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ScienceDirect
Trans. Nonferrous Met. Soc. China 27(2017) 117−124
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Compressive properties and energy absorption characteristics of open-cell nickel foams

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Received 19 October 2015; accepted 5 July 2016

Abstract: Open-cell nickel foams with different relative densities and pre-stretching degrees were subjected to room temperature quasi-static compressive tests to explore their compressive properties. The compressive properties of the nickel foams including yield strength, elastic modulus, energy absorption density and energy absorption efficiency were calculated accurately. The results show that the compressive properties of yield strength, elastic modulus and energy absorption density increase with the increase of relative density of nickel foams. The compressive properties are sensitive to the pre-stretching degree, and the values of yield strength, elastic modulus and energy absorption density decrease with the increase of pre-stretching degree. However, the energy absorption efficiency at the densification strain state exhibits the independence of relative density and pre-stretching degree. The value of energy absorption efficiency reaches its peak when the strain is at the end of the collapse plateau region.

Key words: nickel foam; compressive property; relative density; pre-stretching degree

1 Introduction

Metal foams are cellular materials that exhibit a unique combination of physical properties owning mainly to their structures [1]. They can be used as not only structural materials but also functional materials because of their excellent mechanical and functional properties, such as high specific strength, sound absorption capacity, high flame resistance and excellent vibration reduction capacity [2−5]. Metal foams are widely used in electromagnetic, thermal insulation, railway or aerospace industries and crash energy absorption during device crash [6−8]. Nickel foams, constituted by open cells with a porosity exceeding 90% (volume fraction), are one of the most useful metal foams and usually used in nickel−cadmium-type (Ni−Cd) or metallic nickel−hydride (Ni−MH) batteries. The nickel foams need to support the positive electrode in the battery, so that they required good mechanical and electrical properties [9].

In order to make sure the flat surface of the nickel foams, the original polyurethane foams always need to stretch to a certain extent during the progress of production before they are produced into nickel foams. By specific method, a certain tension is applied at the ends of the product during the production process. However, the research work on the relationship between pre-stretching degree of the original polyurethane foams and the compressive characteristics of the nickel foams is seldom reported. Therefore, experiments were designed to explore the relationship between such two parameters.

In order to simulate the mechanical response of the metal foams, GIBSON and ASHBY [10] considered the cell of the foams as a simple cube or hexagon. They expressed the plastic yield strength $\sigma_{\rm pl}^*$ as the following equation [10]:

$$\frac{\sigma_{\rm pl}^*}{\sigma_{\rm ys}} \approx 0.3\left(\frac{\rho^*}{\rho_0}\right)^{3/2} \tag{1}$$

where $\sigma_{\rm ys}$ (MPa) stands for the yield strength of full dense material, ρ^* and ρ_0 stand for the densities of solid and foam structure, respectively. It can be learnt from this equation that relative density is one of the most important structural characteristics of metal foams [11,12]. In order to explore the relationship between the relative density and the yield strength, and at

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Foundation item: Project supported by the 2015 Shandong Province Project of Outstanding Subject Talent Group
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DOI: 10.1016/S1003-6326(17)60013-X

the same time verify whether the equation is suitable for the compressive properties of the nickel foams, some experiments were designed in this paper. And the effects of different parameters, such as the density and pre-stretching degree, were also analyzed.

2 Experimental

The specimens used in this experiment were open-cell nickel foams, which were electro-deposited on the surface of the polyurethane foams at first. Then, a suitable heat treatment was used to burn the polymer foams. As a result, the structure of nickel foams was similar to the structure of the origin polyurethane foams [13].

Quasi-static compression tests were performed on a MTS 810 universal testing machine at ambient temperature. All the tests were conducted under displacement control at an initial strain rate of 4.629×10^{-3} s^{-1}. The specimens were cut into four squares with 30 mm in length and 1.8 mm in thickness. The specimen is shown in Fig. 1. The pore size ranges from 100 to 300 μm, and the average pore size is about 260 μm. The microstructure and cell morphology characteristic were investigated by scanning electron microscope (JEOL JSM−7800F).

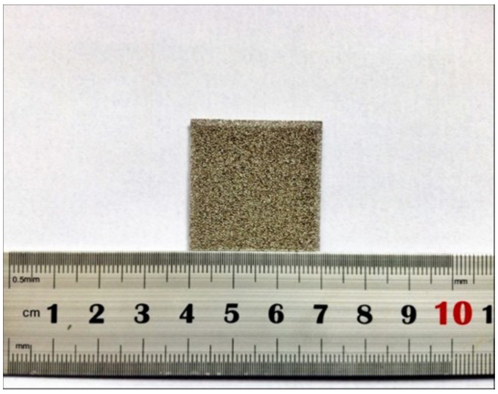

Fig. 1 Morphology of specimen

The relationship between the relative density and compressive properties was investigated in this paper, so nickel foams with different relative densities were prepared. The relative densities of nickel foams studied in this paper were 1.56%, 1.75%, 1.99%, 2.18%, 2.62%, 2.81% and 3.12%, respectively. In order to investigate the effects of the pre-stretching degree, nickel foams with different pre-stretching degrees were also produced. The nickel foams with densities of 1.56%, 1.75%, 1.99%, 2.18% and 2.62% were studied in this part of experiment. The pre-stretching degrees of them were 1%, 3%, 5% and 8%. The original polyurethane foams were stretched in different degrees before they were produced into nickel foams during the process of production.

3 Results and discussion

3.1 Compressive behavior of nickel foams

The morphologies of open-cell nickel foams before and after compression can be seen in Fig. 2. Figure 2(a) shows the original morphology of the nickel and Fig. 2(b) shows the morphology of the nickel foam after compression.

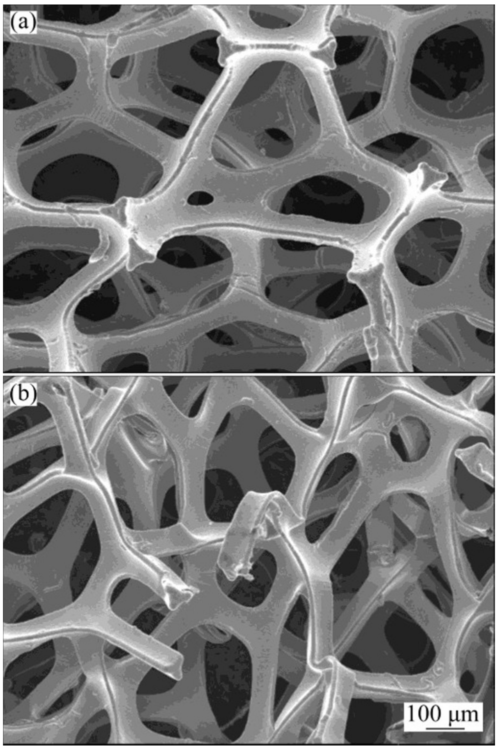

Fig. 2 Morphologies of open-cell nickel foams before and after compression: (a) Nickel foam before compression; (b) Nickel foam after compression

The compressive stress−strain curves of open-cell nickel foams with different relative densities are shown in Fig. 3.

As shown in Fig. 3, the compressive stress−strain curves of nickel foams exhibit three distinct states. The first state is the linear elastic deformation state and then the collapse plateau state, and the densification state [14,15].

In the linear elastic deformation state, the compressive stress increases quickly with the increase of strain. However, the linear elastic region appears only with a small strain degree less than 0.1. At this state, the main deformation of open-cell nickel foams is the bending of the cell walls or ligaments. At the linear deformation stage, the bending of the ligaments is slight and the ligaments will almost restore to the original state after the unloading of the pressure. So, the bending of the ligaments at this stage can hardly be observed. But after