Numerical analysis on the reliability of characterizing dynamic mechanical properties of metal foam by SHPB test

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Abstract

Split Hopkinson pressure bars (SHPB) technique has been widely used to characterize dynamic mechanical properties of various materials, and one of its basic assumptions is uniform deformation of specimen during the experiment. However, some studies in recent years have found the obvious deformation localization within metal foam specimens in SHPB tests, which may violate the basic assumption and lead to unreliable result. In this paper, we carried out numerical SHPB-test to study the problem based on the experimental verification. The specimens of metal foam are modeled to have 3D meso structures with given matrix mechanical properties. Numerical SHPB-tests of aluminum foam specimens with varying thickness at different strain rates were performed. Deformation non-uniformity in each local region of the specimen was examined, and the influences of specimen thickness and testing strain rate on the deformation non-uniformity were quantitatively analyzed as well as the size effect. Criteria to judge the reliability of characterizing dynamic mechanical properties of metal foam by SHPB test were proposed.

Keywords: SHPB, metal foam, dynamic properties, deformation non-uniformity.

Introduction

One of the basic assumptions of SHPB technique is that deformation of the specimen is uniformly distributed along the thickness direction [1], and researchers have adopted various criteria to determine whether a specimen’s deformation is uniformly distributed in SHPB tests. The most commonly used criterion cares about the ratio of the difference and mean value of the stresses at the specimen’s two ends, as suggested by Ravichandran [2].

SHPB technique has been used to test dynamic mechanical properties of aluminum foam at high strain rates ranging nearly from 900/s to 3200/s [3-7]. In recent years, with the help of high speed cameras and numerical simulation technique, some studies have found the obvious nonuniform deformation in aluminum foam specimens in SHPB tests [8]. In order to investigate the factors which have effects on the deformation non-uniformity of aluminum foam specimens, in the present study, finite models containing meso-structure of aluminum foam were established and numerical SHPB-tests were conducted. Criteria to judge the reliability of the experiments have been put forward based on the simulation results.

Model construction and validation

The bars of SHPB facility employed in this work were made of aluminum, and the aluminum foam was closed-cell foam with the average cell size of 3-6 mm and relative density of about

20%. The specimen of 74 mm in diameter and 37 mm in height was used in the experiments. In numerical-SHPB tests, all components were modeled according to the actual shapes and sizes except the porous specimen since Voronoi model was used to describe the 3D meso-structure of the aluminum foam, as shown in Fig. 1. The stress-strain curve fitted by ABAQUS/Explicit was obtained and compared with the experimental one, as shown in Fig.2. Overall Fig.2 shows a good agreement between the two curves, which means it is reliable and effective to simulate the behavior of aluminum foam in SHPB test using the finite model with foam's 3D meso-structure.

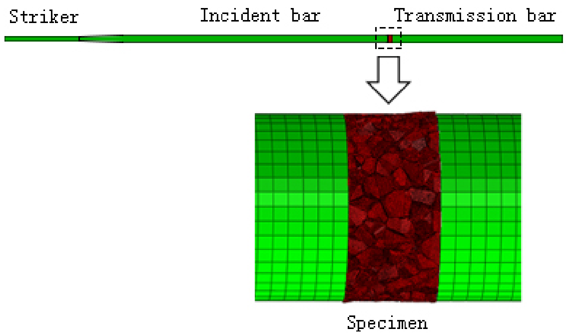

Fig.1 Finite element model containing meso-structure of aluminum foam

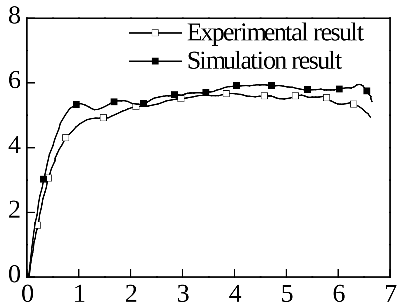

Fig.2 Comparison of experimental and simulation dynamic

Numerical SHPB-test scheme

For a specimen with thickness of 37 mm, stresses at two ends are unable to reach balance if the strain rate is raised to 1000/s. When the specimen thickness is decreased to 12 mm, the stresses at two ends of the specimen can get equilibrium at the strain rates ranging from 1000/s to 4000/s. In order to study the effect of specimen thickness on the deformation non-uniformity, three thicknesses (12 mm, 9 mm and 6 mm) were focused on. This paper mainly concerns about the deformation non-uniformity when the specimen's average strain reaches 50%, for the stresses at two ends are always balanced at this time. Numerical SHPB-tests for the specimens with thickness of 12 mm at the testing strain rates of 2000/s, 3000/s and 4000/s were conducted.

For the purpose of characterizing the deformation non-uniformity quantitatively, maximum excess ratio of localized strain R is introduced. The higher value R reaches, the less uniform is the deformation within the specimen.

Conclusions

Series of numerical SHPB-tests of aluminum foam were conducted, and distribution of localized strain was obtained to study the deformation non-uniformity of specimen. The main aspects that can be drawn as a conclusion are:

1. In an SHPB test of metal foam, strain at two ends of the specimen will be much higher than that at the middle region, and the deformation non-uniformity will be weakened but never vanish as total average strain increases.

2. Testing strain rate has small influence on deformation non-uniformity while specimen thickness affects it appreciably, as shown in Fig.3. Reducing specimen's thickness can help to

weaken the deformation non-uniformity, and thinner specimen usually has a lower degree of strain localization at the same total average strain than thicker one.

3. Deformation of specimen is more uniform in distribution when specimen thickness decreases, but disturbance from size effect increases. Criterion to judge the reliability of characterizing dynamic mechanical properties of metal foam using the SHPB technique is whether the deformation non-uniformity and size effect can be accepted simultaneously.

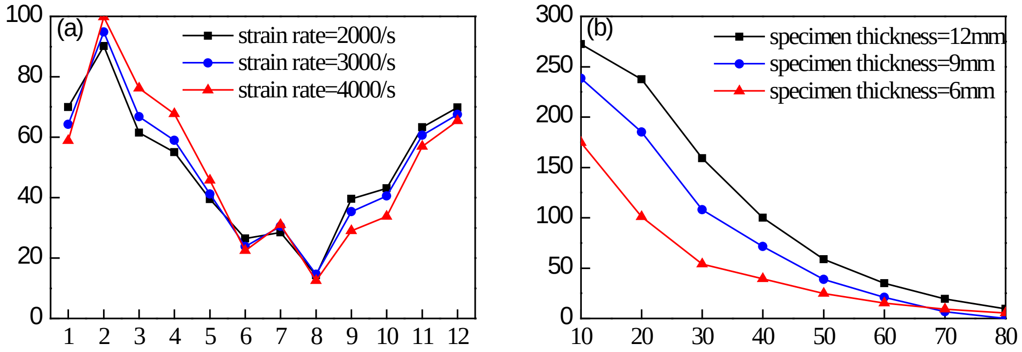

Fig.3 Effects of (a) strain rate and (b) specimen thickness on the deformation

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