QUANTIFYING THE DYNAMIC PROPERTIES OF METALLIC THIN-WALLED HOLLOW SPHERE FOAMS

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Summary Metallic foams made of thin-walled hollow spheres are attractive in transport applications where weight saving is a critical issue. The dynamic behaviour and impact energy dissipation capacity of the foam were characterised at different loading velocities up to 160 m s^{-1} using various experimental techniques. It was found that both dynamic strength and dissipated energy increase with the loading velocity. Finite element modelling of single hollow spheres was performed to link their properties to the bulk foam behaviour.

INTRODUCTION

Metallic foams made of thin-walled hollow spheres are attractive in transport applications where weight saving is a critical issue [1-3]. New manufacturing technologies such as electrodeposition are able to produce hollow spheres with a wall thickness (t) to external diameter (D) ratio as low as 0.006 [3]. Hollow sphere foams have the potential to dissipate energy during an impact damage process. Quantification of impact behaviour and energy dissipation capacity in hollow sphere foams is therefore important when they are used in transport components, in particular those subject to higher velocity loads.
The aim of this work was to quantify the dynamic behaviour and impact energy dissipation capacity in metallic thin-walled hollow sphere foams under high velocity impact loads (60 – 140 m s^{-1}). Finite element (FE) modelling of single hollow spheres was developed to simulate dynamic properties and to link them to the bulk behaviour.

EXPERIMENTS AND FINITE ELEMENT MODELLING

Hollow spheres of diameter D = 2.5 ± 0.1 mm and wall thickness t = 15 ± 5 μm were produced by electrodepositing nickel on Styrofoam spheres, which were then removed by subsequent heat treatment. Rectangular foam plates (a height of 50 mm and a square base of side 150 mm) were manufactured by randomly agglomerating these thin-walled hollow spheres with epoxy resin. The relative density of the foams was approximately 2.5%. High velocity impact tests on the foam plates were performed in a light gas gun facility with an initial projectile velocity (v_i) ranging from 60 to 140 m s^{-1}. Hemispherical ended projectiles (radius 7.5 mm) tailed with a long cylindrical rod (diameter 5 mm and length 75 mm) were used and made of lightweight grey nylon (mass $m \approx$ 3.9 g). These provided nearly pure compression on at least 9 spheres along any maximum arc length (equator) during the impact process. The position history of projectiles during impact testing was recorded using a Phantom™ 7.3 high-speed imaging system (~47,000 frames per second). Fig. 1(a) illustrates two photographs of a projectile during an impact test (v_i = 110 m s^{-1}). Note that alternating black/white stripes were marked on the projectile tail to enhance the image contrast.
An axisymmetric finite element model was developed using ABAQUS/Explicit solver to predict the response of a single hollow sphere (t = 15 μm, D = 2.5 mm) compressed between two rigid anvils at loading velocities v = 8 – 200 m s^{-1}. An elastic-plastic material formula was specified for electrodeposited nickel based on the observed nanocrystalline feature [4].

RESULTS AND DISCUSSION

Using an in-house grid tracking code, rectangular boxes (e.g. A – C in Fig. 1(a)) were created in the first image and then tracked in subsequent images. The velocity of track boxes during the complete impact process was then derived from the position history of boxes measured in photography. The kinetic energy of projectiles as shown in Fig. 1(b) was finally calculated for the impact process. The x value defines the tip position of the hemispherical head of projectiles along the plate thickness (50 mm), which is equal to the depth of the damaged portion of the plate. After the entire hemispherical head of the projectile enters the foam plate at x = 7.5 mm (equal to the radius of the hemisphere, R), the impact contact area equal to hemispherical surface area ($A_s = 2\pi R^2$) maintains constant; an approximately linear relationship between the projectile energy (E) and the impact depth (x) was observed in Fig. 1(b). As the impact process by a hemispherical head produces nearly pure compression locally on sphere foams, the average compressive plateau stress (σ_p) of the foam was estimated as the change of dissipated energy per unit volume in the direction normal to the hemispherical contact surface:

$$\sigma_p = -\frac{dE}{A_s dx} \quad (1).$$

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The average plateau stress of the foam increases with the impact loading velocity (see Fig. 1(b)). This may suggest a rate sensitivity of the foam. Note that the calculated plateau stress was an average for the impact process where the impact velocity decreased. Further work is required to measure the plateau strength at exact loading rates, in particular high impact loading rates.

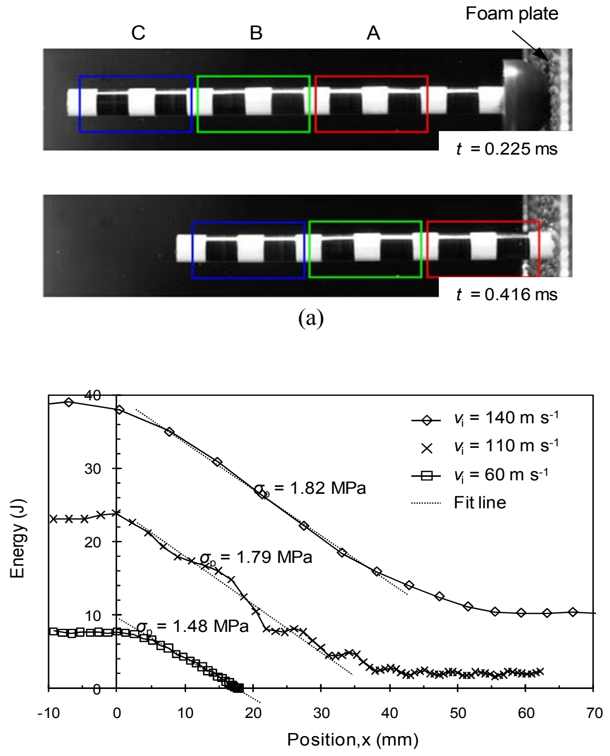

Fig. 1. (a) High speed photographs of the projectile fired toward a foam plate during an impact test, on which three boxes – A, B, and C were used in image analysis to track the projectile position, and (b) the calculated kinetic energy of projectiles as they impacted the plates.

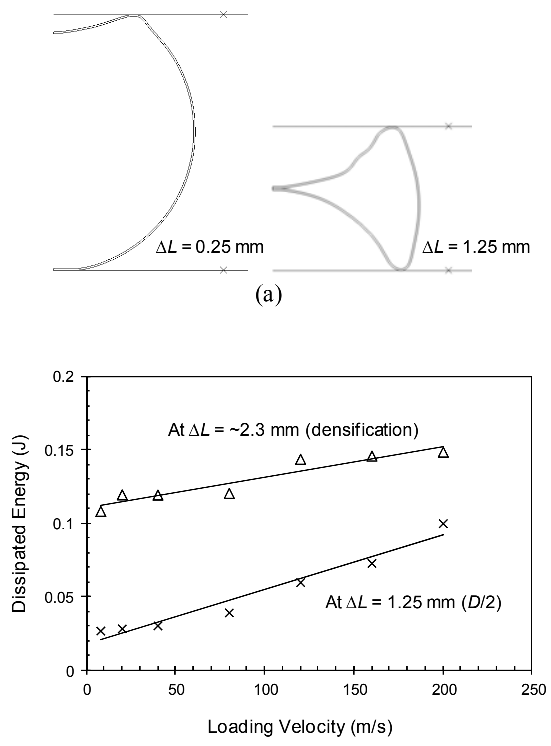

Fig. 2. (a) Predicted compressive deformation history of single hollow spheres at the loading velocity of 80 m s^{-1}, and (b) Predicted energy absorbed by single hollow spheres to two given displacements (ΔL = 1.25 and ~2.3 mm) as a function of impact loading velocity.

The impact behaviour of thin-walled hollow spheres is significantly influenced by the loading velocity (Fig. 2). The loading velocity dependent behaviour is essentially the result of inertia effects associated with the dynamic localisation of wall crushing, a shock like characteristic [5]. As shown in Fig. 2(a), more dynamic crushing is localised in the wall near the input anvil (ΔL = 0.25 mm). The impact energy dissipated by a single hollow sphere at a given stage can be quantified by the area under the force/displacement curve. The energy dissipation capacity almost linearly increases with the loading velocity up to 200 m s^{-1} (Fig. 2(b)). This rate dependent impact behaviour of single hollow sphere will contribute to the rate sensitive bulk behaviour of the foam made of them.

CONCLUSIONS

It was found that

- The energy dissipated by thin-walled hollow sphere foams increases with the impact loading velocity. This is due to the fact that the impact energy dissipated by a single hollow sphere increases linearly with the loading velocity.
- The average compressive plateau stress of hollow sphere foams directly derived from the impact energy dissipation processes, increases with loading rates, which may imply the rate dependency of the foam at high impact loading velocity.

References

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