On the Mechanical Properties of Steel Foams

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Abstract

The production of steel foams using a powder metallurgical (P/M) method has been successfully demonstrated. To date, the foamed steel has a range of density from 2-5 gm/cm³. The foamed steel exhibits a relatively isotropic closed-cell pore structure. This type of microstructure is particularly attractive for applications requiring high specific stiffness (stiffness to weight ratio) and energy absorption. This paper reports the result of a study on compression testing of P/M steel foams.

1. INTRODUCTION

In a recent steel foam program Fraunhofer conducted for the U.S. Office of Naval Research, it was demonstrated that the foaming of steel via the powder metallurgical method is feasible. The foamed steel exhibits a relatively isotropic closed-cell pore structure which is particularly attractive for applications requiring high specific stiffness (stiffness to weight ratio) and energy absorption. The attributes of the prospective steel foam structures are of interest for many innovative structural applications. For example, steel foams for naval decks or elevators have the potential to reduce weight and to provide the necessary stability against fire and corrosion.

2. Steel Foaming and Macrostructure

A series of steel powder consolidation and foaming experiments were conducted [1]. Two types of chemical compounds were considered for steel foaming: strontium carbonate ($SrCO_3$) and chromium nitride (Cr_XN) [2]. The selected chemical compounds help to build up sufficient gas pressure in the steel matrix before foaming starts. This gas pressure has to work against the atmospheric pressure, the metal surface tension and the hydrostatic pressure of the metal bath.

To date, steel foam of density in the range 2-5 g/cm³ (relative density = 25-60%) could be obtained. Lower densities are possible, but may lead to unsatisfactory pore size and distribution, associated with pore inter-connectivity. Figure 1 shows a 2.5 wt.% C steel foam structure having a relative density of 55% (density of 4.39 g/ cm^3). The foaming was conducted using convection heating under reduced inert gas pressure. A relatively uniform pore structure was obtained.

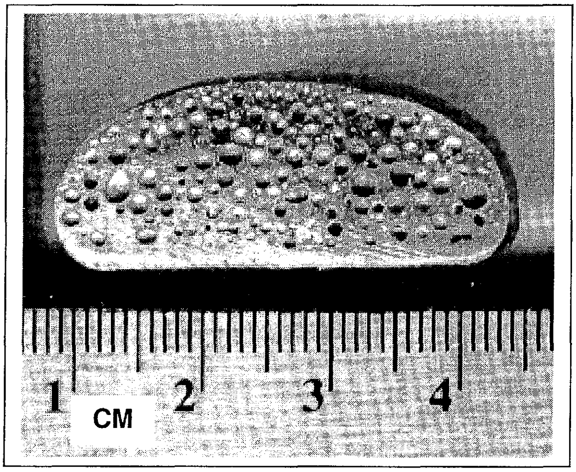

Figure 1: Steel Foam (Fe-2.5 wt.% C) with 55% fractional density.

3. Compression Tests

In general, the mechanical properties of metal foams are defined as a function of their relative density as shown by the following equation [3]:

$$\varphi_F = \varphi_S \cdot \left(\frac{\rho_F}{\rho_S} \right)^n \tag{1}$$

where φ_F is the specified property of the foam; φ_S is the specified property of the matrix material; ρ_F is the density of the foam, ρ_S is the density of the solid material and n is an exponent between 1.5 and 2.

Mechanical compression tests were conducted on the pressed and foamed steel samples. Figure 2 shows the typical stress-strain curves obtained. The relative density of the steel foam samples presented in Figure 2 ranges from 41%-44%. The peak stresses of these steel foam samples are between 65-100 MPa. It is speculated that this variation is partially due to the inhomogeneous pore size and distribution in the test samples. In a separate project conducted by UltraClad and Fraunhofer for making steel foams by hot isostatic pressing [4], the peak stress was measured as high as 175 MPa at 50% relative density. In this case, a relatively uniform pore structure was obtained. It is suggested that a better control of the pore size and distribution is needed for the optimal steel foam properties.

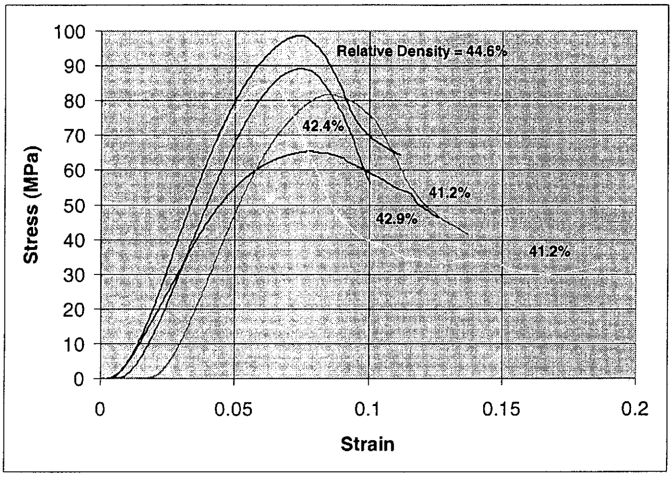

Figure 2: Compression testing of hot-pressed and foamed samples.

A decrease in the stress level after reaching the peak stress is observed. Possibly, it is due to the formation of carbide in the steel matrix causing the brittle failure in the steel foam during deformation. From the standpoint of energy absorption, it is important to maintain the peak stress as deformation proceeds. Addition of other alloying elements is being considered to increase the ductility of the steel matrix.

Figure 3 shows a log-log plot of the compressive stress of the steel foams as a function the foam density. A relatively linear relationship was obtained with the exponent n equal to 1.79. An attempt was also made to relate the compressive modulus to the foam density. However, significant scatter in the measured values was observed.

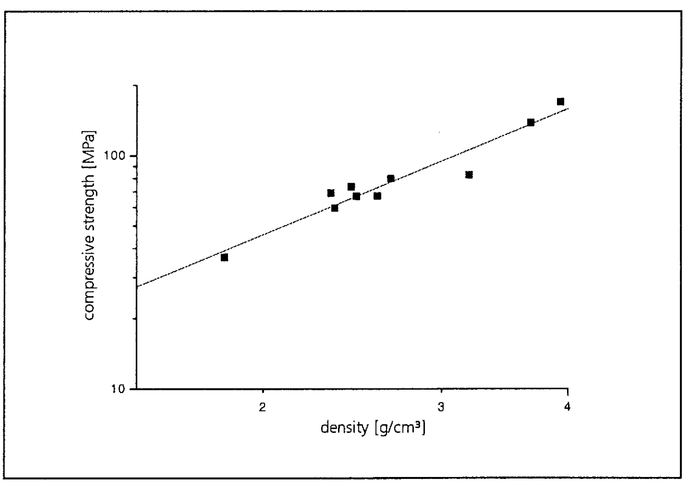

Figure 3: compressive strength vs. density in a log-log plot

4. Summary

Recent investigations on steel foaming show that foam densities within the range 2-5 g/cm^3 (relative density 25-60%) could be obtained. Further density reduction may lead to an unsatisfactory pore structure. Compression tests were conducted for the foamed steel samples. The peak stresses of the steel foam samples were recorded and related to the foam densities. A linear relationship was obtained with the exponent n calculated to be about 1.79. It was also found that a decrease in the stress level after reaching the peak stress occurs possibly due to the brittleness of the material. The addition of other alloying elements may increase in ductility.

It is planned that large steel foamable sandwich panel be fabricated by either the hot isostatic pressing (HIP) process or by the cold isostatic pressing (CIP) process followed by hot rolling and roll-cladding processes.

Acknowledgements

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