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Loading Rate Effect on Flexural and Indentation Behaviour of Foam Core Composite Sandwich Panel

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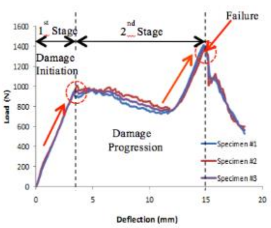
Graphical abstract



Abstract

The present study focuses on the flexural and the indentation behaviour of foam core sandwich panel subject to three point bending and indentation loading at different loading rates. The load-deflection, stress-deflection responses and energy absorption properties of foam core sandwich panel are determined experimentally. The foam core sandwich panel was fabricated using vacuum infusion process. The sandwich structure consists of chopped strand mat fibreglass skins and polyurethane foam core. The flexural and the indentation tests were conducted using Instron Universal Testing machine. It was found that loading rate influences the flexural and the indentation behaviours of foam core sandwich panel. By increasing the loading rate, the stiffness, strength and energy absorption of flexural and indentation of these structures were increased.

Keywords: Loading rate; flexural; indentation; energy absorption; sandwich panel

1.0 INTRODUCTION

Composite sandwich structures consist of two facesheets and a thick core material. When these structures are subjected to transverse loads, the applied moment components are carried by the facesheets and shear load components are carried by the core. Isotropic metallic materials such as aluminium, zinc, steel or composite materials such as glass/epoxy, glass/polyester and carbon/epoxy can be used as face sheets. Lightweight honeycomb, balsa and polyurethane foam are usually used as core materials to reduce weight and increase flexural stiffness of the composite sandwich structure.

The physical and mechanical analyses of these structures subject to different types of loading are challenging. Analytical and experimental investigation of foam core composite sandwich panel under different kinds of loading such as tensile, compression, bending and impact have been carried out [1-4]. For example, the flexural behaviour of aluminium composite sandwich panel subject to three point bending at different loading rates and support spans were studied by Abdi *et al*. [5]. From the study, it was shown that strain rate has an effect on the flexural behaviour of aluminium composite panel. The behavior of glass/epoxy foam-core composite sandwich under static and fatigue was studied by Chemami *et al*. [6]. They reported that the fracture surfaces revealed the different modes of damage causing the material to fracture. Bîrsan *et al*. [7], analysed three-point bending of sandwich composite beams using a direct approach. They derived general formulae for the effective stiffness coefficients of composite elastic beam to compare with experimental measurements.

Earlier studies mainly focused on the behaviour of composite sandwich panel subjected to subject different kinds of loading and different types of sandwich panel. There were no results reported on the loading rate effect on flexural and indentation response of foam core sandwich panels. Therefore, the aim of this study is to investigate the loading rate effect on the flexural and the indentation behaviour of foam core sandwich panel subject to three point bending and indentation. Load-deflection, stress-deflection and energy absorption were determined at different loading rates and the results were then analysed.

2.0 EXPERIMENTAL MATERIALS AND METHODS

2.1 Foam Core

The sandwich panel is made up of 0.33mm-thick glass fibre/polyester facesheets and 11.5mm thick polyurethane foam core with a density of 139.13kg/m^3. The facesheets are made of three layers of chopped strand mat glass fibre (600gm) and polyester resin by using vacuum infusion process. The structural constituents of foam and facesheets were fabricated and then tested individually. Polyurethane foam specimens with dimensions 50mm × 50mm × 11.5mm were prepared according to ASTM Standard [8] and subjected to flatwise compression loading at a loading rate of 1mm/min. Figure 1 shows the compressive load- contraction response of polyurethane foam.

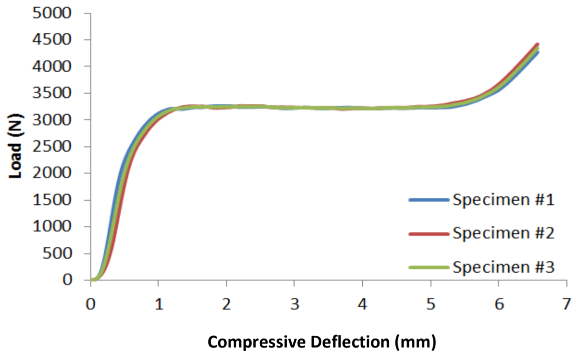


Figure 1 The load-contraction responses of polyurethane foam core subject to flatwise compression loading

2.2 Facesheet

To determine the mechanical properties of chopped strand mat glass fibre/polyester facesheet material, dogbone specimens with dimensions 15 mm width and 100 mm gauge length were prepared and tensile tests were carried out at a constant loading rate of 1mm/min. The strains were measured by an extensometer. Stress-strain curves were then plotted, as shown in Figure 2. The mechanical properties of the facesheet material that are extracted from Figure 2 are Young's modulus E, Poisson's ratio v, failure stress σ_F, and failure strain ε_F and are listed in Table 1.

Table 1 Mechanical properties of chopped strand mat glass fibre/polyester composite facesheets

E (GPa)	v	σ_F (MPa)	ε_F
15.75	0.22	154.1	0.0136

2.3 Manufacturing Process

The sandwich panels were fabricated using resin vacuum infusion process. The dry glass fibres and foam core were laid up. Vacuum pressure was applied over the layup and bubble-free resin was driven into the dry laminate through a tubing system. The schematic of the vacuum infusion process for fabrication of the sandwich panels is shown in Figure 3.

A total of 24 specimens were prepared to investigate the flexural and indentation behaviour. Specimens with dimension of 240mm × 30mm and 100mm × 100 mm were prepared for the three point bending and indentation tests, respectively. The details of the specimens are listed in Table 2.

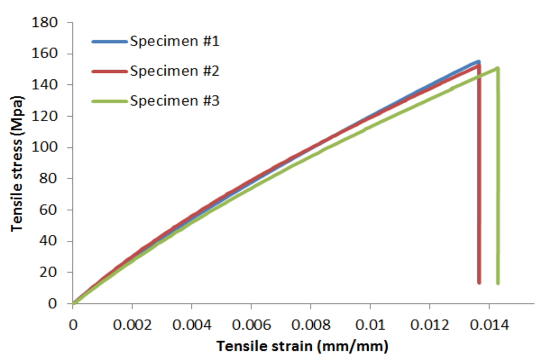


Figure 2 Tensile stress-strain curves of chopped strand mat glass fibre/polyester facesheet material specimens

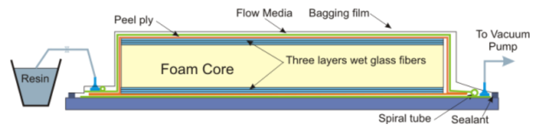


Figure 3 The schematic of vacuum infusion process for foam core sandwich panel

Table 2 Details of the specimens for flexural and indentation tests

Type of sandwich test	Number of specimens	Total thickness (mm)	Total weight (g)
Flexural	12	13.5±0.2	71±1
Indentation	12	13.5±0.2	49±1

2.4 Flexural And Indentation Tests

The flexural and indentation tests of the sandwich panels were carried out using a 100kN Instron Universal Testing Machine at loading rates of 1 mm/min, 10 mm/min, 100 mm/min and 500 mm/min. The hemispherical-nosed indenter is made of steel with diameter 12.5 mm. A square frame with dimensions of 100 mm×100 mm was used to support the specimen for indentation tests. The support span of 180 mm was used for flexural test in accordance with ASTM standard D790-10 [9]. All tests were repeated three times. The average results were used for further analysis. The flexural and indentation tests of the sandwich panels are shown in Figures 4 and 5.

3.0 RESULTS AND DISCUSSIONS

3.1 Load-Displacement Behaviour

Figures 6 and 7 respectively show the stress-deflection response and force-displacement of foam core sandwich panels subjected to flexural and indentation loadings. At a constant loading rate of 10mm/min. In both tests the variation in ultimate load and displacement at failure load is less than 3%. The failure stress was calculated by using Equation 3.1. Form Figure 7 shows that two peak happened in the indentation test. The first peak declared as first failure load, where the indenter penetrated the top facesheet and the second peak was the ultimate load when the the indenter fully penetrated the foam core sandwich panel.

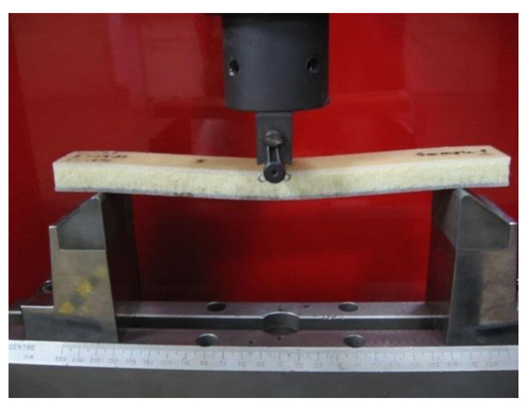


Figure 4 Flexural test of foam core composite sandwich panel

Figure 5 Indentation test of foam core composite sandwich panel

$$\sigma_f = \frac{1.5 \times F \times L}{b \times d^2} \quad (1)$$

where:

σ_f = Stress in outer fibres at midspan, (MPa)
F = load failure, (N)
L = Support span, (mm)
b = Width of test beam, (mm)
d = Depth of tested beam, (mm)

In indentation test, the behaviour of foam core composite sandwich panel is divided into three stages. The first is penetration through top facesheet as indicated by linear line. At the top of this straight line the facesheet was damaged due to matrix cracking, fibre delamination and also debonding between top facesheets and core. The second stage is penetration through foam core. Because the foam is much weaker than facesheet the force drops in the foam core and cause debonding between top facesheets and the core became larger and causes a core crushing that leads to be core cracking. Here, the core started to damage and debonding between bottom facesheets and core appeared. The third stage is the linear line againas the indenter is penetrating the bottom facesheet. At the top of this line the indenter has passed through the bottom facesheet. Large fibre breakage happened at the bottom facesheets and also fibre delamination at the bottom facesheets is greater than top facesheets. This is where the failure of the foam core sandwich panel happened.

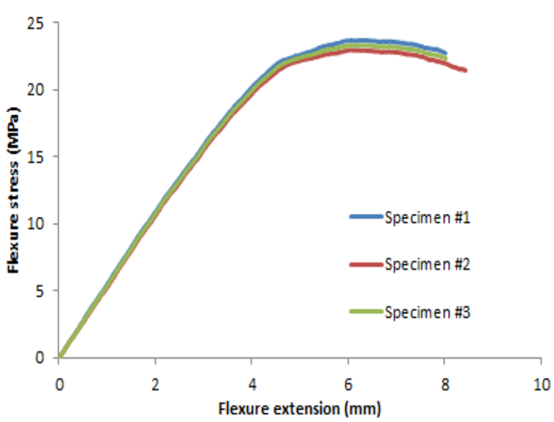


Figure 6 The stress-deflection response of foam core sandwich panel subject to flexural test at loading rate of 10mm/min

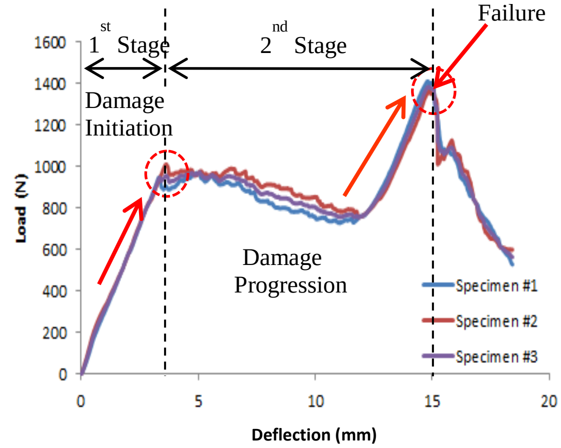


Figure 7 The load-deflection response of foam core sandwich panel subject to indentation loading at loading rate of 10mm/min

3.2 Loading Rate Effect

In this study, the quasi-static flexural and the indentation behaviours of foam core composite sandwich panel subject to flexural and indentation test were determined and followed by the effect of the loading rate. The flexural behaviours of the composite panel subjected to flexural at loading rate of 1 mm/min, 10 mm/min, 100 mm/min and 500 mm/min are shown in Figures 8.

Figure 8 shows that the flexural properties of the sandwich panel were increased with loading rate. The properties are stiffness, ultimate strength and displacement at failure. For loading rate from 1 mm/min to 10 mm/min, the ultimate flexural stress was increased by 5.6% and the flexural deflection was decreased by up to 10%. By increasing the loading rate from 10 mm/min to 100 mm/min, the ultimate flexural stress and the deflection were increased by around 11.9% and 10%, respectively. By increasing the loading rate from 100 mm/min to 500 mm/min, the ultimate flexural stress and the deflection were increased by 3.4% and 12.5%, respectively. Therefore, it can be seen that the dynamic loading influenced the flexural properties of foam core sandwich panel. A similar study was carried out on aluminium mineral filled core sandwich plates [5] and the results are very similar to the present ones. At low loading rates, the core started to fail earlier than facesheets.

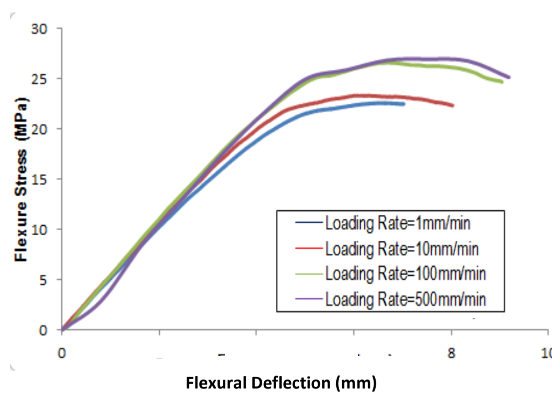


Figure 8 Flexural stress behaviour of foam core composite sandwich panel subject to three point bending test at different loading rates

The effect of loading rate on load-deflection behaviours and properties, and energy absorption properties of foam core composite sandwich panel subject to indentation loading were studied and the results are shown in Figures 9 and 10. The energy absorption was determined by using Equation 2. It can be seen that the rate of loading has an effect on the load-deflection behaviour of the structure. The first failure load occurs on the top facesheet where the indenter penetrated the facesheet and matrix cracking, fibre delamination and also interface debonding happened. Increasing the loading rate from 1 mm/min to 10 mm/min, the first failure load was increased by 2.4% and the deflection decreased by 34%. By increasing the loading rate from 10 mm/min to 100 mm/min, the first failure load and the deflection were increased by 26.5% and 11.9% respectively. By increasing the loading rate from 100 mm/min to 500 mm/min, the first failure load and the deflection were increased by 7.3% and 3.2%, respectively. The ultimate load was defined as the indenter fully penetrated the foam core sandwich panel. By increasing the loading rate from 1 mm/min to 10 mm/min, the ultimate load and the deflection were increased by 27.8 % and 8.9% respectively. By increasing the loading rate from 10 mm/min to 100 mm/min the ultimate load increased by around 2.1% and the deflection decreased by 1.1%. By increasing the loading rate from 100 mm/min to 500 mm/min, the ultimate load and deflection was increased by 6.8% and 2.4% respectively.

$$E = \int_{\delta_0}^{\delta} F(\delta)\, d\delta \qquad (2)$$

where:

E = energy at displacement δ (N-mm).

δ = indenter displacement during the test (mm).

δ_0 = indenter displacement at initial specimen contact (mm).

F = measured contact force at indentor displacement δ (N).

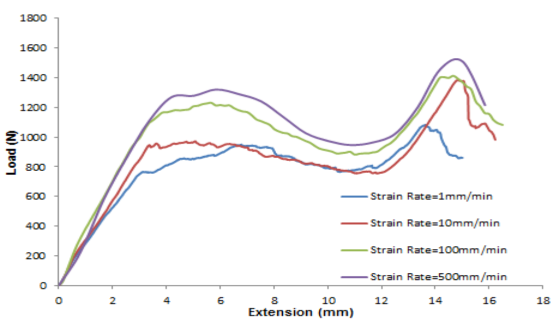


Figure 9 Load-deflection behaviour of foam core composite sandwich panel subject to indentation test at different loading rates

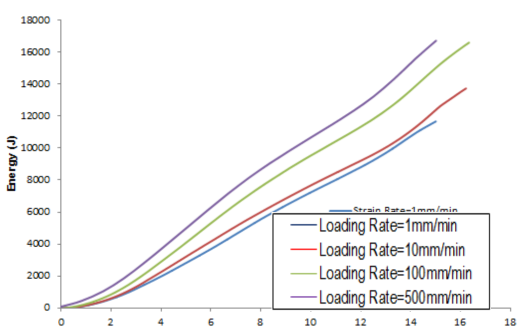


Figure 10 Total energy absorption behaviour of foam core composite sandwich panel subject to indentation test at different loading rates

It can be seen from Figure 10, by increasing the loading rate, the total energy absorption behaviour of foam core composite sandwich panel was increased. By increasing the loading rate from 1 mm/min to 10 mm/min, the energy absorption and the deflection were increased by 17.7% and 8.2%, respectively. Increasing the loading rate from 10 mm/min to 100 mm/min, the energy absorption and the deflection were increased up to by 20.9% and 1.7% respectively. Increasing the loading rate from 100 mm/min to 500 mm/min, the energy absorption increased by 0.7% while the deflection decreased by 4.1%. Finally, increasing the loading rate from 1 mm/min to 500 mm/min, the maximum energy absorption and the deflection has risen up by 43.3% and 5.6%, respectively. It shows that the loading rate enhance the energy absorption.

4.0 CONCLUSIONS

In this study, foam core composite sandwich panel with polyurethane core subject to flexural loading and indentation was studied experimentally. It was found that loading rate influence flexural and indentation behavior of foam core sandwich panel. By increasing the loading rate in both flexural and indentation loadings the stiffness and ultimate strength of these structures were increased and the panel showed initial damage at earlier deflections. This feature of foam core sandwich panel should be taken into account in the design and optimization of these structures subject to flexural and indentation loadings.

Acknowledgement

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Deflection (mm)