# EFFECT OF LOW TEMPERATURE ON THE POST-IMPACT COMPRESSION RESPONSE OF COMPOSITE SANDWICH STRUCTURES

Mohammed Elamin[1], Bing Li[2] and K.T. Tan[3]

[1] Department of Mechanical Engineering, The University of Akron, Akron OH 44325-3903, USA
Email: me61@zips.uakron.edu, Web Page: https://metacomposites.uakron.edu/
[2] Department of Mechanical Engineering, The University of Akron, Akron OH 44325-3903, USA
Email: bingli@uakron.edu, Web Page: https://metacomposites.uakron.edu/
[3] Department of Mechanical Engineering, The University of Akron, Akron OH 44325-3903, USA
Email: ktan@uakron.edu, Web Page: https://metacomposites.uakron.edu/

**Keywords:** sandwich structures, impact behavior, compression-after-impact, low temperature

## Abstract

In this study, the effect of extreme low temperatures on the compression after impact (CAI) behavior of Polyvinyl chloride (PVC) foam core composite sandwich structures is studied. Utilizing Instron CEAST 9350 impact machine, composite sandwich specimens are subjected to low-velocity impact tests at different temperatures (23°C, 0°C, -30°C, -70°C), and impact energy levels (5J and 10J). Subsequently, at the same range of temperatures, the CAI behavior of impacted and non-impacted samples are investigated using Instron 5582 universal testing machine. Results from CAI tests show that low temperatures significantly reduced the compressive strength of the impacted structures. Particularly, at -70 °C, impacted specimens experienced severe and complex damages; leading to huge reduction in compressive stiffness, due to the expanded damage region. The stiffness of non-impacted sample is, however, increased with decreasing test temperature. This research evidently shows that the CAI strength of composite sandwich structure is reduced in arctic conditions and the susceptibility of global structural failure is ultimately higher.

## 1. Introduction

The use of composite sandwich structures in the engineering fields has been significantly increased due to their excellent specific flexural stiffness and ultra-light structural weight. However, composite sandwich structures are susceptible to dynamic loading such as low-velocity impact loads. The repeated load cycles on the structures afterward will lead to severe reduction in the residual mechanical properties of the structure [1]. Numerous impact damages can occur in the composite sandwich structures such as delamination of the facesheets, core crushing, and facesheets debonding. Facesheets debonding significantly reduces the core layer support; thus, resulting in higher susceptibility of compressive after impact (CAI) failure. Several studies have investigated the significance of the compression after impact failure on composite structures at room temperature [2-5].

Due to the global warming, the arctic region experiences a severe reduction in the amount of ice, opening up new water ways which could be utilized for faster naval transportation. However, the harsh cold environment affects the strength properties of marine and naval structures [6]. Therefore, some literature discussed the effect of low temperature on the impact damage modes of composite sandwich structures. Elamin *et al.* [7] studied the impact behavior of carbon fiber sandwich structures with PVC foam core at very low temperatures. They observed a significant reduction in the maximum strength accompanied by a great increase in the debonding damage area at – 30 °C and -70 °C. Salehi-Khojin *et al.* [8] analyzed the behavior of sandwich structures with a honeycomb core at very low temperatures. They found the greatest impact damage occurred at the lowest test temperature (-50 °C). In regards to the effect of low temperature on the CAI behavior of composite structures, Sánchez-Sáez *et al.* [9] showed that the CAI strength of carbon fiber laminates is decreased at lower test temperatures. However, Halvorsen *et al.* [10] studied the CAI behavior of honeycomb composite sandwich structures with carbon/glass fiber facesheets. They showed an increase in the compressive strength at low temperatures by about 20%. Most of the previous work focused on understanding the effect of low temperature on the CAI behavior of composite laminates and honeycomb sandwich structures but not foam core sandwich structures. Foam core composite sandwich structures are easier to manufacture with an excellent impact damage tolerance. To the best of our knowledge, no work has been reported on the CAI behavior of foam core composite sandwich structures in low-temperature environments.

Therefore, this study investigates the CAI behavior of foam core composite sandwich structures at a wide range of low temperatures. In particular, 0°C, -30°C, -70°C have been respectively chosen to simulate the standard freezing temperature, the average temperature in the arctic region, and the lowest temperature ever recorded in the arctic region. Furthermore, the compressive strength and the compressive stiffness of the samples impacted at 0 J, 5 J and 10 J have been analyzed at low temperatures and compared with their respective values at room temperature. The results from this research provide a comprehensive analysis of the damage propagation in low-temperature environments, which will significantly contribute to the design guidelines of future arctic structures.

## 2. Experimental Procedure

Composite sandwich specimens have dimensions of 150×100×7mm and comprise of carbon fiber facesheets attached to a layer of PVC foam core. Specimens are first subjected to low-velocity impact tests using Instron CEAST 9350 drop tower machine with a 16mm diameter hemispherical impactor and a total impactor mass of 3.482 kg as shown in Figure 1. The machine has a built-in environmental chamber that provides the desired temperatures. The samples are completely clamped and placed inside the chamber. Low-temperature samples are kept in a freezer for 24 hours prior to the impact test, and then conditioned for 15 minutes during the test. Impact test energies of 5 J and 10 J are selected to provide a comprehensive explanation of the barely visible damages and the visible impact damages. For each energy level and test temperature, at least two samples are tested to ensure the consistency of the results.

After completion of impact tests, damaged specimens are then conditioned for another 24 hours inside the freezer prior to the CAI test. CAI test is performed using Instron 5582 universal testing machine (Figure 2a) for all damaged and undamaged samples. During the CAI test, an environmental chamber is attached to control the desired temperatures. Specimens are also conditioned for 15 minutes during the CAI test. The specimens are clamped using ASTMD 7137M [11] standard compression after impact fixture (Figure 2b). The load is applied from a 100 kN load cell directly to the CAI fixture, and the test matrix is completely controlled by a Bluehill software.

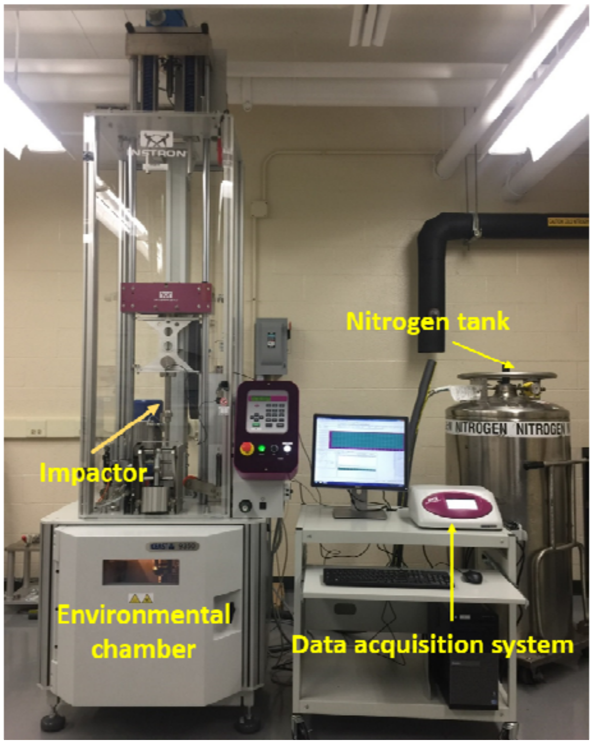

**Figure 1.** Impact test setup.

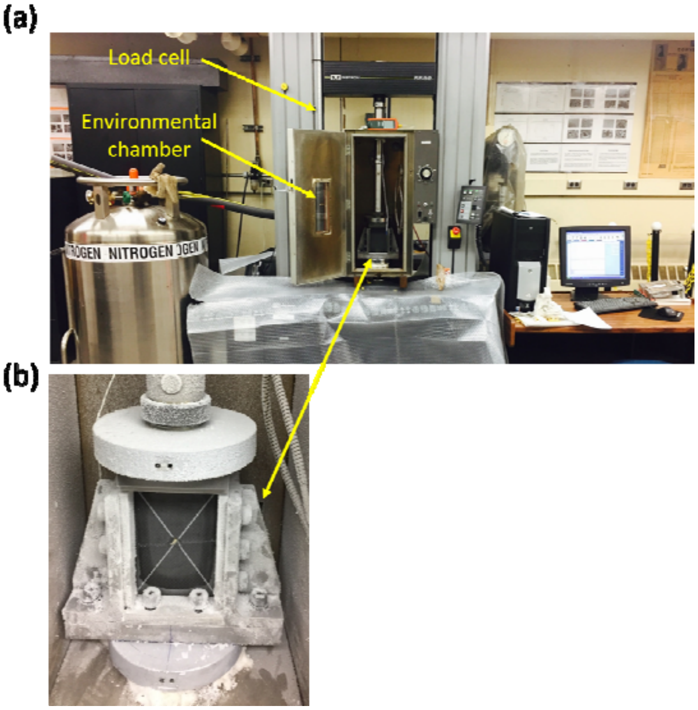

**Figure 2.** (a) CAI test setup; (b) CAI test fixture.

## 3. Results and Discussion

The results of the impact behavior of the samples used in this study are provided in details in [7]. Clearly, greater impact damages are associated with low temperatures. The CAI strength of the damaged and undamaged samples at all test temperatures are shown in Figure 3. For undamaged samples, the CAI strength increases with decreasing test temperature. However, 5 J and 10 J samples behave differently due to the pre-compression impact damage behavior. For instance, at 5 J, a significant drop in the amount of the compressive load is observed at -30 °C and -70 °C compared to the drop in the compressive load at room temperature. At 10 J, the compressive failure load becomes significantly lower at low temperatures implying that the residual strength of the impacted samples is a function of test temperature and the impact damage. Therefore, at 10 J, the drop in the compressive loads due to the impact damages counters the increase in the compressive load due to low temperatures (as seen in undamaged samples) resulting in lower CAI strength at low temperatures. Another important CAI parameter is the compressive stiffness. Figure 4 shows the compressive stiffness of the damaged and the undamaged samples at all test temperatures. The stiffnesses of the damaged samples are greatly affected by test temperature and the existing impact damages, such that at high energy levels and low test temperatures, the stiffness is tremendously reduced. Nevertheless, the stiffness of the undamaged sample is increased with decreasing test temperature (Figure 4). This is attributed to the increase in matrix stiffness when the polymer molecules become immobilized at extreme low temperature.

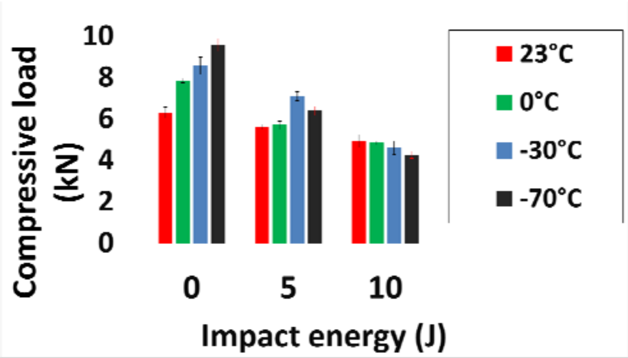

**Figure 3.** Compressive load of the damaged and undamaged samples at different temperatures.

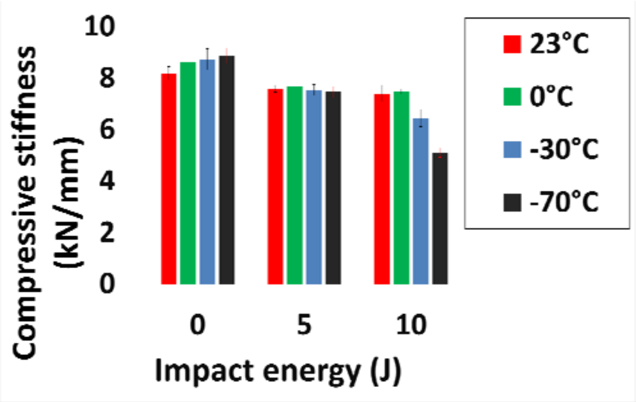

**Figure 4.** Compressive stiffness of the damaged and undamaged samples at different temperatures.

## 4. Conclusions

The effect of low temperature on the compression after impact (CAI) behavior of carbon/fiber composite sandwich structures with PVC foam core has been investigated using Instron ceast 9350 drop tower machine and Instron 5582 compression testing machine. Tests were conducted at four different temperature (23°C, 0°C, -30°C,-70°C) and impact energy levels of 0 J, 5 J, and 10 J. The results from this study showed that the compressive load and the compressive stiffness of the undamaged specimens are increased at low temperature. However, the compressive load and the compressive stiffness are significantly reduced at low temperatures due to the greater impact damages.

## Acknowledgments

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

## References

[1] S. Abrate. Impact on Composite Structures. Cambridge University Press, Cambridge, 1998.
[2] S. Sánchez-Sáez, E. Barbero, R. Zaera, and C. Navarro. Compression after impact of thin composite laminates. *Composites Science and Technology*, 65:1911–1919, 2005.
[3] M.D. Rhodes, J.G. Williams, and J.H. Starnes Jr. Effect of low-velocity impact damage on the compressive strength of graphite-epoxy hat-stiffened panels. *Technical reports*, National Aeronautics and Space Administration Hampton Langley Research Center, 1997.
[4] G. Davies, D. Hitchings, T. Besant, A. Clarke, and C. Morgan. Compression after impact strength of composite sandwich panels. *Composite Structures*, 63:1–9, 2004.
[5] K.T. Tan, N. Watanabe, Y. Iwahori, and T. Ishikawa. Effect of stitch density and stitch thread thickness on compression after impact strength and response of stitched composites. *Composites Science and Technology*, 72:587–98, 2012.
[6] P.K. Dutta. Low-temperature compressive strength of glass-fiber-reinforced polymer composites. *Journal of Offshore Mechanics Arctic*, 116:167–172, 1994.
[7] M. Elamin, B. Li, and K.T. Tan. Impact damage of composite sandwich structures in arctic condition. *Composite Structures*, 192:422-433, 2018.
[8] Salehi-Khojin, M. Mahinfalah, R. Bashirzadeh, and B. Freeman. Temperature effects on kevlar/hybrid and carbon fiber composite sandwiches under impact loading. *Composite Structures*, 78:197–206, 2007.
[9] S. Sánchez-Sáez, E. Barbero, and C. Navarro. Compressive residual strength at low temperatures of composite laminates subjected to low-velocity impacts. *Composite Structures*, 85:226–232, 2008.
[10] Halvorsen, A. Salehi-Khojn, M. Mahinfalah, and R. Nakhaei-Jazar. Temperature effects on the impact behavior of fiberglass and fiberglass/Kevlar sandwich composites. *Applied Composite Materials*, 13:369-383, 2006.
[11] ASTMD 7137/D 7137M-07, Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates.