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Experimental investigation on uniaxial tensile properties of high-porosity metal fiber sintered sheet

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ABSTRACT

A novel porous metal fiber sintered sheet (PMFSS) with a three-dimensional network structure has been produced via solid-state sintering of copper fibers. The copper fibers, approximately 100 μm in diameter, were fabricated using the cutting method. In this study, a uniaxial tensile test was used to study the tensile fracture process of the PMFSS. The effect of the porosity and sintering parameters on the tensile properties of the PMFSS was investigated in detail. It was found that the tensile strength of the PMFSS decreased significantly with an increase in the porosity, but the elongation remained relatively constant with different porosities. In addition, for sintering temperature between 700 °C and 900 °C, the tensile strength increased with increasing sintering temperature and decreased with increasing sintering time.

1. Introduction

Porous metal material, an interesting engineering material, is being explored due to its porous structure and unique properties [1]. However, many porous materials are dismissed as engineering materials due to their poor mechanical and thermal properties. For example, porous organic polymer materials have low density and cannot withstand high temperature; porous ceramics are brittle and have bad thermal shock resistance; metal wire meshes are easily destroyed and plugged; and sintered powder materials are fragile, with insufficient pathways for liquid to pass through. The porous metal fiber sintered sheet (PMFSS), made from metal fibers, belongs to a new class of porous metal materials, with its three-dimensional network structure, interconnected pores, high porosity, and large specific surface area. The PMFSS, with its unique structural characteristics, has the potential to overcome some of the shortcomings seen in other porous materials. In general, the PMFSS is composed of a metallic skeleton and many pores, which is produced by sintering metal fibers instead of metal powder. To date, as part of a new generation of structural and functional materials, the PMFSS has many applications, including filtration and separation [2], catalyst supports [3,4], chemical processing [5,6], high temperature gas dust removal [7], acoustic damping [8], and fuel cells [9].

In recent years, new applications with strict specifications have focused PMFSS research efforts on improving the mechanical properties of the sheet. Kostornov et al. [10] produced a porous sintered metal using Ni–Cr alloy fibers as a starting material, investigating the relationship between low porosity and tensile strength. Ducheyne et al. [11] produced a new type of low-porosity PMFSS using AISI 316 L stainless steel fibers with the two kinds of diameters of 50 μm or 100 μm, studying the tensile and compressive properties of the sheet. Clyne and Markaki [12,13] produced highly porous sheets by first using liquid phase sintering of short stainless steel fibers with a diameter of 100 μm, followed by an electroplating step to coat the surface with a 5 μm thick layer of copper. The porous sheets were obtained after sintering the copper-coated fibers for 5 min at approximately 1100–1200 °C. They found that the sheets have a porosity varied from 75% to 95% and a tensile strength below 1 MPa. Liu [14–17] developed a theoretical model for the relationship between structural parameters and mechanical characteristics of a metal foam with high porosity. And a series of experiments were conducted at different operation conditions using nickel foams prepared by electro-deposition. The experimental results were broadly consistent with the theoretical model.

In this work, the PMFSS with a three-dimensional network structure was produced using solid-state sintering of copper fibers. We used uniaxial tensile tests to study the tensile fracture process of the PMFSS, as well as the effect of the porosity and sintering parameters on the tensile properties of the PMFSS.

2. Experiment procedures

2.1. Processing procedures of the PMFSS

The PFMSS samples used in this study were fabricated according to the procedures described below.

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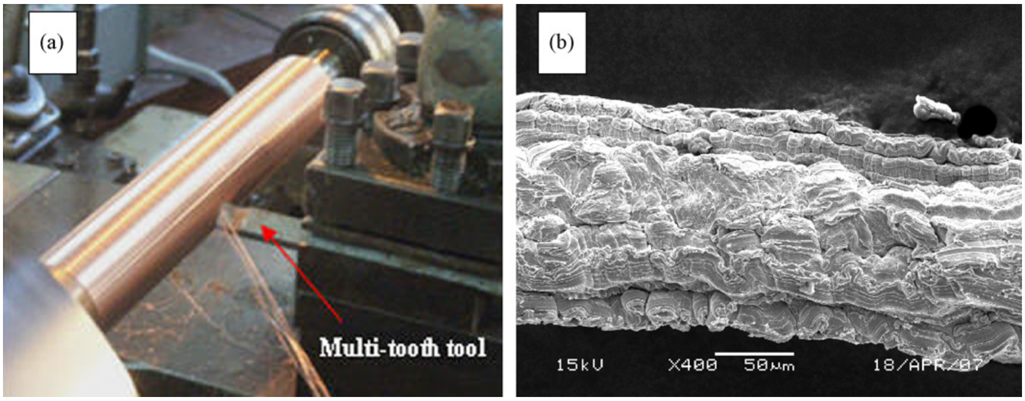

Fig. 1. (a) Manufacturing process and (b) SEM image of copper fibers using a multi-tooth tool.

First, continuous copper fibers were fabricated using a multi-tooth tool via the cutting method, as shown in Fig. 1a. The diameter of the resulting copper fibers was approximately 100 μm (Fig. 1b). These copper fibers were then cut into fiber segments 10–20 mm in length. Next, the copper fibers with random direction were uniformly packed into the predetermined packing chamber of the mold pressing equipment, and then a pressure was applied by screwing the bolts. This resulted in a semi-finished PMFSS with the three-dimension network structure and the same shape as the predetermined packing chamber. The appearance (a) and assembling principle (b) of the mold pressing equipment for the PMFSS is shown in Fig. 2. The height and shape of the PMFSS can be adjusted by changing the design of the packing chamber in the mold pressing equipment.

To prevent the copper fibers from oxidizing, the sintering procedure was carried out in a box-type furnace (NO: FXL-12-11) in a gas protection atmosphere. The sintering temperature was kept between 700 °C and 900 °C by a programmable temperature controller. The sintering time was either 30 min or 60 min. For optimum heating rates in the sintering process, we used the stage heating method. When the temperature was below 800 °C, the heating rate was kept at 300 °C/h, and when the temperature was above 800 °C, the heating rate was decreased to 200 °C/h. After the mold pressing equipment was put into the sintering furnace, nitrogen gas was used to flush the chamber. After the chamber had been purged of air, it was filled with hydrogen gas, which was later ignited. The pressure of the hydrogen gas in the furnace chamber was kept at 0.3 MPa. When the sintering was complete, the sample was moved and cooled to room temperature, at which point the mold pressing equipment could be disassembled. After a final test and examination, the PMFSS with the specified shape was obtained.

2.2. Characterizations and tensile test of the PMFSS

Since the obtained PMFSS has a regular geometric shape, we can calculate the average porosity using the quality-volume method according to the following equation:

$$E\,(\%) = \left(1 - \frac{M}{\rho V}\right) \times 100 \qquad (1)$$

where V is the volume of the PMFSS (cm^3), M is the mass of the PMFSS (g) and ρ is the density of red copper (g/cm^3).

The microscopic structure of the PMFSS was observed by scanning electron microscopy (JSM-6380LA, Japan). The tensile test was carried out on a universal material testing machine (INSTRON 2369, USA) with the value of loading error less than 1%. To meet the requirements for the tensile test, the PMFSS was designed to be 120 mm in length, 15 mm in width, and 2 mm in thickness. To avoid the deformation and destruction of the network structure in the clamping and pulling process, rubber pads were placed between clamps prior to testing. After the clamps were in place, the effective length of the samples was reduced to 100 mm. All samples were pulled at a constant tensile rate of 1.5 mm/min, with an extensometer with 50 mm gauge length used to measure displacement and strain. To minimize measurement error, the measuring range was adjusted in situ according to the actual pulling force, so that the value of the pulling force was always within the range, but close to the failure when the sample was pulled off. The tensile test was performed at room temperature (approximately 25 °C).

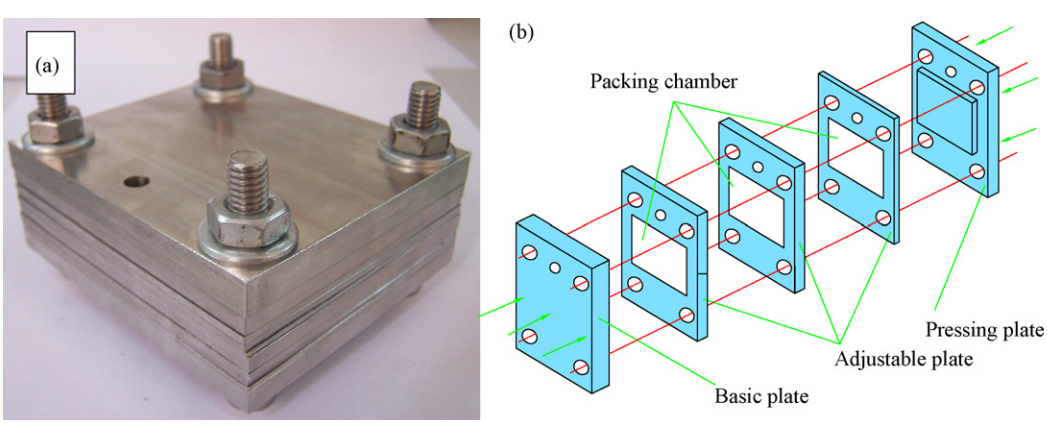

Fig. 2. (a) Appearance and (b) assembling principle of the mold pressing equipment for the PMFSS.