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Material characterization of porous bronze at high strain rates

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ABSTRACT

This study investigates the behavior of porous bronze under high strain rate loadings. The focus is on the effects of porosity and strain rate on the yield strength, energy absorption and load carrying capacity of the material. Samples of porous bronze with 10% tin were fabricated using powder metallurgy technology with porosity ranging from 20% to 40%. High strain rate tests were conducted using split Hopkinson pressure bar (SHPB) at strain rates from $500\,s^{-1}$ to $3.5 \times 10^3\,s^{-1}$, and uni-axial quasi-static compression tests were carried out using MTS universal testing machine. It is evident from the test results that the materials show a bi-linear behavior in the specified range, and the porosity has direct effect on the yield strength, Young's modulus and post yield behavior of the material. The strain rate also affects both the load carrying capacity and energy absorption capability of the material.

1. Introduction

Recently, there has been a growing interest in applications of light weight structural components with capability of absorbing energy, when subjected to impact. Cellular materials, belonging to a relatively new class of materials, become much popular because of their unique mechanical properties. They have applications in automotives, railways and aerospace where weight efficiency with considerable strength is required [1–3]. Metallic foams (porosity >70%) are traditionally used as filters, sandwich filaments and cores etc. The research on mechanical behavior of metallic foams under various loading conditions has been thoroughly investigated and is available in open literature e.g. [1]. It was reported that energy absorption capability for closed cell aluminum foam under dynamic loading was greater than that under quasi-static loading [2,3]. The energy absorption capability was also found dependent on cell morphology and the porosity of porous materials. Porous metals have porosity in the range of 10–70%, i.e. between that of typical solid materials and metallic foams. Their mechanical properties, such as relative higher strength, load carrying capacity and impact energy absorption capability [4,5] along with weight efficiency, make them very attractive for structural components. It should be noticed that the behavior of such materials will change with many parameters, such as porosity and strain rate, and so on. However, these have not been thoroughly investigated.

The quasi-static and dynamic tests at low loading speed on porous iron and bronze were reported in [5] with the strain rates up to 10/s. An experimental investigation on porous materials using Taylor's impact tests were conducted and showed that the materials were sensitive to strain rates in terms of yield strength [6]. The effect of powder size on compressive behavior of porous copper, prepared by sintering process, revealed the effects of porosity on modulus, yield strength and deformation mechanism of the material under quasi-static loading [7]. Rate dependent behavior of porous iron was investigated experimentally [8].

In this study, the behaviors of the porous bronze with 10% tin are investigated experimentally, including the effects of porosity and loading rate on yield strength, energy absorption and load carrying capacity of the materials. The next section will give the experimental details; afterwards, the test results will be described. Finally, some conclusions will be drawn.

2. Experimental setup

2.1. Sample preparation

Sample size becomes very critical to get reasonable repeatability and to avoid scattering in measurement, during tests, due to heterogeneous nature of the materials. For porous materials, the number of samples required to attain coincident data is generally much higher than those required for conventional solid materials. A previous study [9] suggests that to average the overall mechanical behavior of cellular materials, the nominal dimensions of the specimen should be 10–20 times greater than the cell size in both

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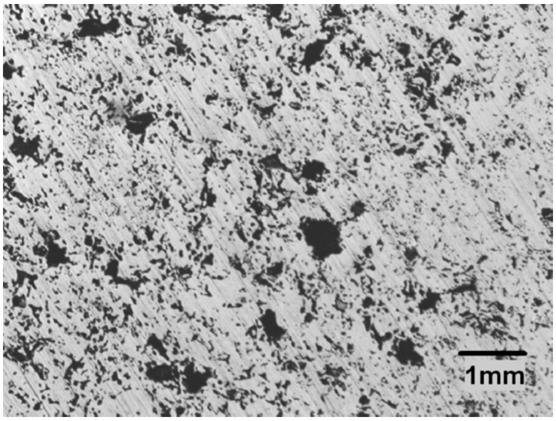

Fig. 1. Micrograph (50×) vertical sectioning of un-deformed 32% porous bronze.

Table 1
Specification of specimen with size $D \times L = \varnothing$ 7.5 mm × 7.5 mm.

	Bronze			
No.	1	2	3	4
Density (g/cm^3)	5.35	5.96	6.62	6.89
Porosity	38.5%	32%	24%	20%

the axial and radial directions. Therefore, samples of 7.5 mm diameter and same length were prepared for four different porosities of bronze. Average pore size was observed 50–500 μm for different porosities. Micrograph image (50×) of vertical section for 32% porosity is shown in Fig. 1. Details of bronze samples with different porosities are shown in Table 1.

2.2. Quasi-static testing

A universal testing machine was used to achieve 0.001/s and 0.1/s loading rates. The tests were performed at room temperature. Force–displacement data was obtained and then converted to stress–strain data.

2.3. Split Hopkinson pressure bar testing

Split Hopkinson pressure bar (SHPB) is most widely used equipment to evaluate the material's behavior at high strain rates. A schematic diagram of conventional SHPB is shown in Fig. 2. SHPB consists of an incident bar, a transmission bar and a striker bar. The specimen is sandwiched between incident bar and transmission bar. As the striker bar strikes with the incident bar, a compression stress wave is generated that propagates in the incident bar. When this incident wave reaches the interface of incident bar and specimen, part of the wave is reflected back into the incident bar due to the mismatch in materials' impedance, whereas the other part passes through the specimen and then through the transmission bar. The strain gages installed on the incident and transmission bars, at equal distances from the specimen, measure the incident strain (ε_i), transmitted strain (ε_t) and reflected strain (ε_r). Based on these measurements, strain rate (ε'), strain ($\varepsilon(t)$) and stress ($\sigma(t)$)

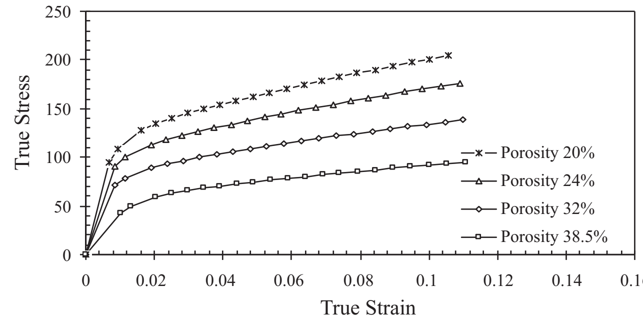

Fig. 3. Behavior of bronze at 10^{-3} s^{-1} strain rate.

in the specimen can be calculated as follows by the formulations developed by Kolesky [10] using one dimensional stress wave theory.

$$\varepsilon' = -\frac{2C\varepsilon_r(t)}{L_s}$$

$$\varepsilon(t) = \int_0^t \varepsilon'(\tau)d\tau$$

$$\sigma(t) = \frac{AE\varepsilon_t(t)}{A_s}$$

where C is the longitudinal sound speed of the bar material, $C = \sqrt{E/\rho}$, ρ is its mass density. A, E are the cross-sectional area and the Young's modulus of the bars, respectively. L_s and A_s are the length and cross-sectional area of the specimen, respectively. Both the incident and transmitted bars of SHPB, used in the present study, were made of Maraging steel, with diameter of 12.7 mm and length of 1220 mm.

Specimens were lubricated with grease to minimize the friction at the interfaces of the bars. Copper made pulse shapers were used to ensure uniform distribution of stress during deformation of specimen and appropriate size of pulse shaper was determined by pre-testing. Grease was used to connect pulse shaper with incident bar.

3. Results

Bronze samples with four different porosities (38.5%, 32%, 24% and 20%) were tested at five different strain rates, i.e.10^{-3} s^{-1}, 10^{-1} s^{-1}, 500 s^{-1}, 1800 s^{-1}, and 3400 s^{-1}. The results of typical quasi-static and dynamic tests are shown in Figs. 3–7, each corresponding to a specific strain rate against all samples of different porosities. The results are further reorganized, as shown in Figs. 8–11 to elaborate the effects of different strain rates corresponding to a given porosity. Following points can be inferred from these results:

(a) Porosity has a clear effect on yield strength, the Young's modulus and the post yield behavior of the material;

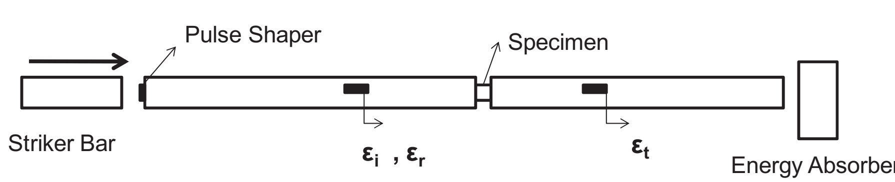

Fig. 2. Schematic diagram of SHPB.