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Localized deformation in aluminium foam during middle speed Hopkinson bar impact tests

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A B S T R A C T

Split Hopkinson pressure bar (SHPB) technique is a widely adopted method to study the dynamic mechanical behaviors of materials. However, the strong localization of the deformation in aluminium foams (near the ends of the specimen) may invalidate the assumption of uniform strain within the specimen granted in the analysis of SHPB results. To appraise how critical this issue could be, the deformation process of aluminium foam under middle speed impact was investigated by combining SHPB technique with high speed photography. Based on the experimental results, finite element analysis was carried out to explore the characteristics of the localized deformation in aluminium foam. The strain distribution was quantitatively analyzed and showed the dependence on the imposed strain rate. An evaluation of the deformation localization by defining maximum loacalized strain and strain rate indicates that the maximum strain and strain rate in the specimen can be more than 100% higher than the average values.

1. Introduction

Aluminium foam, as a type of maturely developed metal foam materials, is employed in a wide variety of engineering applications nowadays due to its light weight and outstanding ability for energy absorption [1]. In the past decades, dynamic mechanical response of aluminium foam under impact has been intensively investigated using the split Hopkinson pressure bar (SHPB) [2] technique with focus on energy absorption [3,4], strain rate sensitivity [5,6] and compression deformation [7,8]. The deformation of aluminium foam containing heterogeneous meso-structure was observed to be spatially non-uniform, accompanied with localized weak bands [7] and progressive cell wall breakage [8]. The deformation process can be characterized as cell-level distortions and rotations together with localization of the deformation bands according to the images of specimen surfaces taken after dynamic compression [9]. A series of SHPB experiments indicated that the deformation of aluminium foam concentrated near the front end of specimen (the end collided with incident bar) [10–12]. For example, Cady [10] found that over 90% of the deformation of aluminium foam occurred in 30% part of the specimen near the front end, and the rest part of the specimen remained almost undeformed after the SHPB tests with strain rate of 2000 s^{-1} and the ultimate strain of 32%.

The rapid progress of high-speed photography in recent years provides an effective way to monitor the deformation of metal foams in-situ during impact tests. Employing this technique, Lopatnikov [13] and Radford [14] carried out the observation of deformation process in aluminium foam. The specimens used as the bullets to hit the Hopkinson bars were found to consist of two parts: deformed and undeformed, between which the traces of propagating wave front were visible. Liu et al. [15] quantitatively studied the non-uniform deformation of aluminium foam by analyzing the in-situ strain distribution along the specimen at the striker speed of 47 m s^{-1}. In their work, the strains localized near the front end of the specimen can reach up to 60%. The non-uniform deformation of aluminium foam also aroused the interest in modeling and simulation areas [16–18]. According to the reported simulation work, the deformation mode of foam shows the strong dependence on impact speed. Under a sub-critical impact speed, the non-contiguous deformation localized at weak bands [16]. As the speed gets higher, more crushing bands appear near the front end [16,18].

It is well known that SHPB-based analysis stems from the assumptions of one-dimensional wave propagation and stress equilibrium in the bars. The strain and imposed strain rate of specimen usually refers to the average values calculated according to the difference of displacements between the ends of incident bar and transmission bar [2,19], simply assuming a uniform deformation within the specimens. The stress equilibrium in foam materials has been discussed particularly, and can be satisfied by the specific design of experiment [19–24].

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However, the implicit assumption of strain equilibrium is far from the practical situation according to the aforementioned experimental study. The localization of deformation in aluminium foam leads to much higher regional strain and strain rate within specimens than the average values. For example, the strain rate of the material at the front end of the specimen can be 2.6 times as high as the average strain rate of the whole specimen in Liu's work [15]. Neglect of this large discrepancy may impair the reliability of SHPB technique for the research of metal foams and may misdirect the exploration of the deformation mechanisms. More seriously, the R&D of aluminium foam parts based on the unreliable research might result in potential safety issues in engineering applications. Unfortunately, a systematic research of the non-uniform deformation in metal foams is still in a very beginning stage hitherto.

In this work, we have built a testing system combining SHPB with high-speed photography to monitor the in-situ deformation of aluminium foam during middle speed impact tests [25]. The localized deformation in the specimen was quantitatively investigated via digital image analysis. Based on the experimental findings, numerical simulation, using a 3D Voronoi model, has been carried out to reproduce the deformation localization at a wider range of strain rate for a comprehensive study of its characteristics.

2. Experiments

2.1. Material and pre-processing

The closed-cell aluminium foam was provided by Shanghai Osenter Metal Composite Material Co. Ltd. in the form of plate (600 mm × 600 mm × 37 mm) with cell size ranging from 3 to 6 mm, elastic modulus of 1 GPa, relative density of 0.2 and wave speed of 1361 m/s. The aluminium foam was prepared by foaming

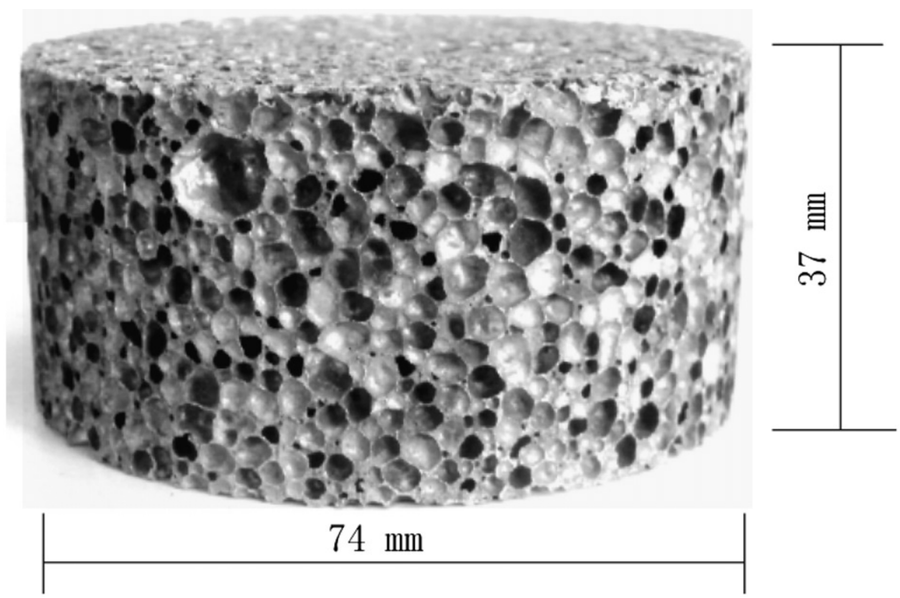

Fig. 1. Specimen of aluminum foam.

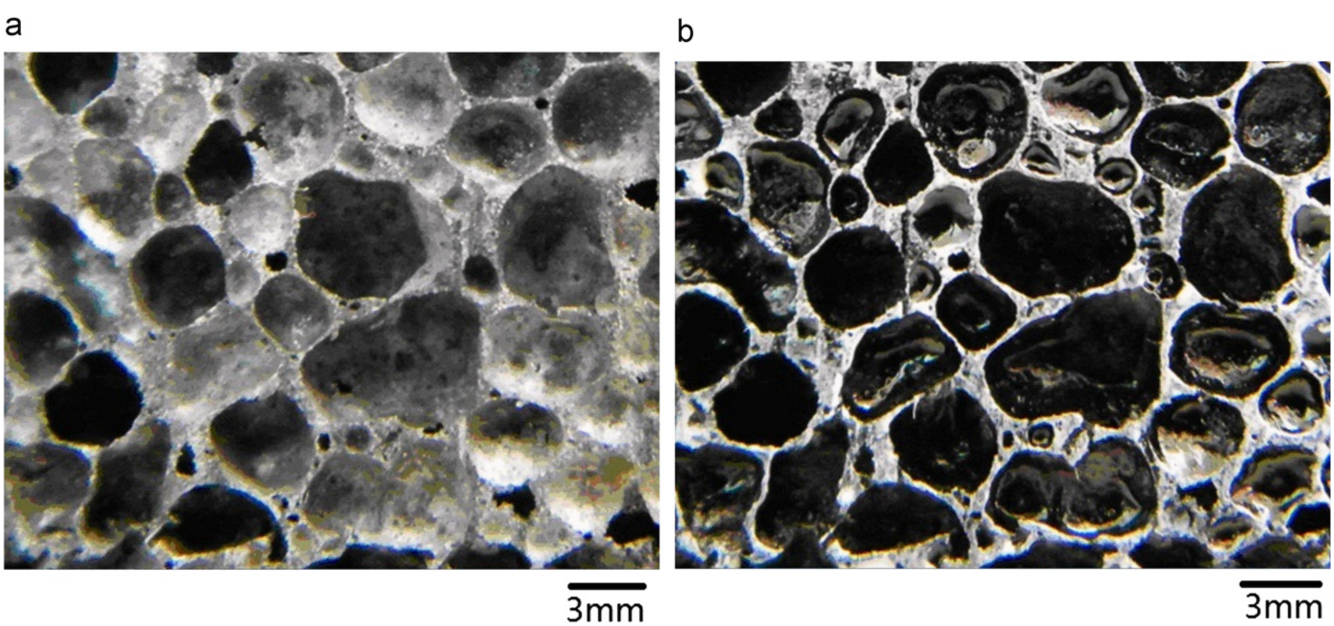

Fig. 2. Images of the specimen surface: (a) before and (b) after pre-processing.