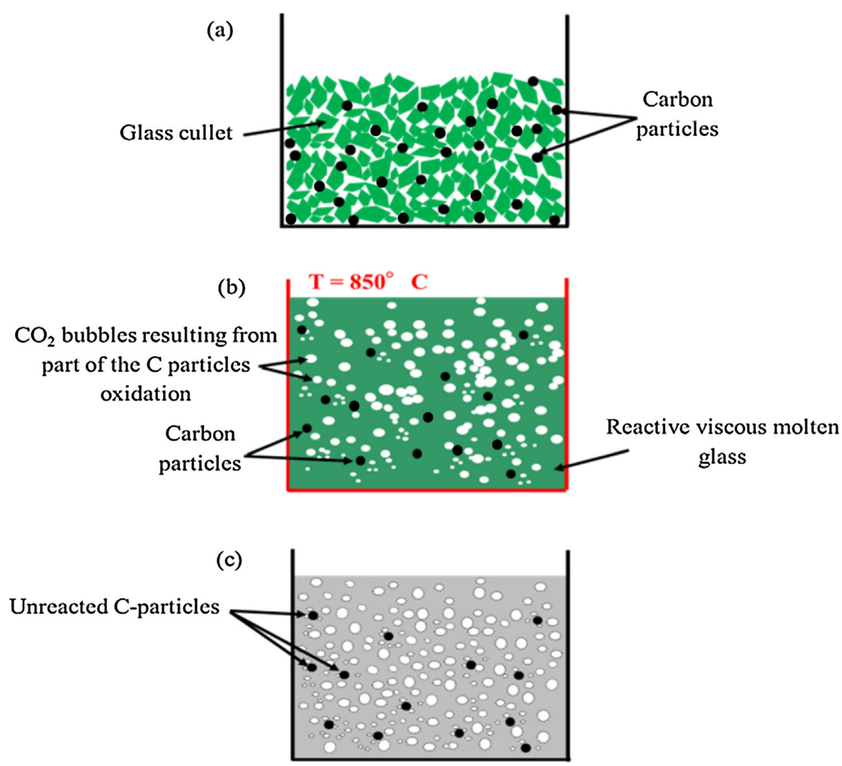

Fig. 1. Schematic illustration of the elaboration process: (a) Glass cullet and foaming agent mixture, (b) Foaming process at 850 °C and (c) Resulting glass foam/C particles composite.

Table 1
Synthesis parameters (cullet type and foaming agents) and density of the glass foam samples.

Glass cullet	Carbon load rate (wt%)	Others foaming agents	Density (g/cm^3)	Comments
CRT	0.5	–	0.58	Too brittle to be measured
CRT	1	–	0.47	–
CRT	1.5	–	0.30	–
CRT	2	–	0.23	–
CRT	3	–	0.26	–
CRT	5	–	1.76	No foaming process
CRT	1.5	MnO_2 (4 wt%) + AlN (2 wt%) + TiO_2 (2 wt%)	0.16	–