Composites: Part A 80 (2016) 1–12

Contents lists available at ScienceDirect

Composites: Part A

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

Finite element analysis of sandwich panels with stepwise graded aluminum honeycomb cores under blast loading

Shiqiang Li [a,b], Xin Li [a,b], Zhihua Wang [a,b,*], Guiying Wu [c], Guoxing Lu [d], Longmao Zhao [a,b]

[a] Institute of Applied Mechanics and Biomedical Engineering, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China
[b] Shanxi Key Laboratory of Material Strength and Structural Impact, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China
[c] College of Mechanics, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China
[d] Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn, VIC 3122, Australia

ARTICLE INFO

Article history:
Received 25 July 2015
Received in revised form 27 September 2015
Accepted 30 September 2015
Available online 9 October 2015

Keywords:
A. Honeycomb
Sandwich structures
B. Plastic deformation
C. Finite element analysis (FEA)

ABSTRACT

This paper presents details and brief results of an experimental investigation on the response of metallic sandwich panels with stepwise graded aluminum honeycomb cores under blast loading. Based on the experiments, corresponding finite element simulations have been undertaken using the LS-DYNA software. It is observed that the core compression stage was coupled with the fluid–structure interaction stage, and the compression of the core layer decreased from the central to the peripheral zone. The blast resistance capability of sandwich panels was moderately sensitive to the core relative density and graded distribution. For the graded panels with relative density descending core arrangement, the core plastic energy dissipation and the transmitted force attenuation were larger than that of the ungraded ones under the same loading condition. The graded sandwich panels, especially for relative density descending core arrangement, would display a better blast resistance than the ungraded ones at a specific loading region.

1. Introduction

Sandwich panels have been increasingly exploited as blast resistant structures [1–6]. When they are subjected to impulsive loading, the core enables large compressive deformation and hence absorbs a large amount of impact energy, contributing to the superior blast resistance of the sandwich structure relative to monolithic counterpart with equivalent mass [3,4,7]. Dharmasena [3] and Deshpande and Uth [7] studied the dynamic mechanical response of honeycomb core sandwich structures by experiments and finite element simulations. The honeycomb sandwich structures significantly outperform monolithic structures of equal mass, resulting from the superior energy absorption capacity of core layer and the higher bending strength of the sandwich structure. However, Langdon et al. [8] studied the blast response of sandwich panels with PVC foam cores, and found that at a specific loading region the monolithic panels perform better than the sandwich panels with PVC foam core. It is attributed to the lower transverse stiffness of the individual components of the sandwich panel. Consequent's, considerably higher transverse velocity of the face sheet develops at the beginning of the process causing larger deflections and therefore larger in-plane stresses in the face sheet, despite the high energy absorbing capacity of the foam core. Hence, optimization between impact resistance and core configurations of sandwich panel design is one of the important issues [9]. Tilbrook et al. [10] used an analytical approach to define several regimes of behavior of sandwich beams. The FE calculations were also employed to construct design charts in order to select the optimum transverse core strength that either minimizes the back face deflections or the support reactions for a given sandwich beam aspect ratio or blast impulse. As expected, the optimal core strength also depends on the level of blast impulse and core strength [9,10]. A higher strength core will assure a better blast resistance performance. However, the force transmitted to the sandwich back face will be increased. In general, soft cores in front transmit less impulse to the support attached to the main structure [10,11]. Since the properties of layered graded core structures can be designed and controlled, they showed great potential to be an effective core material for absorbing the blast energy and improving the overall blast resistance of sandwich structures [12].

In recent years, stepwise graded materials, where the material properties vary gradually or layer-by-layer within the material itself, were utilized as a core material in sandwich composites

* Corresponding author at: Institute of Applied Mechanics and Biomedical Engineering, Taiyuan University of Technology, Taiyuan, Shanxi 030024, China. Tel.: +86 3516010560.

E-mail address: wangzh@tyut.edu.cn (Z. Wang).

http://dx.doi.org/10.1016/j.compositesa.2015.09.025
1359-835X/

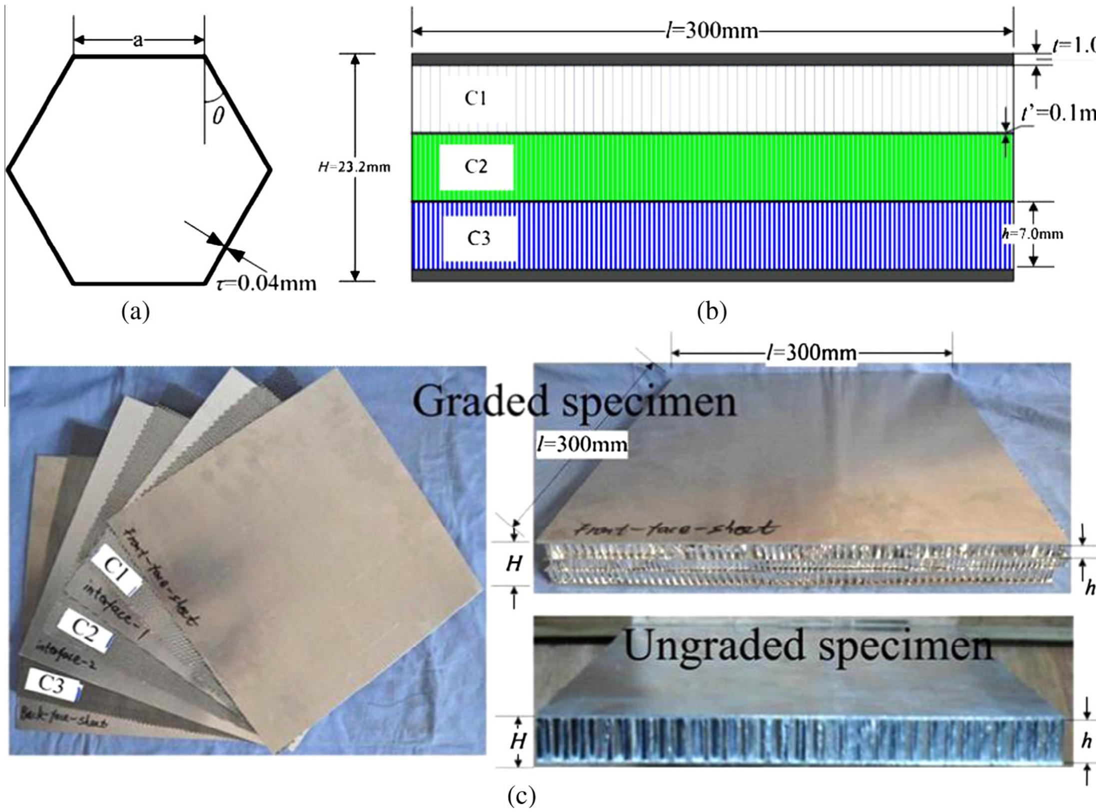

Fig. 1. Geometry and dimension of the specimen: (a) geometry and dimension of a single cell; (b) sketch map of the graded sandwich panel; (c) geometry and dimension of the graded and ungraded sandwich panels. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[12–19]. The failure modes of the sandwich structures mainly depend on their geometric parameters, and the graded core sandwich structures subjected to bending loads are optimally designed for minimum weight [20]. Due to the superior core compression and the wave dissipation characteristics of the graded core layers, the energy absorption ratio of core layers and the blast resistance of the sandwich structure can be improved [19,21,22]. Zhang et al. [11] analyzed the dynamic response of sandwich steel panels with three kinds of corrugated core arrangements consisting of identical core density, subjected to dynamic air pressure loading. It was found that the sandwich plate with relatively smoothly graded core outperforms the other two arrangements. Liu et al. [14] investigated the dynamic responses and blast resistance of all-metallic sandwich-walled panels with graded aluminum foam cores and compared them with those of conventional ungraded ones. When graded specimens and ungraded ones are subjected to identical air blast loadings, the blast resistance of the graded composites was better than that of the ungraded ones, and the relative density tapered configuration had advantage over the others. Li et al. [23] and Apetre et al. [24] numerically investigated the dynamic responses of metallic sandwich structures with functionally graded cores. The particular core design can exhibit better energy absorption and mitigate or completely prevent impact damage on the sandwich structures.

Although the graded sandwich components outperform the ungraded structures of equal mass, the relation between the density graded distribution of core layers and the blast resistance of sandwich panels is still not entirely understood. To investigate the behavior of blast loaded graded metallic sandwich panels, a large number of experiments have been conducted, and the experimental results were presented and discussed in detail in a separate paper [22]. Based on the experiments, in this paper corresponding finite element simulations are conducted using LS-DYNA software. After validating the FE model, the structural response process and the blast resistance of the structure under different TNT charge conditions are analyzed.

2. Experimental procedure and results

The experimental procedure and results are briefly presented in the following two sub-sections. The blast resistance of graded sandwich panels, which were constituted of aluminum alloy face sheets and triple layered graded honeycomb cores, were tested on a ballistic pendulum. And the experimental results were compared with conventional ungraded sandwich panels under the same loading condition.

2.1. Experimental procedure

The specimens used in the tests were divided into two groups: Graded group (consisting of two face sheets, two interface sheets and three layers of honeycomb cores), Ungraded group (consist of two face sheets and a core of honeycomb). The face-sheets and interface sheets were made from AA2024-O aluminum alloy. The aluminum honeycomb core was made from AA-5052-H32 aluminum alloys. A single regular honeycomb cell includes three critical geometric parameters, that is, cell side length (a), wall thickness ($\tau = 0.04$ mm) and the expanding angle ($\theta = 30°$), as indicated in Fig. 1(a); (b) and (c) shows the geometry and dimension of sandwich panels, in which the overall side length (l) and thickness of interface (t') are constant and equal to 300 mm and 0.1 mm, respectively. Three different cell side length a are adopted for the core layers: L ($a = 2.5$ mm), M ($a = 2.0$ mm) and S ($a = 1.5$ mm).