Magnetic permeability and theoretical model of porous metal foams

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The paper presents the relative magnetic permeability and the calculation model of porous metal foams. First, the porosity of porous foam metal is tested and obtained by the fusible paraffin; the magnetic permeability of three kinds of porous metal foam, that is, Fe, Cu, Ni, with the same structure parameters and different relative permeability are tested by vibrating sample magnetometer (VSM). Based on the equivalent reluctivity, the initial relative permeability of the electrodeposited metals is simulated and the calculated results are close to the testing results. The results show that the calculation model can be used to describe the relative permeability of electrodeposited metals, at the same time, according to the calculation, the relative permeability of porous metal foams will increase with the increased relative permeability of electrodeposited metals, and decrease with the increased porosity, which provide the theorical and experimental proof for the research on magnetic characteristics of porous metal foams.

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1. Introduction

Porous metal foam, as a kind of new functional materials, its development began from 1948, Sosnik [1] proposed the idea of using mercury gasification in aluminum and preparing foam aluminum, due to the high porosity, small density, large specific surface area, porous metal foam not only has the general characteristics of lightweight porous materials, but also the excellent mechanical properties and physical properties, such as the heat transfer, electricity, etc., thus, the application range of porous material is greatly expanded, soon, which attracted the attention of researchers.

Porous metal foam and it related technology has the great progress achieved in the recent decades [2]. At present, the porous metal foam is mainly used in electrode materials, catalyst carrier, mechanical cushioning material, damping material and other fields [3] [4]. The research of porous metal foam, mainly focused on the mechanical properties of porous metal foam and its preparation process, etc., however, the electromagnetic characteristics of porous metal foam and its calculation model have still seldom investigated, Huang [5] studied the electromagnetic shielding performance of porous metal foam and the effect of porosity on the electromagnetic shielding effectiveness, and its influencing factors were analyzed, but, the corresponding calculation theory also needs to be improved; Liu [6] investigated the resistivity of porous metal foam, and proposed the methods of calculation, but the effect of structure parameters of porous metal foam on the magnetic field is not involved, especially in the actual application.

In order to meet the demands of design, as the difference of the electroplating current density and the porosity, when two or more kinds of metal are electrodeposited, the difference in magnetic permeability among these porous metal foams will be very obvious. In this paper, the magnetic permeability of the electrodeposition of porous metal foam are studied, according to the porosity of porous metal foam and the principle of equivalent magnetic resistance, the calculation model in relative permeability of electrodeposition of metal is established, the influential factors on magnetic permeability of porous metal foam is also studied theoretically and experimentally, which will provide the basis for the research and application for porous metal foam in electromagnetic field.

2. Porous metal foam and the structure parameters

Here, the porous metal foam is mainly produced by electrodeposition of the metal; the template is plastic foam (or the polyurethane). The pore size and thickness of the polyurethane can be adjusted according to the experimental demand, such as, the open porosity is from 100 ppi to 140 ppi (pores per inch). In order to make the nonconducting foam polyurethane conductive and electrodeposit the metal, the polyurethane should be pretreated, the materials used to pretreat are industrial reagent and special conducting paint; the process is mainly as follows:

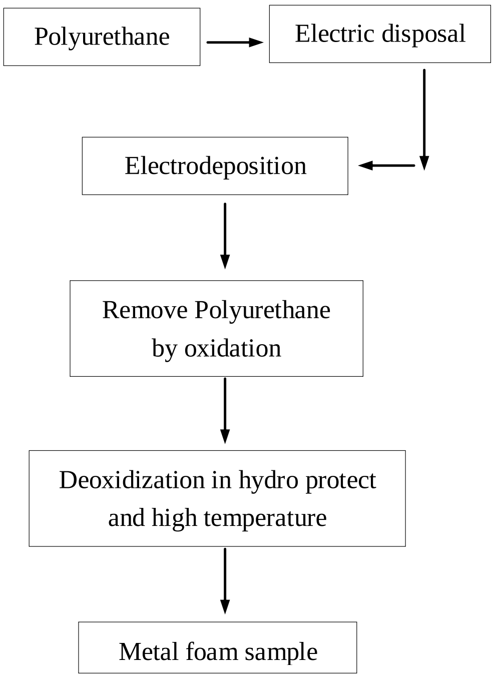


Fig. 1. The produce process of porous metal foams.

1. Roughening and deoxidization

In order to enhance the porosity and wettability, the polyurethane will be soaked in acidic solution with potassium permanganate and be roughened first, and then deoxidized in oxalic acid solution;

2. Preparation of conducting layer

The special conductive adhesive (namely, carbon-containing dope) will be spreaded on the surface of pretreated polyurethane, then dry it, thus, the nonconducting foam polyurethane will be made conductive; the polyurethane will be soaked in the salt solution (a certain of metal element, such as Copper, Nickel etc. dissolved in the solution), so that the polyurethane could be electrodeposited on the metal element.

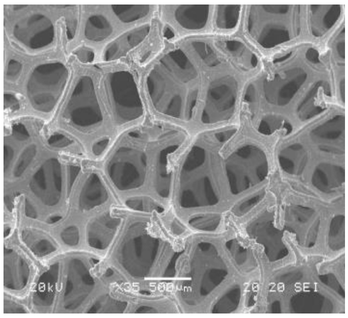
3. Thermal treatment

That is, the deoxidization of the metal foams and get rid of the polyurethane and deoxidize the metal oxide, thus, the mechanical property of the metal foams will be improved greatly.

The metal foams with the various porosity and rigidity are obtained by changing the current density and mould (or polyurethane); the structure of metal foams is as Fig. 2.

According to the above produce process, keep the electrodeposition template unchanged, by changing processing current, the different porous foam meta with the same surface density, porosity and permeability, such as the copper (Cu), iron nickel (Fe + Ni) and copper nickel (Cu + Ni) can be obtained, the inner structure of porous metal foam is also able to be observed by SEM (scanning electron microscope), as shown in Fig. 2, here, the thickness of porous metal foam is about 2.0 mm.

a) Porous metal foam Cu



b) The internal structure (SEM)

Fig. 2. The metal foams.

As can be seen from Fig. 2, the samples in the different stages maintained the original template structure, the average pore size of the porous metal foam is about 400 ~ 500 microns, the electrodeposited metal arranged in a crisscross pattern. The porosity of these porous metal foams will be measured by means of melting paraffin wax, as follows:

1. The regular porous metal materials are made, their volume will be obtained, and this is the volume of the porous materials V_1;

2. melting paraffin wax, in the melting state, the paraffin wax will immerse in porous metal foam, keep the molten state for about 5 minutes, make the pore of the porous metal foam full of the molten paraffin, and then cooling;

3. scrape off the paraffin wax on the surface of porous metal foam, measure the difference in the quality of the porous metal foam before and after the soaking paraffin wax, the difference will be the quality of paraffin wax immersing the porous metal foam, and then, according to the density of paraffin wax, the volume of paraffin wax V_2 will be obtained, which is the volume of paraffin wax

immersing the porous metal foam, thus, V_2 / V_1 will be the porosity of porous metal foam;

By the above test methods, the results will be repeated five times, the average porosity of these porous metal foams is about 85%.

3. Magnetic permeability of porous metal foam and calculation model

The magnetic permeability of porous metal foam and electroplated metal is mainly tested by VSM (vibrating sample magnetometer), the magnetic permeability of three kinds of porous metal foams mentioned above are measured, and it is shown in Fig. 3, here, the relative magnetic permeability: $\mu_r = B/\mu_0 H$, and μ_0 is the relative permeability of air.

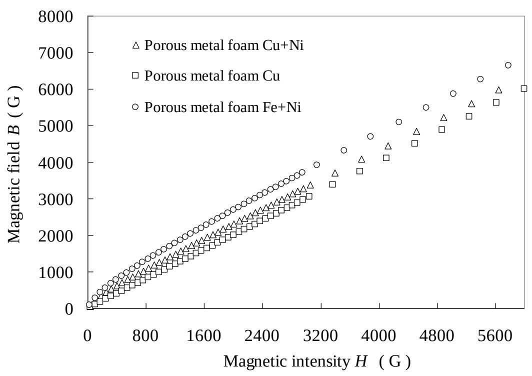


Fig. 3. Relative permeability of porous metal foam.

From Fig. 3, we can see that the porous metal foam Cu can be thought as nonmagnetic, its relative permeability μ_r =1, the initial relative permeability of porous metal foam Fe+Ni is the maximum, the data in the figure was calculated as 2.55, the next is the porous metal foam Cu+Ni, it is about 1.5, at the same time, the porous metal foam Fe+Ni and Cu+Ni can be considered as the super paramagnetic materials.

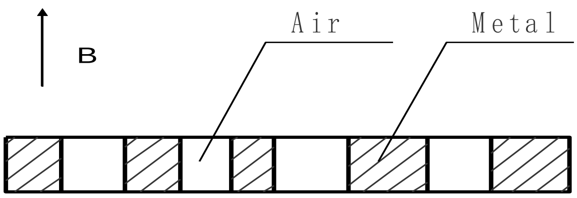
According to the porosity of porous metal foam and the measured magnetic properties, the magnetic properties of electrodeposited metal was studied, the calculation model is shown in Fig. 4, according to the calculation of equivalent magnetic resistance, the relationship among the air reluctance and the magnetic resistance of porous metal foam is as

$$\frac{1}{R_P} = \frac{1}{R_m} + \frac{1}{R_g} \tag{1}$$

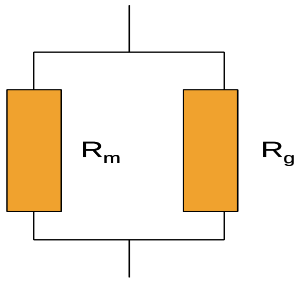
Here, R_p is the reluctance of porous metal foam, R_m is the reluctance of the electrodeposited metals, R_g is the resistance of air, according to the calculation formula of reluctance

$$\mu_{\mathrm{m}} \cdot \mathrm{s}_{\mathrm{m}} + \mathrm{s}_{\mathrm{g}} = \mu_{\mathrm{p}} \tag{2}$$

S is the surface area of porous metal foam, in the case of a certain thickness, the S can stand for the respective volume in equation (2), and the magnetic permeability of the metal is calculated in Table 1.



(a) Calculation model



(b) The equivalent model

Fig. 4. The model of permeability of porous metal foam.

Table 1.The calculation of magnetic permeability.

Porous metal foam	porosity	The initial relative permeability of porous metal foam	The initial relative permeability of electrodeposited metal
Cu	85%	1	1
Cu+Ni	85%	1.5	4.33
Fe+Ni	85%	2.55	11.3

The calculation of the above initial permeability of porous metal foam and the electrodeposited metal is mainly based on the porosity and Eq.2. After the porous metal foam material is compressed, which can be considered as the electrodeposited metal, by the VSM (vibrating sample magnetometer), and its permeability is tested, as shown in Fig. 5.

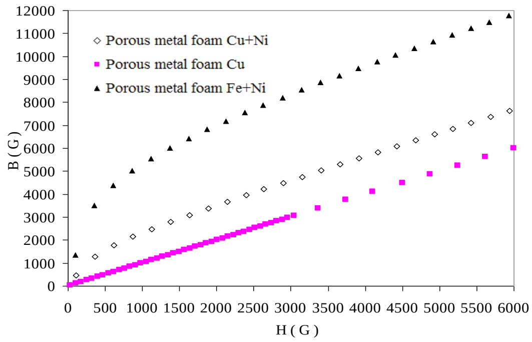


Fig. 5. The test results of permeability of electrodeposited metals in porous metal foam.

In Fig. 5, the initial relative permeability of porous metal foam Ni+Cu is 4.33, the porous metal foam Fe+Ni 14.1; the results are in the following Table 2.

Table 2. The initial relative permeability of electrodeposited metals.

Electrodeposited metals	Calculation	Experiment test	Error (%)
Cu	1	1	0
Cu+Ni	4.33	4.3	0.7
Fe+Ni	11.3	14.1	25

In Table 2, the error of porous metal foam Cu+Ni is 0.7%, it shows that the calculation process is feasible, and the error of the porous metal foam Fe+Ni is larger, which mainly comes from the error of the porosity test, it is difficult to control the compression of porous metal foam sample.

According to the eq.2, if the porosity of porous metal foam is given, with the permeability of electrodeposited metals increased, the magnetic permeability of porous metal foam will also increases; If the permeability of electrodeposited metals is a constant, the magnetic permeability of porous metal foam will decrease with the increase of porosity, therefore, in order to obtain the better electromagnetic performance, two methods mentioned above will be applied.

4. Conclusions

The paper investigated the electromagnetic characteristics of porous metal foam. First, melting paraffin wax is employed to measure the porosity of the porous metal foam, it is about 85%; and then, the magnetic permeability of three different kinds of porous metal foam (Cu, Cu+Ni, Fe+Ni) ,with the same structural parameters, were tested by vibrating sample magnetometer, according to the calculation model and experimental results of the equivalent reluctance, the calculation model of magnetic permeability of porous metal foam is established, which will provide the theoretical and experimental basis for the investigation of magnetic properties of porous metal foam.

Acknowledgments

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