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# Impact behavior of honeycombs under combined shear-compression. Part I: Experiments

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ABSTRACT

This paper presents a combined shear-compression impact test for soft cellular materials designed in order to investigate their behavior under impact multiaxial loadings. A large-diameter Nylon Split Hopkinson Pressure Bar system (SHPB) with beveled ends of different angles is used to apply the desired shear-compression combinations. The data processing methods are studied and validated by virtual testing data generated with FEM simulations. A series of experiments on an aluminum honeycomb were performed at the impact velocity of about 15 m/s with the loading angles ranging from 0° (corresponding to the pure compression) to 60°. It shows a strong effect of the additional shear loading because both the initial peak and the crush strength decrease with increasing loading angles. The quasi-static shear-compression experiments were also performed using the same beveled ends on a universal INSTRON machine and a notable strength enhancement under impact loading is observed. Images captured during quasi-static and impact tests permit for the determination of the two co-existing deforming patterns under combined shear-compression and reveal the influence of the loading rate on the occurrence of these two patterns.



## 1. Introduction

Honeycombs as well as the other cellular materials are commonly used for energy absorption designs in aerospace and modern vehicle applications. Their mechanical behaviors were extensively studied under various quasi-static loadings (Wierzbicki, 1983; Zhang and Ashby, 1992). Under impact loading conditions, which are the real working condition for energy absorbing systems made of cellular materials, only a few investigations limited to uniaxial compression are reported in the open literatures (Wu and Jiang, 1997; Zhao and Gary, 1998; Goldsmith and Louie, 1995; Zhao et al., 2005). Experimental investigations of cellular materials under dynamic multiaxial loading are not available as yet. The main reason for such situations lies in the difficulties to perform dynamic multiaxial experiments because of the requirements for both a feasible multiaxial design in a tiny limited space and an accurate data measurement under these conditions.

In the past decade, various multiaxial quasi-static loading methods suitable for cellular material were developed (Papka and Kyriakides, 1999; Deshpand and Fleck, 2001; Chung and Waas, 2002; Chen and Fleck, 2002; Mohr and Doyoyo, 2003; Mohr and Doyoyo, 2004; Kintscher et al., 2007; Hong et al., 2006; Hong et al., 2008; Karagiozova and Yu, 2008). For example, Papka and Kyriakides (1999), and Chung and Waas (2002) employed a quasi-static biaxial loading machine to investigate the in-plane biaxial compression properties of honeycombs. In their facilities, the specimen was placed between two pairs of loading platens which could move independently in two orthogonal directions. Mohr and Doyoyo (2003) modified the standard Arcan apparatus using a clamped configuration to restrict the rotations of the grips and tested the combined out-of-plane shear-compression behavior of honeycombs. They estimated possible errors of ignoring the additional horizontal force produced by the clamped configuration (Mohr and Doyoyo, 2002) and integrated another load cell to measure it. Mohr and Doyoyo (2004) also had another universal biaxial testing device which employed three load cells to measure the forces in two different directions. Based on a Zwick static test facility, Kintscher et al. (2007) developed a test device with the combination of a roll and a steel towing rope to apply combined out-of-plane shear-compression to a folded sandwich double-core specimen. Hong et al. established two systems (so-called the independently controlled test fixture (Hong et al., 2006) and the inclined test fixture (Hong et al., 2008)) to perform the quasi-static biaxial experiment on honeycombs. These aforementioned quasi-static biaxial loading methods succeed in measuring the in-plane

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