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ARTICLE

Microwave Absorbing Properties of MnAl Alloy Powder

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Abstract: $Mn_{55}Al_{45}$ alloy powder was prepared by the combined use of arc melting, high energy ball milling and tempering heat treatment process. The phase structure and the microstructure of the alloy powder were analyzed by X-ray diffraction (XRD) and scanning electron microscopy (SEM), and then their microwave absorbing properties were tested by a vector network analyzer. The results show that an increase of phases for Al_2Mn_3 and $Al_{11}Mn_{14}$ are accompanied by the increased milling time; the resonant frequency and the absorption peaks of ε'' and μ'' shift towards lower frequency region simultaneously. A better result of electromagnetic properties is brought to the alloy powder when the ball milling time is set to 18 h in first attempt. While the ball milling time is increased to 24 h during later experiment, the minimum reflectivity value reaches to –28 dB at a frequency of 16 GHz. The Al_2Mn_3 phase increases with an artificial increase of tempering temperature. The $Mn_{55}Al_{45}$ alloy powder ball milled for 18 h and tempered at 400 °C exhibits preferably comprehensive microwave absorbing properties in the range of 6~8 GHz. The minimum reflectivity value and absorption peak frequency at the coating thickness of 2.0 mm are –26.4 dB, 17 GHz, respectively.

Key words: MnAl alloy; absorbing material; high energy ball milling; tempering heat treatment

With the rapid development of science and technology, the application of electromagnetic technology has brought material civilization to the communities. However, the serious problems of the electromagnetic interference and electromagnetic compatibility have become increasingly prominent in recent years. R and D of microwave absorbing materials for controlling the radioactive electromagnetic pollution is a pressing matter at the moment. In the civil field, absorbing materials, have been widely used in the fields of radio, television, radar, microwave anechoic chamber and electronic devices. In military field, stealth weapon plays an important strategic role in wars in future. Microwave absorbing materials are the key materials for stealth weapon; the functionality is to reduce or eliminate the target detection performance[1-6]. For this reason, the microwave absorbing materials are vitally important for both civil and military field[7-12]. Microwave absorbing materials stand at an important position in stealth technology owing to their easy preparation, the properties of outstanding absorbing performance[13]. The intention of making them thin, good thermal stability, light in weight, as well as corrosion resistance is of great significance to the application of magnetic microwave absorbing materials.

MnAl alloys are guite useful as microwave absorbers due to their advantages with respect to good thermal stability, corrosion resistance and light in weight[14]. But as permanent magnets, MnAl alloys have shortcomings such as their difficulty of fabrication and high costs that prevent them from being used as permanent magnets. A great value would be brought to either theory or practice through proper treatments to further improve properties. The purpose of this paper is to investigate the effects of different high-energy ball milling time and different tempering temperatures on absorption properties of $Mn_{55}Al_{45}$ alloy.

1 Experiment

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The selected starting materials Al and Mn had purities no less than 99.5%. The experimental powder was prepared based on the chemical composition of $Mn_{55}Al_{45}$. The sample was smelted in an electric arc furnace with a three-time-rollover under the protection of high purity argon. The MnAl ingot was homogenized for 24 h at 1050 °C in vacuum, then quenched in ice water after the homogenization heat treatment, and crushed into coarse powder with particle size smaller than 0.5 mm. The coarse powder was ground under the protection of ethanol for 12, 18 and 24 h, by QM-lSP planet ball milling machine at the speed of 300 r/min. The mass ratio of the balls to the powder was 20:1. Hereafter, the powder milled for 18 h was tempered at 200, 400 and 600 °C. The prepared MnAl powder was mixed with paraffin in ratio of 30:70 (by volume). The mixture was made into a coaxial ring with a thickness of 3.5 mm, outer diameter of 7 mm, and inner diameter of 3 mm. The complex permeability and the complex permittivity of the samples were measured with vector network analyzer (HP8722ES) in the frequency range of 2~18 GHz, and the measurement data were taken in each 0.08 GHz. According to the theory of equivalent transmission lines, calculation formula of the single absorbing material reflectivity R could be deduced as following [15]:

$$R = 20\lg\left|\frac{\sqrt{\dfrac{\mu_r}{\varepsilon_r}}.\tanh\left(\mathrm{j}\dfrac{2\pi fd}{c}\sqrt{\mu_r\varepsilon_r}\right)-1}{\sqrt{\dfrac{\mu_r}{\varepsilon_r}}.\tanh\left(\mathrm{j}\dfrac{2\pi fd}{c}\sqrt{\mu_r\varepsilon_r}\right)+1}\right| \quad (1)$$

where, ε_r, μ_r and d denote the relative permittivity, relative permeability, and thickness of absorbing material, respectively , f is the frequency of electromagnetic wave, c is the velocity of electromagnetic wave in free space (the speed of light), and j is the imaginary unit.

2 Results and Discussion

2.1 Morphology and Structure of the MnAl powder

The SEM images of the as-milled $Mn_{55}Al_{45}$ powders are shown in Fig.1. As it can be seen from the image, the particle size without ball milling is less than 0.35 mm. The particle size is less than 5 μm for the powder milled for 12 h . With the increase of the milling time, more irregular powder was milled into flaky particles. When the ball milling time is 18 and 24 h, the powder particle sizes become less than 5 μm.

The XRD patterns of the $Mn_{55}Al_{45}$ powders milled for different milling time ranging from 0 h to 24 h are demonstrated in Fig.2. The as-milled powder mainly consists of Al_8Mn_5, Al_2Mn_3 and $Al_{11}Mn_{14}$ phases. The number of new phase such as Al_2Mn_3 and $Al_{11}Mn_{14}$ increases with the increase of milling time. But at different milling time, the diffraction peaks are unobviously broadened.

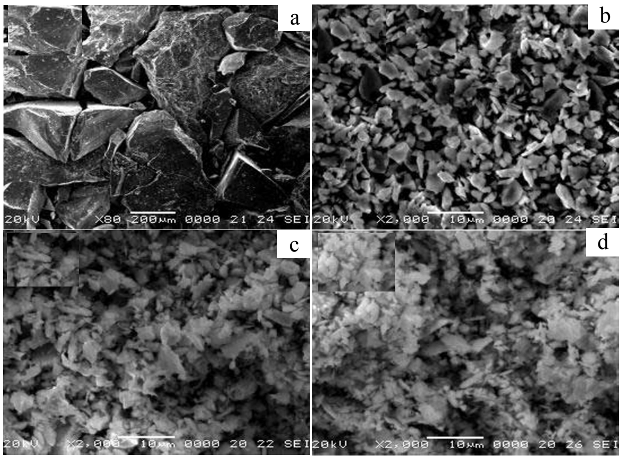

Fig.1 SEM morphologies of $Mn_{55}Al_{45}$ alloy powders milled for different time: (a) 0 h, (b) 12 h, (c) 18 h, and (d) 24 h

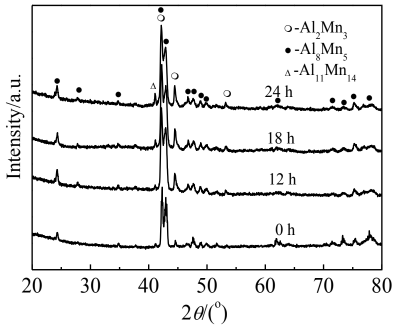

Fig.2 XRD patterns of MnAl powders milled for different milling time

The relationships between the frequency and imaginary parts of complex permeability (μ'') and complex permittivity (ε'') at different milling time in the frequency range of 2~18 GHz are demonstrated in Fig.3. It shows that the resonant frequency moves towards lower frequency region as the milling time increases. This is mainly because the particle size becomes fine, and the relative contents of Al_2Mn_3, $Al_{11}Mn_{14}$ increase, which makes the crystal defects increasing and conductivity decreasing, and finally causes the resonant frequency of ε'' to move to lower frequency. As the particle size becomes fine, the crystal integrity is damaged more seriously and the anisotropy field (Ha) decreases correspondingly. According to the relationship between the resonant frequency of μ'' (f_r) and Ha, the resonant frequency of μ'' moves towards lower frequency as the milling time increases.

The reflectivities of the powders at different milling time were computed from Formula (1) when the coating thickness d = 2.0 mm, in the range of frequency between 2 GHz to 18 GHz, as shown in Fig.4 and Table 1. The as-milled powder have several absorption peaks in the frequency range of 2~18