International Journal of Solids and Structures 48 (2011) 698–705

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Impact behavior of honeycombs under combined shear-compression. Part II: Analysis

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ARTICLE INFO

Article history:
Received 25 March 2010
Received in revised form 3 October 2010
Available online 5 November 2010

Keywords:
Honeycombs
Combined shear-compression
FEM
Dynamic strength enhancement

ABSTRACT

In this paper, a numerical virtual model of honeycomb specimen as a small structure is used to simulate its combined shear-compression behavior under impact loading. With ABAQUS/Explicit code, the response of such a structure made of shell elements is calculated under prescribed velocities as those measured in the combined shear-compression tests presented in Part I of this study.

The simulated results agree well with the experimental ones in terms of overall pressure/crush curves and deformation modes. It allows for the determination of the separated normal behavior and shear behavior of honeycomb specimen under dynamic combined shear-compression. It is found that the normal strength of honeycombs decreases with increasing shearing load. Quasi-static calculations were also performed and a significant dynamic strength enhancement found in experiments was validated again in the numerical work. A crushing envelope in normal strength vs. shear strength plane was obtained on the basis of these simulations.

1. Introduction

Dynamic multiaxial behavior of honeycombs as a basic energy-absorption design parameter is eagerly desired in order to perform numerical simulations for various industrial applications. Many previous works in this domain have been reported in the open literatures and a large number of these works concern mainly the in-plane behavior, and mostly under quasi-static loadings (Gibson and Ashby, 1997; Gibson et al., 1989; Klintworth and Stronge, 1988; Yang and Huang, 2005; Papka and Kyriakides, 1999). However, the most interesting behavior of honeycombs for an energy absorption application is the out-of-plane crushing behavior, especially the one under combined out-of-plane shear-compression which is the most realistic loading mode for such use.

Under quasi-static loadings, some testing methods for the combined shear-compressive loading have been reported (Doyoyo and Mohr, 2003; Mohr and Doyoyo, 2004a; Hong et al., 2006) and they were used to determine the yield envelope of aluminum honeycombs under this particular loading state (Hong et al., 2006; Mohr and Doyoyo, 2004b,c). For examples, (Hong et al., 2006) derived a quadratic yield criterion suitable for orthotropic materials by modifying Hill's quadratic yield criterion. (Mohr and Doyoyo, 2004b,c) suggested a linear fit for the crushing envelope based on their quasi-static calculating results.

Under dynamic loading, many reported works revealed that the strength of honeycombs under uniaxial dynamic compression is higher than under quasi-static loading (Wu and Jiang, 1997; Baker et al., 1998; Harrigan et al., 1999; Goldsmith and Louie, 1995; Goldsmith and Sackman, 1992; Zhao and Gary, 1998; Zhao et al., 2005), even the shock wave effect is not involved (Elnasri et al., 2007). However, the behavior of honeycombs under dynamic multiaxial loading is rarely reported up to now. The main reason for such situations lies in the difficulties to achieve dynamic multiaxial experiments with accurate data measurements.

Some previous work proposed the dynamic multiaxial testing methods using drop-weight or high speed machine (Hong et al., 2008; Chung and Waas, 2002), but the accuracy is not optimal at higher loading rates. In order to improve the measurement accuracy, we proposed in Part I of this study a new testing method using large diameter Hopkinson bar with beveled ends to perform combined shear-compression test under impact loading. It permits to obtain interesting overall pressure/crush curves but can not give a separate normal and pure shear behavior. Thus, with the tests developed in Part I, there is no means to identify directly a given yield criterion.

In Part II of the work, a numerical approach is presented to study a yield criterion. The dynamic and quasi-static combined shear-compression experiments are numerically reproduced with a detailed FEM model for honeycomb specimen. The accuracy of these simulations is validated by comparing the numerical results with the testing ones. Such virtual tests provide a separated normal and shear behaviors of honeycomb specimen, which allow

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doi:10.1016/j.ijsolstr.2010.11.004