

# INDENTATION BEHAVIOUR CHARACTERISTICS CAUSED BY DOMINANT PARAMETERS IN POLYMERIC SANDWICH PANELS

Gang Zhou\*<sup>1</sup>, Qingchun Jiang<sup>1</sup> and Yiou Shen<sup>2</sup>

<sup>1</sup> Department of Aeronautical and Automotive Engineering, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK, \* Corresponding author ([G.Zhou@Lboro.ac.uk](mailto:G.Zhou@Lboro.ac.uk))

<sup>2</sup> School of Aeronautics and Astronautics, Tongji University, Shanghai, China

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## ABSTRACT

### 1 INTRODUCTION

Sandwich panels are vulnerable to local loads presented by low-velocity impact and they could be damaged, if the level of the local impact loads reaches critical. The initial responses of the sandwich panels up to incipient damage are dictated by the local interaction between the impactor and the sandwich panel. Since such local interaction, so-called indentation behaviour, is coupled with the bending of the panels, its specific contribution to the occurrence of the incipient damage has not been looked at in earnest. The indentation behaviour characteristics in the sandwich panels are much more complex than that of the monolithic laminates, as they depend not only on the local interaction of dominant parameters being varied individually but are also on the coupled effects. This is why it is necessary to isolate the indentation behaviour from the bending responses. The earlier related research [1] identified the indenter diameter, skin thickness and core density as three dominant parameters and investigated the effects of the first two on the indentation behaviour characteristics under rigid support. This work extends it significantly with the focus on the effects of varying core density on the indentation behaviour characteristics of the sandwich panels.

### 2 SANDWICH MATERIALS AND PANEL MANUFACTURING

Sandwich panels were constructed with laminate skins and an aluminium honeycomb core. The skin laminates were made of unidirectional 34-700/LTM45 carbon/epoxy prepreg with a nominal ply thickness of 0.128 mm in a cross ply (CP) or quasi-isotropic (QI) lay-up. They were laid up in the 300×300 mm panels and cured in an autoclave at 60<sup>o</sup>C under a pressure of 0.62 MPa for 18 hours. The honeycomb core with a depth of 12.7 mm had a density of 70 and 110 kg/m<sup>3</sup> with a constant cell size of 4.7625 mm. Adhesive VTA260 with built-in nylon mesh was used for skin-core bonding. Both skins were bonded individually to the core in an oven at 60<sup>o</sup>C for 6 hours under a pressure of 0.1 MPa. The panels with 8-ply skins are called 'thin' panels and the ones with 16-ply skins are called 'thick' panels. The nominal size of each specimen was 100×100 mm.

### 3 EXPERIMENTAL SET-UP AND QUASI-STATIC INDENTATION TESTS

Three hemispherical indenters used had a diameter of ranging 8 mm to 20 mm with an increment of 6 mm. An indentation specimen was placed on a rigid support and finger-tightened with a metal frame of 80 mm circular central opening, as shown in Fig. 1. A universal testing machine was used at a load rate of 2 mm/min with the loader displacement providing an indentation measurement. A trial and error had to be exercised to establish an initial unknown critical load when an incipient damage occurred in each test group and the tests were stopped once the incipient damage was judged to have occurred. A total of 34 tests were conducted in twelve groups, with all but two having three tests per group. All the tested panels were diametrically cut up in both the 0<sup>o</sup> and 9<sup>o</sup> directions with one quarter of the specimen being reserved as shown in photographs in Figs 2 and 3 for a microscopic examination of damage mechanisms.

### 4 DISCUSSION OF TEST RESULTS

**4.1 Mechanism of incipient damage**

The distal skins in all the tested sandwich panels did not make any contribution to the indentation behaviour under rigid support and hence incipient damage was expected of the loaded skin and core right under the indenter where the normal stresses and interlaminar shear stresses in the loaded skin were highest, just like in the earlier investigation [1]. Thus, in all the tested specimens, the nature of the incipient damage was found to be combined delamination in the skin and crushed core, as shown in Figs 2 and 3. Although this nature of the damage mechanism was the same for all the tested specimens in all the groups, the through-the-thickness locations of the delaminated interfaces varied slightly, dependent on skin thickness, core density and indenter diameter. Multiple delaminations were observed in some cases when a substantial loading beyond the incipient damage was permitted.

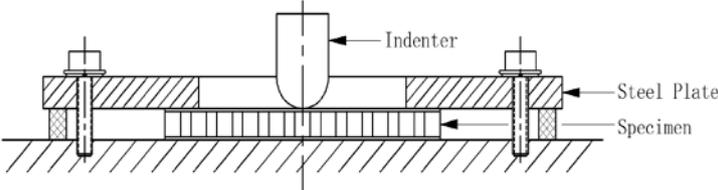


Fig. 1 An indentation test set-up for a sandwich panel under rigid support

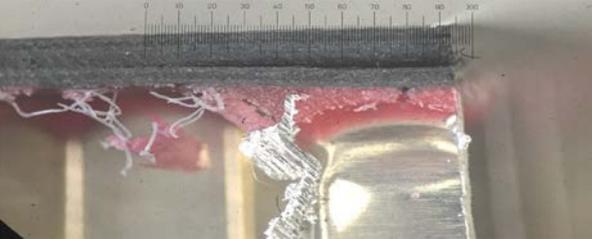


Fig. 2 A cut-up thin sandwich specimen

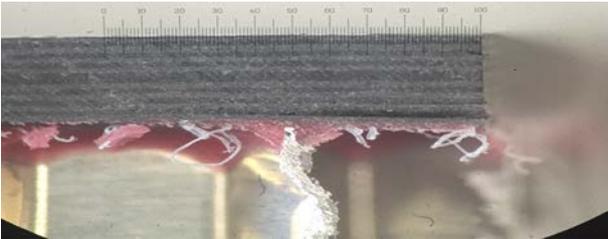


Fig. 3 A cut-up thick sandwich specimen

**4.2 Effects of core density on incipient damage**

The critical loads corresponding to the occurrence of the incipient damage were used to evaluate the coupled effects of varying the core density, skin thickness and indenter diameter on the damage characteristics, as shown in Figs 4-6. For the thin panels shown in Fig. 4, the 57% increase in core density had little effect on the critical load when 8-mm diameter indenter was used. However, once the diameter of indenter was increased up to 14 mm and 20 mm, the effects of increasing the core density are clearly shown with the steady increase of the critical loads by 36% and 51%, respectively. This is because the 1-mm thick skin had the limited shielding protection over the core and the core density of 70 kg/m<sup>3</sup> offered little normal resistance so that the indentation was much localised.

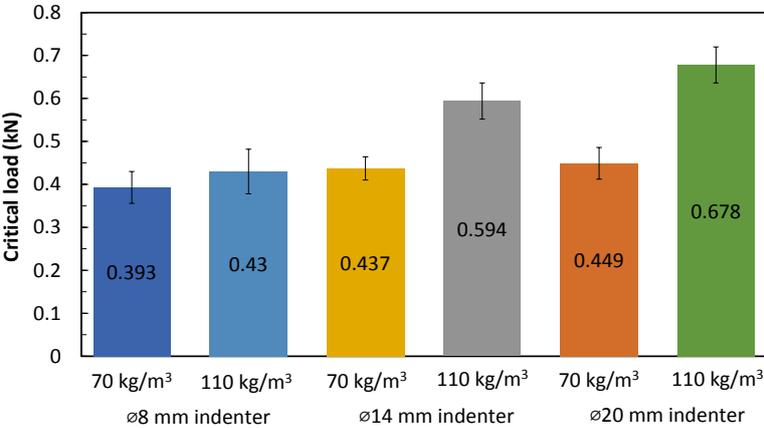


Fig. 4 Effects of indenter diameter and core density in thin sandwich panels

For the thick panels whose results are shown in Fig. 5, the 2-mm thick skin had the substantial shielding over the core. For the relatively larger indenters (14 mm and 20 mm diameter), the variation of either core density or indenter diameter had the only marginal effect on the critical loads so that the indentation behaviour was much less sensitive to their respective variations under these circumstances.

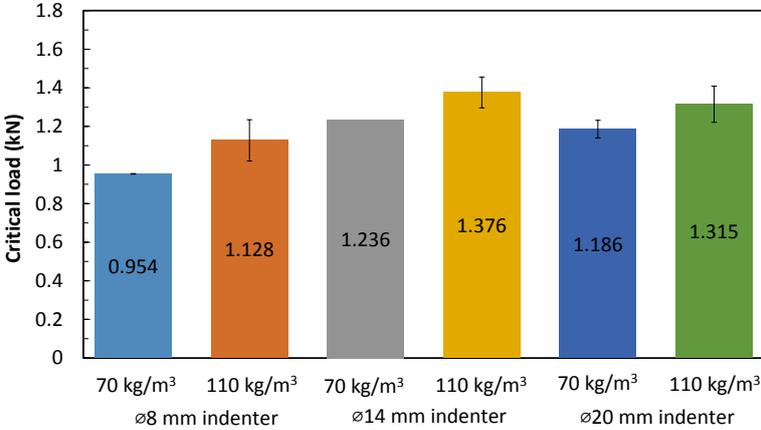


Fig. 5 Effects of indenter diameter and core density in thick sandwich panels

From Fig. 6, a couple of interesting features could be observed. Firstly, the critical loads appear to be exponentially proportional to the increase in skin thickness, irrespective of core density or indenter diameter. Secondly, the effect of increasing the core density on the critical loads was greater for the thin panels than for the thick ones, when the indenter diameter was either 14 mm or 20 mm. Finally, the effect of increasing the indenter diameter on the critical loads was initially observable only from the indenter of 8 mm to 14 mm. However, from 14 mm to 20 mm, there appears to show little change. What this suggests is that this marginal overall effect of varying the indenter diameter on the critical loads can be speculated due to that the actual contact areas associated with the indenter of 8 mm diameter could be less than the extent of two honeycomb cells so that there was some uncertainty.

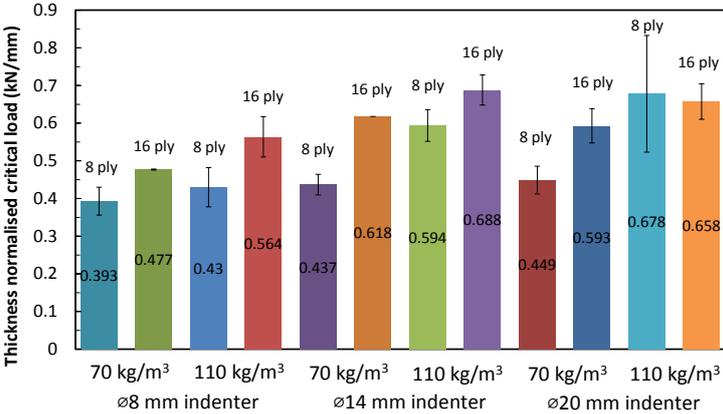


Fig. 6 Net effects of indenter diameter and core density in all sandwich panels

**5 CLOSING REMARKS**

The effects of varying the dominant parameters in the indentation behaviour on the critical loads are coupled. The variation of the core density affected significantly the indentation behaviour.

**REFERENCES**

[1] G. Zhou, B. Zhang and A. Pasricha, A study of indentation behaviour of sandwich panels supported rigidly, *Int. J. of Structural Integrity*, in press, 2017.