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Crushing mechanism of hierarchical lattice structure

Fangfang Sun[a], Changliang Lai[a], Hualin Fan[a,*], Daining Fang[b]

[a] State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
[b] College of Engineering, Peking University, Beijing 100871, PR China

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ABSTRACT

Hierarchy greatly enhances anti-crushing behavior of thin-walled tubular structures. To reveal the energy-absorbing mechanism, hierarchical triangular lattice structures with lattice-core sandwich walls were designed. Crushing experiments were carried out to reveal the progressive collapse modes and folding mechanisms. Compared with single-cell and multi-cell lattice structures, hierarchical structures possess greater mean crushing forces (MCFs), three to four times higher. Three mechanisms, including hierarchical folding, shortening wave length and enlarging plastic bending moment of sandwich wall, help hierarchical structure greatly enhance its anti-crushing behavior. Folding styles turning from single fold, multi-fold, hierarchical fold to single sandwich-fold when increasing micro-cells in the wall were revealed by numerical simulation to propose optimized hierarchical lattice structure possessing the best specific energy absorption (SEA). Based on progressive folding mechanism, global bending mechanism and hybrid folding mechanism, theoretical models were built to predict the MCF. The predictions are reasonable.

1. Introduction

Hierarchy can make thin-walled structures even more weight-efficient in energy absorption. Fan et al. (2008) described the mechanism of hierarchical structure in improving the stiffness and strength, which has been verified by various hierarchical structure designs (Andrea and Damiano, 2013; Chen and Pugno, 2013; Chen et al., 2014; Qing and Mishnaevsky Jr, 2009, 2011; Sourish, 2014; Taylor et al., 2011; Tran et al., 2014, 2015) and experiments. Bhat et al. (1989) made hierarchical honeycomb sandwich panels having a compressive strength about six times greater than an equal mass honeycomb sandwich panel. Lakes (1993) constructed hierarchical paper honeycomb whose plastic strength was a factor of 3.8 times stronger. Kooistra et al. (2007) and Côté et al. (2009) made hierarchical corrugated or honeycomb core sandwich panels with higher strength. Kazemahvazi et al. (2009) made hierarchical sandwich structures, which have more than seven times higher specific strength compared to its monolithic counterpart, but the structure is brittle. In these studies, the authors did not reveal the ductile deformation mechanism and energy absorption properties of the hierarchical cellular structure. Actually, hierarchical structure is an efficient way to enhance the anti-crush property of light-weight materials. Fan et al. (2012, 2013) and Zheng et al. (2012) have made hierarchical honeycombs using ductile woven textile composites. Specific energy absorption (SEA) is even greater than metallic lattice trusses and honeycombs. Yi and Chen (2012) pointed out that with hierarchical cellular cores the impact response of clamped sandwich beams should be obviously improved. Zhang and Zhang (2013) revealed the excellent anti-crushing behaviors of rhombic and Kagome honeycombs.

Hong et al. (2013), Fan et al. (2015) and Wang et al. (2015) studied the crushing behaviors of triangular

* Corresponding author. Tel.: +8602580821697.
E-mail addresses: fanhualin@163.com, fhl02@mails.tsinghua.edu.cn (H. Fan), fangdn@pku.edu.cn (D. Fang).

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tubes. Hong et al. (2014) revealed axial crushing behaviors of multi-cell tubes with triangular lattices. Based on these researches, in this paper hierarchical lattice tubes (HLTs) were fabricated and compressed to reveal the progressive crushing behaviors and advantages in energy absorption.

2. Hierarchical structures

Usually tubular structure has thin solid walls and buckling controls its failure. Even yielding is the initial failure style, post-failure characterized by plastic bending greatly reduces its post-failure strength and makes the structure

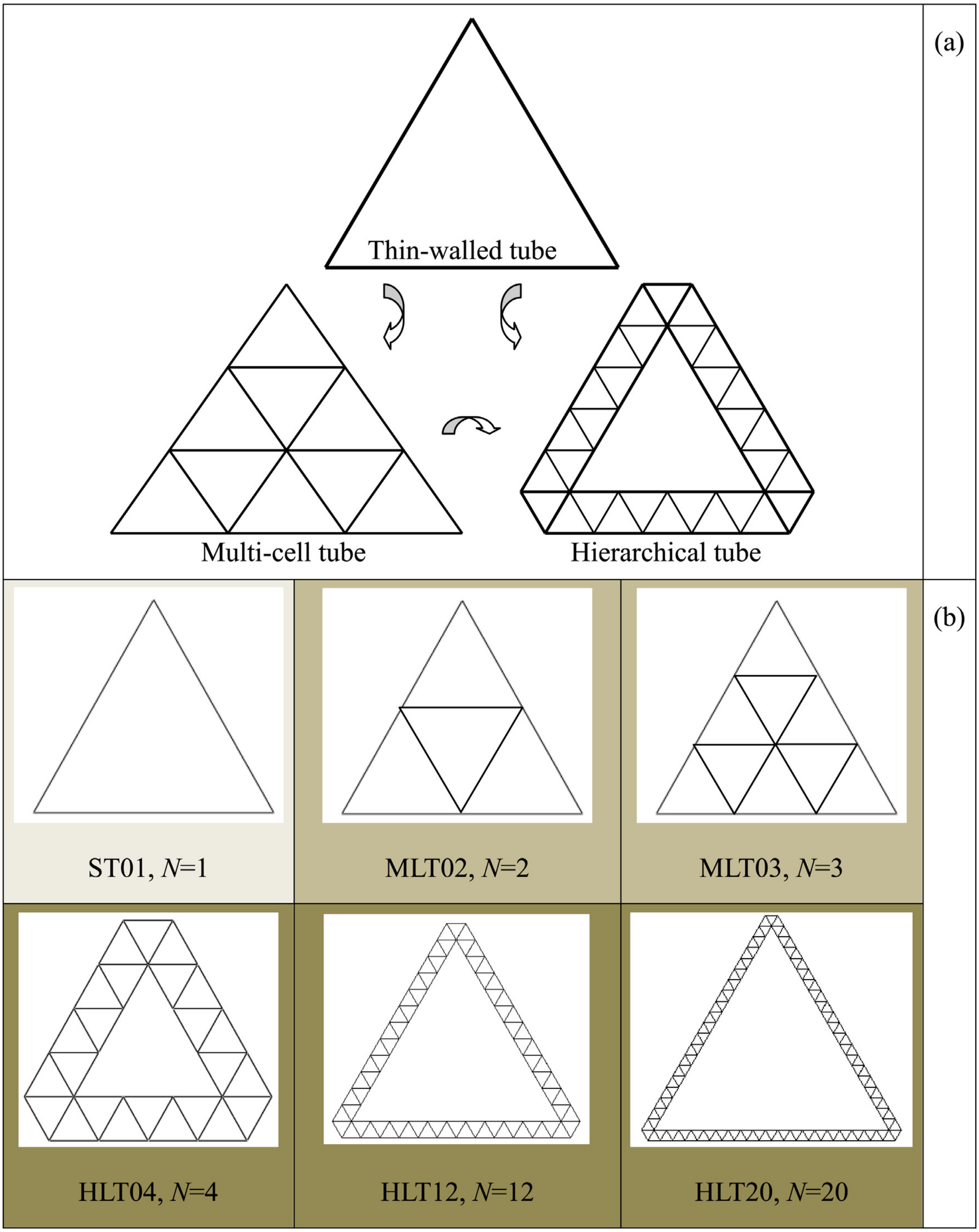

Fig. 1. Structural (a) hierarchy of cell of triangular lattice tube and (b) geometry evolution of HLT with various side wall segment number, *N*.