Materials Science and Engineering B 185 (2014) 21–25

Contents lists available at ScienceDirect

Materials Science and Engineering B

journal homepage: www.elsevier.com/locate/mseb

Short communication

Improving high-frequency properties via selectable diameter of amorphous-ferroalloy particle

M. Zeng [a,b,*], X.X. Zhang [a], R.H. Yu [a,**], D.L. Zhao [b], Y.H. Zhang [b], X.L. Wang [b]

[a] School of Materials Science and Engineering, Beihang University, Beijing 100191, China
[b] Division of Functional Material, China Iron & Steel Research Institute Group, Beijing 100081, China

ARTICLE INFO

Article history:
Received 24 August 2013
Received in revised form 22 January 2014
Accepted 4 February 2014
Available online 18 February 2014

Keywords:
Amorphous-ferroalloy particle
Complex permittivity
Complex permeability
Reflection loss
High-frequency property

ABSTRACT

The permeability and reflection loss of the composites filled by water-atomized amorphous-ferroalloy particle are investigated in the range of 1–18 GHz. The results show that the granular size strongly influences the permeability and absorbing property of the material. The soft magnetic property of the particle of 10 μm which is of the order of the skin depth differs from that of 40 μm particle. The Bruggeman effective medium theory can well predict the dynamic magnetic properties in high frequency region for the materials. The composite with the 10 μm particle shows excellent performance in high-frequency absorption compared to the one with the bigger size particle. The size-selectable amorphous-ferroalloy particle is one of the promising candidates for microwave absorption applications.

1. Introduction

In comparison with traditional ferrite absorbents, ferromagnetic alloys have larger saturation magnetization and higher Snoek's product which provides the limitation on the permeability spectra of magnetic composites [1]. High value of permeability could allow the materials to be used in high frequency occasions [2–4]. However, eddy current induced by the electromagnetic wave inside the metallic magnetic material will reduce the permeability [5]. Amorphous ferromagnetic alloy, in addition to the large saturation and high permeability, exhibits high resistivity that can attenuate the eddy current and improve the impedance matching of the material with the free space [6–9], which make it a promising candidate for electromagnetic shielding. It's high resistivity is due to the disorder of ingredient and structure and to some non-metallic elements abounding in the alloy that contribute to forming amorphous state [10]. There are many ways to fabricate amorphous alloy such as melt spinning, ball milling, etc., among which water atomized method is suitable for high efficient powder-alloy fabrication [11,12]. The amorphous alloy should have big glass-forming ability since it's powder is formed quickly during the atomized process. The sizes of the amorphous particle can be controlled as small as several microns and will have a relatively broad distribution. The size is a very important parameter for the magnetic granular material. It has been reported that the particle size has great influence on the permeability of the materials [13]. Moreover, the absorbing resonance frequency also relates to the permeability. Therefore, the microwave responding properties will fluctuate with the variance of the radii of the amorphous-ferroalloy particles. In order to better understand the microwave absorbing mechanism, it is significant to learn how the permeability depended on the frequency changes with different size and concentration of the particle embedded in a matrix. In general, it is difficult to measure the intrinsic permeability for the ferromagnetic material. However, an extension of Bruggeman effective medium theory has been used to invert experimental data to extract the intrinsic permeability of the magnetic material [14]. As far as the absorbing properties are concerned, the complex permittivity ($\varepsilon_r = \varepsilon' - j\varepsilon''$) and complex permeability ($\mu_r = \mu' - j\mu''$) of an medium determine the reflection loss based on the model of a single-layered plane-wave absorber [15].

We chose an iron-base amorphous ferromagnetic alloy to prepare micron particle via water atomized method, with an attempt to study the size effects on the permeability and microwave absorption of the composites. By selecting the particle with suitable

* Corresponding author at: School of Materials Science and Engineering, Beihang University, Beijing 100191, China. Tel.: +86 10 82317101; fax: +86 10 82317101.
** Corresponding author. Tel.: +86 10 82317101; fax: +86 10 82317101.
E-mail addresses: min_zeng@buaa.edu.cn (M. Zeng), rhyu@buaa.edu.cn (R.H. Yu).

http://dx.doi.org/10.1016/j.mseb.2014.02.002
0921-5107/

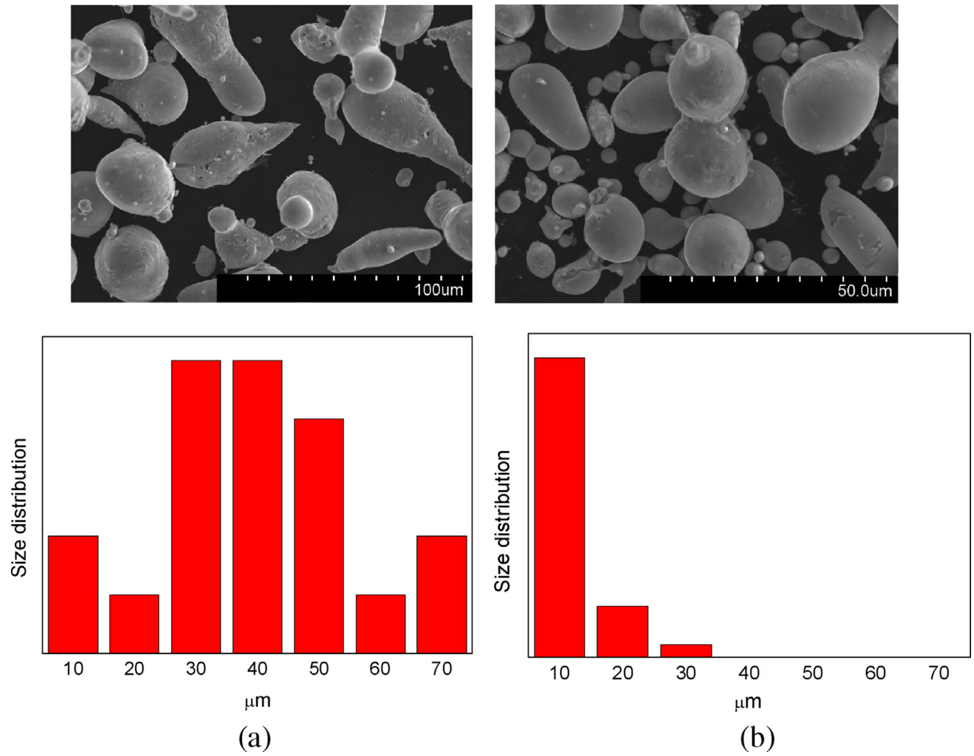

Fig. 1. The SEM images of the amorphous-ferroalloy particles and the calculated size distributions.

diameter, the composite with the amorphous filler dispersed uniformly in an insulating host can well function as microwave absorbers in the gigahertz region.

2. Experimental

2.1. Synthesis

The amorphous-ferroalloy particle with predominant constituents of Fe and 3% Ni, 4.5% Si, 2.2% B and other elements is prepared by water atomization technique. The particle is mixed into the matrix and pressed on a double-roll open mill. This method is a very convenient way to obtain isotropic, homogeneous, and nonporous composite with well-dispersed and individualized particles inside.

2.2. Characterization

SEM photographs of the amorphous-ferroalloy particle are taken by a Hitachi scanning electron microscope (S-3500N). X-ray diffraction patterns of the samples are conducted on a Riga 2500 diffractometer with Cu Ka radiation. Magnetic properties are measured by a vibrating sample magnetometer (BHV-50HTI, Riken Denshi). The permeability and dielectric property (measured within 1–18 GHz) of the toroidal samples, which are of 3 mm inner and 7 mm outer diameters and prepared by uniformly mixing the amorphous-ferroalloy particle in the matrix, are investigated through a HP 8722ES vector network analyzer.

3. Results and discussion

3.1. Morphology and magnetic properties

Fig. 1 shows the SEM images of the amorphous ferromagnetic particles of different sizes and their corresponding size distributions. Most sizes of the subspheroidal particles are under 50 μm. For metallic magnetic materials, it is impossible to enhance the initial permeability and the resonance frequency at the same time due to the Snoek's limit. However, the characteristics of the morphologies also have great impact on the behavior of the magnetic absorber. The particle exhibits some shape anisotropy, that may help to improve the resonance frequency beyond the Snoek's limit [1]. The SEM images show that the diameters of the amorphous ferroalloy particles are not so uniform. The particles are sifted into two groups to investigate the size effects on the permeability and microwave absorbing property. From the calculated distribution graphs, the sizes of the two samples are roughly illustrated as 40 μm and 10 μm, respectively.

Their X-ray diffraction patterns are shown in Fig. 2. The particle of 10 μm shows amorphous status. While the particle of 40 μm contains traces of α-Fe precipitated. It is because that the bigger particle cools down slower than the smaller one during the atomized process, leading to the precipitation of α-Fe. The different phase constituents may lead to the differences of the resistivity,

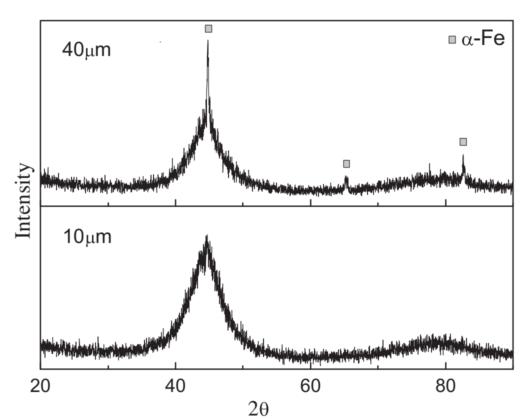

Fig. 2. The XRD patterns of the particles with different sizes.