12th International Conference on Sandwich Structures (ICSS-12) Lausanne - Switzerland, 19–22 August 2018
DOI: 10.5075/epfl-ICSS12-2018-89-91

IMPACT AND POST-IMPACT FLEXURAL BEHAVIOR OF COMPOSITE SANDWICH STRUCTURES IN EXTREME LOW TEMPERATURE ARCTIC CONDITIONS

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1. INTRODUCTION

The reduction in arctic sea ice region over the last three decades has opened new sailing routes which are more efficient and economical. This has resulted in the increased use of marine and naval vessels in extreme low temperature arctic conditions. The fundamental challenge of operating in such cold and harsh environment lies in the understanding of how materials and structures behave and perform in extreme low temperature. In recent years, structural sandwich composites have been widely used in many applications such as aircraft structures, ship hulls, wind turbine blades and bridge decks. This is due to their superior bending stiffness, low weight, excellent thermal insulation and acoustic damping properties. They are commonly used in many engineering fields because they are more superior over the conventional structural construction materials such as having high bending stiffness and good weight saving. The behavior of sandwich beams depends on the properties of the core material, especially under impact loading. They typically consist of two thin, stiff, and strong faces which are separated by a thick, light, and shear-resistant core. However, one of the major concerns in the use of sandwich composites such as in the conventional polymer matrix composites is the impact-induced damages which may occur during normal maintenance operations or during service conditions. Even a relatively minor impact could drastically reduce the residual-strength of the material. In this study, we experimentally investigate the impact response and post-impact flexural behaviour of Divinycell H-100 foam core sandwich panel with woven carbon fiber reinforced polymer (CFRP) facesheets in low temperature arctic conditions.

2. EXPERIMENTAL METHODOLOGY

Materials

The composite sandwich structure specimens have face sheets made of 0°/90° woven carbon fiber epoxy matrix composite. The sandwich core is PVC Divinycell H-100 foam core. The facesheets are either 0.01 inch or 0.03 inch thick, while the foam core is 0.25 inch thick. Individual composite panels were cut into 6 inch x 4 inch specimen size for impact test. The impacted specimens were further cut into 6 inch x 1 inch bending specimen for three point bending test.

Impact Tests

Impact tests were conducted using Instron CEAST 9350 drop tower with an environmental chamber. The samples were impacted across three different temperatures: 23°C (baseline room temperature); -30°C (arctic average temperature); -70°C (arctic coldest temperature). Drop height of the striker was adjusted to control the impact energy level. Each sample type was impacted at two different energy levels at 4 J and 8 J. Impact response data was collected using DAS64K system, in terms of force, time, deflection, velocity and energy.

Bending Tests

Three point bending tests were conducted to evaluate the residual strength and stiffness of the samples. Test procedure was in accordance to ASTM C 393 with a crosshead speed of 0.5 mm/min and a span of 100mm. Samples were flexural tested at room temperature, -30°C and -70°C, at the same respective temperatures as they were impacted.

3. RESULTS AND DISCUSSION

Results show that exposure to low temperature generally causes more severe damage in the specimens. Post-mortem inspection using x-ray micro-computed tomography revealed complex failure mechanisms in the composite facesheets (such as matrix crack, delamination and fiber breakage) and foam core (core crushing, core shearing and interfacial debonding).

Impacted specimens were then subjected to three point bending test to examine their residual flexural properties. Bending characteristics were analysed on both sides of the specimens (front impact face and back distal face), as depicted in Fig. 1. Bending test data suggests that residual flexural properties after impact are more sensitive to the in-plane compressive property of the CFRP facesheet than the in-plane tensile property, as shown in Fig. 2. Results also indicate that degradation of flexural rigidity of the sandwich composite panel strong depends on existing damage state of prior impact test. Analogous to impact behavior, specimens have much reduced flexural properties when exposed to extreme low temperature conditions (-70°C).

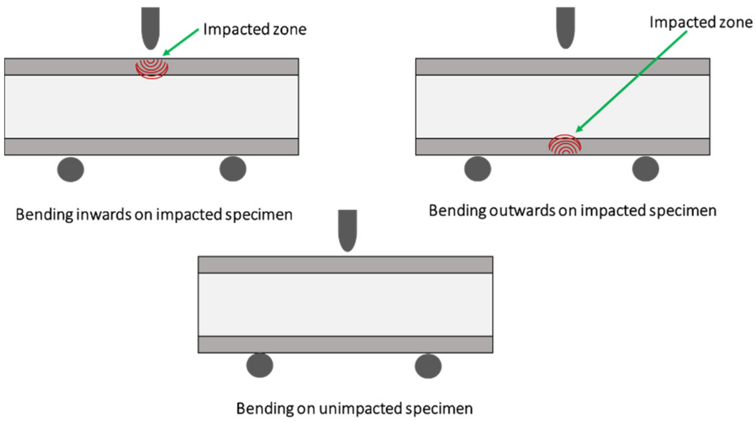

Fig. 1: Schematic view of three point bending test configuration.

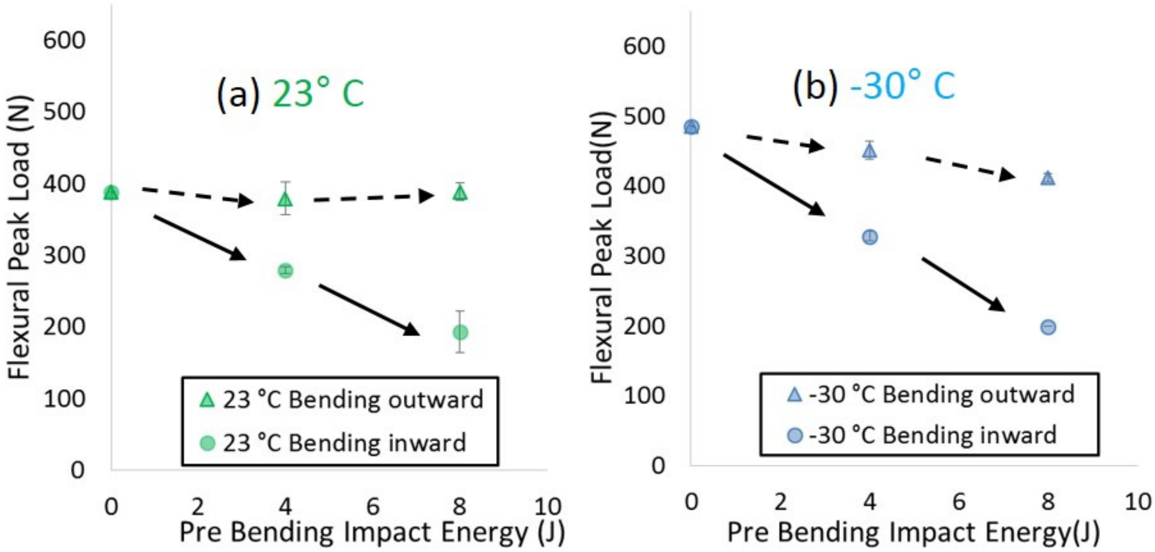

Fig. 2: Flexural load against impact energy plots (a) 23°C; (b) 30°C.

Experimental results obtained in this work are further compared and validated with analytical models that can predict the competing collapse mechanisms for simply support sandwich beams with composite faces and PVC foam core subjected to three point bending [1-2]. Figure 3 shows the peak load prediction based on different failure mechanisms. For the specimens tested in this study, they failed by indentation. Experimental data (shown in markers) are plotted to compare with analytical prediction (linear lines). It is clear that there is good agreement with both experimental and analytical results. The predicted collapse loads for face yielding or microbuckling; core shear failure; face wrinkling and indentation are examined with the physical-based mechanisms obtained in experiments. The analytical models aim to reveal knowledge on the coupling effect of low temperature with damage mechanisms.

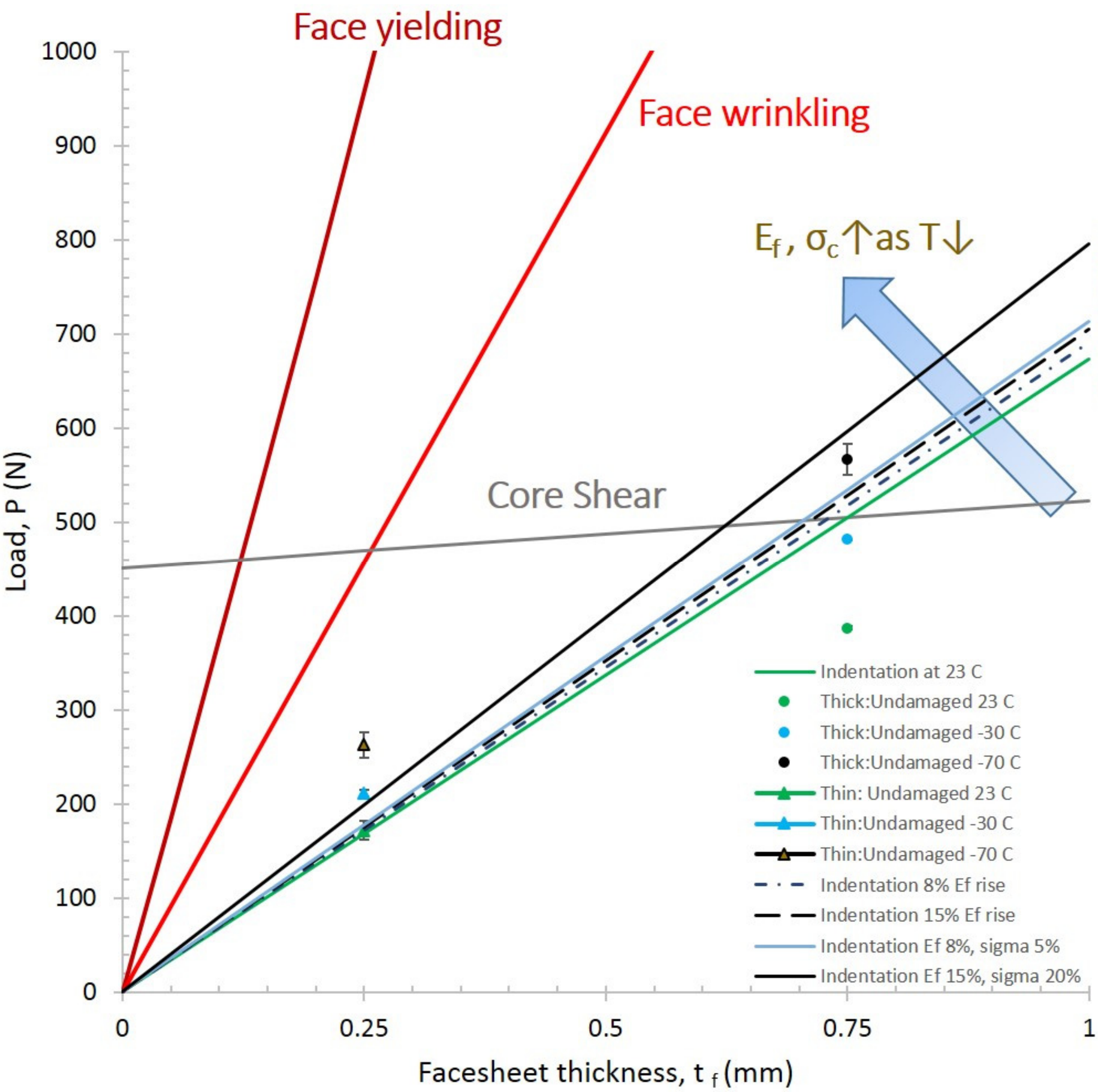

Fig. 3: Flexural load prediction based on analytical models and validation with experimental results.

4. CONCLUSIONS

The findings from this work will lead to better understanding of the dynamic response and failure of composite sandwich structures at extreme low temperature conditions, which will subsequently lead to improved design for naval structures and materials that can operate safely and effectively in arctic environment.

ACKNOWLEDGEMENTS

The authors acknowledge the research grant N00014-16-1-3202 provided by the U.S. Office of Naval Research (ONR Program Manager: Dr. Yapa Rajapakse).

REFERENCES

[1] C.A. Steeves et al., “Collapse mechanisms of sandwich beams with composite faces and a foam core, loading in three-point bending. Part I: analytical models and minimum weight design”, *Int. J. Mech. Sci.*, 2004; 46: 561-583.

[2] C.A. Steeves et al., “Collapse mechanisms of sandwich beams with composite faces and a foam core, loading in three-point bending. Part II: experimental investigation and numerical modelling”, *Int. J. Mech. Sci.*, 2004; 46: 585-608.