Composite Structures 195 (2018) 359–374

Contents lists available at ScienceDirect

Composite Structures

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

Rectangular sandwich plates with Miura-ori folded core under quasi-static loadings

X.M. Xiang[a], Z. You[b], G. Lu[a,*]

[a] Faculty of Science, Engineering and Technology, Swinburne University of Technology, Hawthorn, Vic 3122, Australia
[b] Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, UK

ARTICLE INFO

Keywords:
Sandwich plate
Miura-ori core
Three-point bending
Uniformly distributed pressure

ABSTRACT

This research presents a parametric study by using ABAQUS/Explicit and analytical analysis of rectangular sandwich plates with Miura-ori folded core. Two loading conditions are studied: three-point bending and uniformly distributed pressure loading. Load-displacement curves are obtained and energy absorption performance is assessed. Under three-point bending and uniformly distributed pressure loading of small magnitude, performance of such sandwich plates has been found to be better than that of corresponding monolithic plates of the same mass. In addition, analytical modelling has been conducted based on the plastic hinge theory, which results in a good agreement with those from the finite element analysis (FEA). It has been found that the maximum bending strength is governed by the incipience or fully plastic yielding of the core material for relatively thick cores, or elastic buckling of the core compression for thin cores. Furthermore, the yielding moment, fully plastic bending moment and elastic buckling moment of the incipience of core buckling have been evaluated.

1. Introduction

Sandwich structures are widely used in industries, such as aerospace, satellite, automotive, etc. due to their high energy absorption capacity and excellent bending strength with light weight. Different types of cores have been studied, including foam, truss, honeycomb and folded cores. Honeycombs are fully covered by the bonding faces of the sandwich panel, and hence water and vapours can get trapped inside the cells, which not only adds to the weight of the structure, but also increases the degradation of the mechanical performance. Discontinuous manufacturing process, vulnerability to impact loads and non-uniform failure mode during compressive loads are other disadvantages of honeycomb core [1]. Miura-ori, which is fabricated by folding the sheet along a pattern with straight and zigzag creases, may provide acoustic and heat insulation and act as energy absorbers [2]. Recently, 3D printing technology has been developed rapidly and it enables manufacturing of foldcores and trusses without imperfection [3]. The Miura origami pattern possesses some useful characteristics, such as developability, flat-foldability and rigid-foldability [4]. For military operation and disaster relief application, origami-inspired deployable shelters offer important advantages as they require a very small space in a folded form during transportation [5]. Compared with honeycomb core, air ventilation to avoid deterioration caused by long term moisture exposure is an additional advantage of foldcores.

Experimental and Finite Element Analysis (FEA) methods have been widely used to observe the mechanical behaviour of foldcores [6–9]. In the packaging and vehicle industries, sandwich structures are widely used as an energy absorber element and hence the energy absorption characteristic is an important performance. Recent studies on energy absorption of sandwich structures under quasi-static, low-velocity and high-velocity impact loads have revealed that a foldcore with high capacity is a suitable alternative for honeycomb cores [1,7,10–12]. Quasi-static, low velocity impact and high velocity impact on sandwich plates with foldcore were investigated experimentally and these experiments validated their corresponding modelling tests [13–15]. It is evident that FEA is suitable for the development of core geometries for specific requirements. FEA can not only be used for the complete characterisation of the mechanical behaviour under compression, tension or shear loading in both in-plane and out-of-plane directions, but also allows for a detailed investigation of cell wall deformation patterns and failure modes, which are otherwise difficult to observe through experiment [16]. Quasi-static compression and blast loading on sandwich plate with Miura-ori foldcore were investigated by means of FEA and a parametric study was conducted by altering the fold pattern [17]. It has been found that the compressive collapse strength of the stacked folded core is comparable to other bending dominated cellular materials, such as foams and honeycombs [17].

Large deformation of metal sandwich structures with foldcore under three-point bending and static pressure loadings has not been investigated

* Corresponding author.
E-mail address: glu@swin.edu.au (G. Lu).

https://doi.org/10.1016/j.compstruct.2018.04.084
Received 30 January 2018; Received in revised form 1 April 2018; Accepted 27 April 2018
Available online 30 April 2018

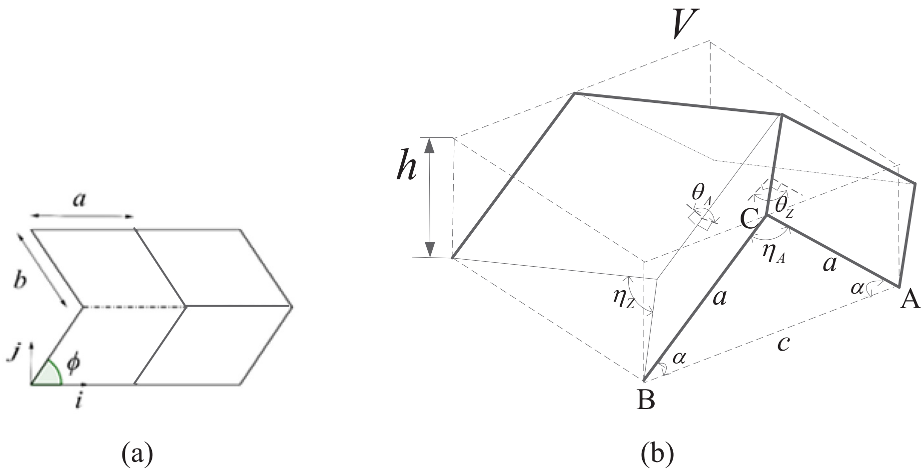

Fig. 1. Parameters of a Miura-ori core: (a) an unfolded Miura-ori unit cell; (b) dihedral and edge angles of a folded unit cell.

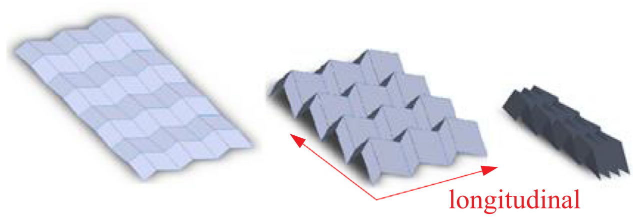

Fig. 2. Folding states of a Miura-ori core.

so far. Besides, an analytical study of this topic has not been presented. In this paper, a parametric study of sandwich plates with Miura-ori foldcore is first investigated. Quasi-static three-point bending and uniformly distributed pressure loading are investigated. The maximum bending strength and energy absorption are compared for sandwich plates with different parameters. The yielding moment, fully plastic bending moment and elastic buckling moment of the incipience of core buckling are analysed. The load capacity and energy absorption capacity of the sandwich plates are compared with those of the corresponding monolithic plates of the same mass.

2. Geometry of Miura-ori core

2.1. Parameters of a Miura-ori core

Miura-ori is fabricated by folding a sheet along a pattern with straight and zigzag creases. The unfolded unit cell consists of four identical parallelograms defined by four parameters, i.e., side lengths a, b and sector angle ϕ (Fig. 1(a)). Fig. 2 demonstrates the folding state of the Miura-ori pattern. This folding progress introduces four other parameters: two lateral dihedral angles θ_A and θ_Z; two edge angles η_A and η_Z (see Fig. 1(b)). m and n are the number of units in width and longitudinal directions (shown in Fig. 2), respectively.

2.2. Nominal density of a folded unit

Side lengths (a and b), sector angle (ϕ) and lateral dihedral angle (θ_A) (see Fig. 1) are defined as the input values, and the other parameters can be calculated by the following equations [10].

The lateral dihedral angles θ_Z is

$$\theta_Z = \arccos\left[\frac{(\cos\theta_A-1)(\cos2\phi-1)+4\cos\theta_A}{4-(\cos\theta_A-1)(\cos2\phi-1)}\right] \tag{1}$$

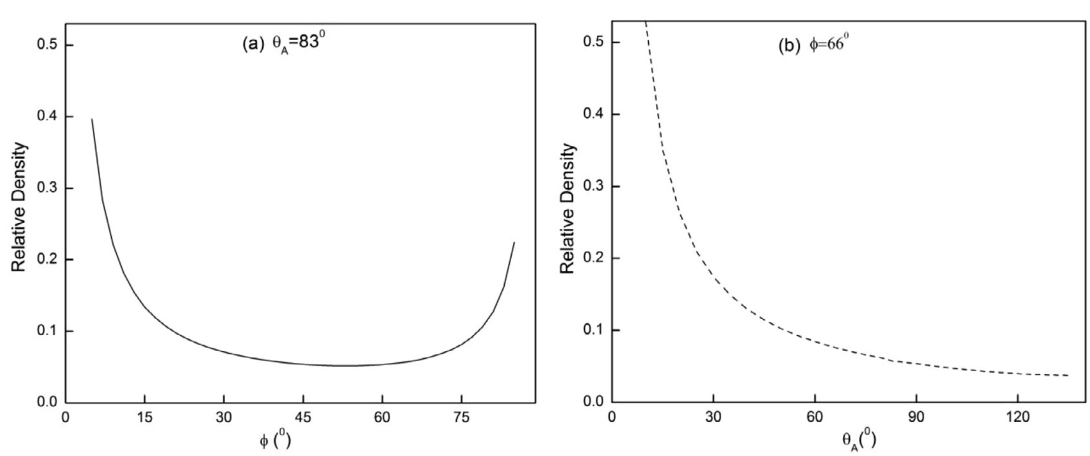

Fig. 3. Relative density of a Miura-ori core: (a) Density- ϕ and (b) Density- θ_A.