Measurement 53 (2014) 161–170

Contents lists available at ScienceDirect

Measurement

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

Identification and prediction of cyclic fatigue behaviour in sandwich panels

Wahid Boukharouba [a,b], Abderrezak Bezazi [b], Fabrizio Scarpa [c,*]

[a] Université Mohamed Seddik Ben Yahia, Jijel, Algeria
[b] Laboratoire de Mécanique Appliquée des Nouveaux Matériaux (LMANM), Université 8 Mai 1945, Guelma, Algeria
[c] Advanced Composites Centre for Innovation and Science (ACCIS), University of Bristol, BS8 1TR Bristol, UK

ARTICLE INFO

Article history:
Received 16 December 2013
Received in revised form 10 March 2014
Accepted 27 March 2014
Available online 3 April 2014

Keywords:
Sandwich panel
Fatigue
Three-point bending
Carbon fibre composite
Nomex honeycomb
Failure modes
Analytical modelling

ABSTRACT

The work describes the development of analytical model to identify and predict the cyclic fatigue behaviour of composite sandwich panels subjected to cyclic fatigue loading under 3-point bending conditions. Sandwich samples made from CFRP skin and Nomex core have been loaded with a mean displacement corresponding to 60% of the failure deformation, and subsequently subjected to cyclic loading under displacement control with different loading levels. The fatigue tests show that the stiffness degradation over the number of cycles is characterised by three different phases according to the loading level used. The evolution of the energy dissipated per unit volume versus the number of cycles has also been considered. The cyclic history of the stiffness degradation is developed here following an alternative approach to the one currently adopted. The approach involves the use of interpolation through empirical functions of the experimental data, with the coefficients of the interpolation based on the material properties of the sandwich structure and the type of loading. The alternative modelling approach presented in this work allows the prediction of the fatigue behaviour in sandwich structures without using a large number of test data currently needed in fatigue testing of sandwich panels.

1. Introduction

Composite sandwich structures are made from two face skins with high bending stiffness enclosing a lightweight core, the latter having a higher thickness than the skins [1–4]. The core can be made of balsa wood, closed-cell polymeric foam or honeycomb structures [5]. The laminated skins carry tensile and compression loading, while the core provides the transverse shear resistance and increases the area moment of inertia of the whole structure [6]. The main advantage of composite structures from a structural perspective is their high bending stiffness per unit weight [7]. Sandwich structures have also shown a remarkable resistance to environmental corrosion [8], thermal resistance and excellent energy absorption capabilities [9]. Sandwich structures have been therefore extensively used in various transport and industrial sectors, like automotive, aerospace and marine engineering [10]. The mechanical behaviour of sandwich structures has been extensively analysed during the last decades because of design issues involved in the fabrication and use of these particular composite structures [11,12]. However, the behaviour under mechanical fatigue and failure is still not completely understood. Mamalis et al. have evaluated a new hybrid sandwich structure from an experimental point of view, compounded by a numerical Finite Element (FE) analysis with models updated from the experimental tests [13]. Zhou et al., have evaluated different types of

* Corresponding author. Tel.: +44 1173315306.
E-mail addresses: w.boukharouba@gmail.com (W. Boukharouba), ar_bezazi@yahoo.com (A. Bezazi), f.scarpa@bristol.ac.uk (F. Scarpa).

http://dx.doi.org/10.1016/j.measurement.2014.03.041
0263-2241/

failure mechanisms exhibited by sandwich panels with different density subjected to three-point bending and various types of indenters (flat and semi-spherical) [5]. The modelling of the homogenised properties of honeycomb cores is of critical importance for the prediction of the global mechanical performance of sandwich structures. Bezazi et al. have performed analytical and FE analysis related to novel configurations of honeycomb structures to simulate the stiffness and in-plane Poisson's ratio under uniaxial tensile loading [14]. Balawi et al. have developed other mechanical and analytical models, which have been compared against experimental results from hexagonal honeycombs [15]. Galletti et al. have proposed a theoretical framework to design a sandwich honeycomb panel under pure bending loading [16]. Bezazi et al. have developed an analytical model to predict both the in-plane mechanical and thermal conductivity properties of a novel honeycomb configuration for multifunctional applications [17]. For what it concerns the behaviour of composite skins under 3-point bending fatigue loading, El Mahi et al. have evaluated new models dedicated to investigate the influence of the mechanical properties of laminates made from fibre glass or Kevlar reinforcement in epoxy matrix over the fatigue and damage behaviour [18]. From a phenomenological perspective, the fatigue behaviour of sandwich structures with honeycomb core can be evaluated looking at the global stiffness, residual stresses or other mechanical properties. Kanny et al. have evaluated the sensitivity of the mechanical fatigue behaviour in sandwich structures with PVC cores at different densities versus the excitation frequency [19]. The Authors have provided evidence that the variation of the stiffness (stiffness degradation) could constitute a suitable metric to quantify failure induced by fatigue loading in sandwich panels. Several research groups have also evaluated the stiffness degradation as an indicator of the cumulative damage in fatigue loading [20–24]. M.Z. Hassan et al. have also investigated the influence of the core density over the compression strength, bending resistance and shear strength of sandwich panels with foam core. The experimental data have been used to calibrate FE models for subsequent prediction [25]. Yi-Ming Jen et al. have considered the effect given by the amount of adhesive between skin and core in various fatigue experiments. The stiffness of sandwich panels under fatigue loading augments significantly when the amount of adhesive is increased [26]. Di Bella et al. have extensively evaluated the performance of sandwich structures in marine engineering applications under a variety of static loadings, and suggested different design solutions to improve the performance of sandwich panels under harsh environmental conditions [27].

The work described in this paper is related to the development of a measurement and predictive tool for quasi-static and cyclic fatigue behaviour of sandwich beams with honeycomb core subjected to three-point bending loading. The sandwich beams are made from carbon woven/epoxy prepreg face skins and Nomex honeycomb core. The stiffness degradation versus the number of cycles generated during the fatigue loading is used as a metric for the level of damage in the sandwich structures. Different types of failure modes have been recorded from the observation of the failure surfaces. A major novelty of this work is represented by the modelling approach to describe the complete evolution of the stiffness loss from only a reduced number of experimental load cases. The model is based on the use of empirical functions with the identification of interpolation coefficients. Only three loading levels r (0.6; 0.7 and 0.8) are required, while stiffness loss levels at intermediate r values are identified through interpolation. Further fatigue 3-point bending tests are carried out at other loading levels to validate the predictive model developed. This approach allows an efficient and cost-effective fatigue design model, because it reduces significantly the number of experimental loading levels r required for the identification.

2. Materials and experimental techniques

2.1. Materials

The sandwich panels are manufactured using components sourced from Hexcel Composites Ltd. (UK). The geometry of the specimen is detailed in Table 1. The two skins (0.50 mm of thickness each) are made from epoxy matrix reinforced by carbon woven (twill 3K 2 × 2). The core is composed by hexagonal cells in aramid paper (Hexcel, Fig. 1) with a density of 64 kg/m^{3}and cell size of 3.175 mm. The geometry and mechanical properties of the sandwich beams are illustrated in Tables 2 and 3 [28].

Table 1
Specimens dimensions [19].

L (mm)	b (mm)	h (mm)	H_C (mm)	t_f (mm)	l (mm)
200	25	10.525	9.525	0.5	150

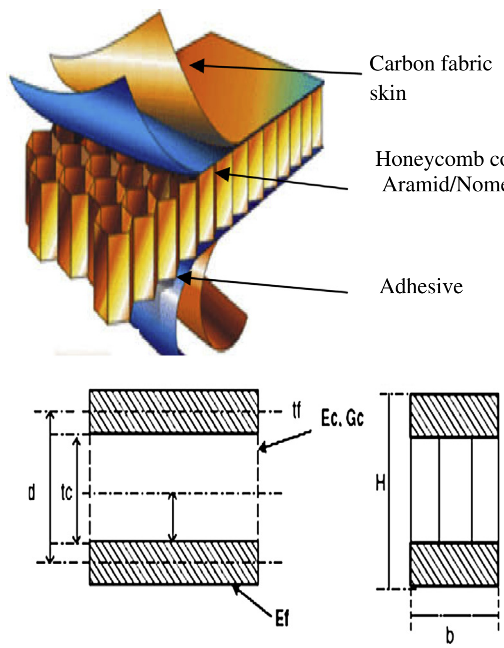

Fig. 1. Geometric configuration of a sandwich panel [7].