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Carbon Fiber Reinforced Plastics with Aluminum Honeycomb Core Design Methodology for Space and Surface Mining Applications

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Introduction

Sandwich composite materials provide high strength and stiffness compared to weight and can be integrated in many industries to improve capabilities and lower costs.

This research explores the application of aluminum honeycomb sandwich composites in space mining structures. A method for defining parameters of aluminum honeycomb composites using the Moment Index Number of the composite and corresponding design charts were developed; parameters include:

- number of plies
- stacking sequence
- core thickness
- core density

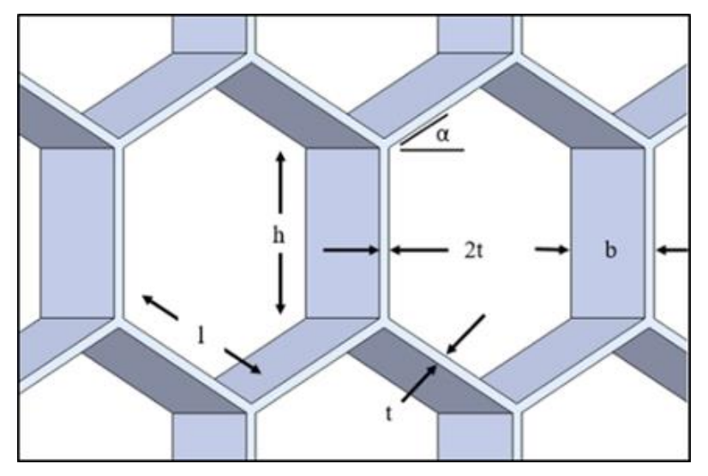
The new method was verified in physical testing. A finite element analysis method was also developed.

The models developed allow engineers to implement sandwich composites into systems and machinery.

Background

Honeycomb Core

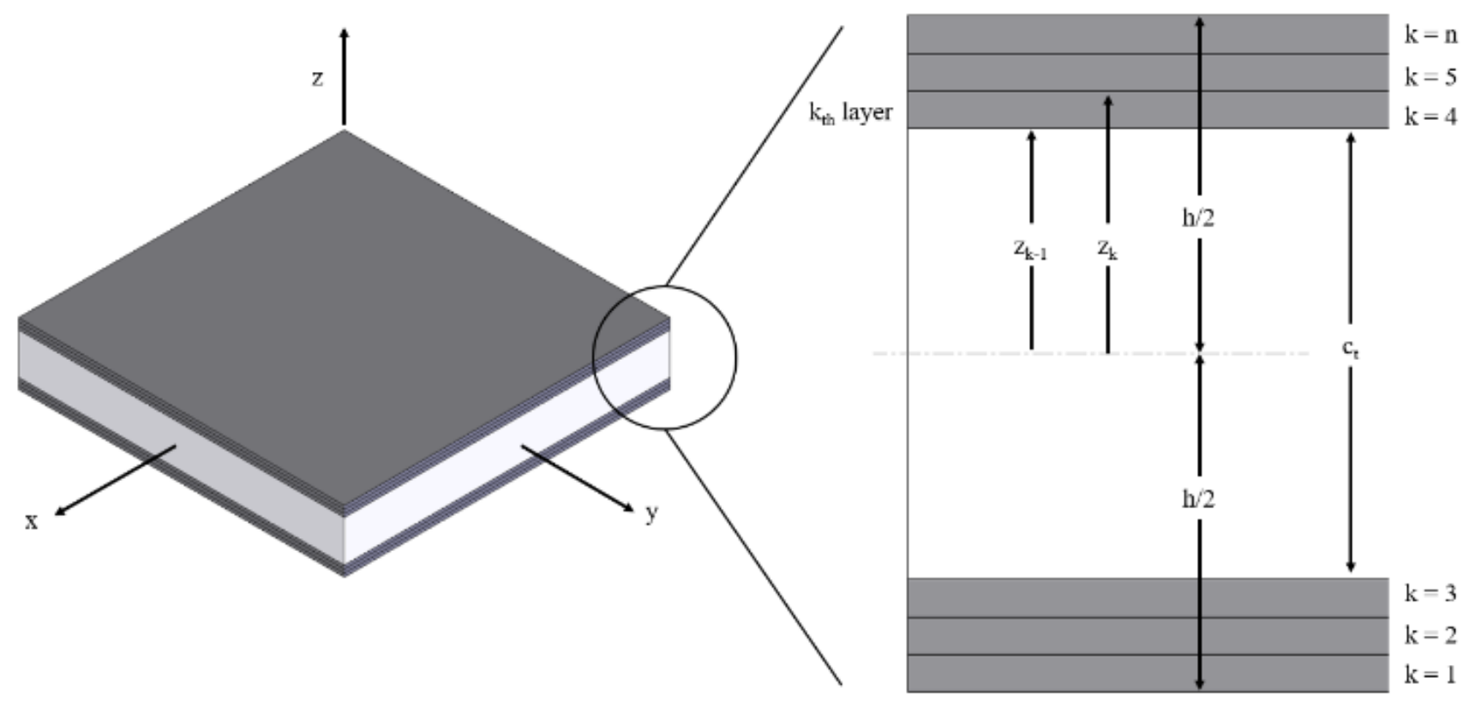
The use of a honeycomb core separates the facesheets of the composite, increasing the moment of inertia and thus increasing the flexural strength.[1] Aluminum cores provide higher compression and shear strength and are the preferred choice for mining applications.



The component density and maximum bearing load of the composite can be controlled through core selection.[3,4] The core must also provide enough stiffness under shear stress to ensure facesheets do not slide while under bending stress.

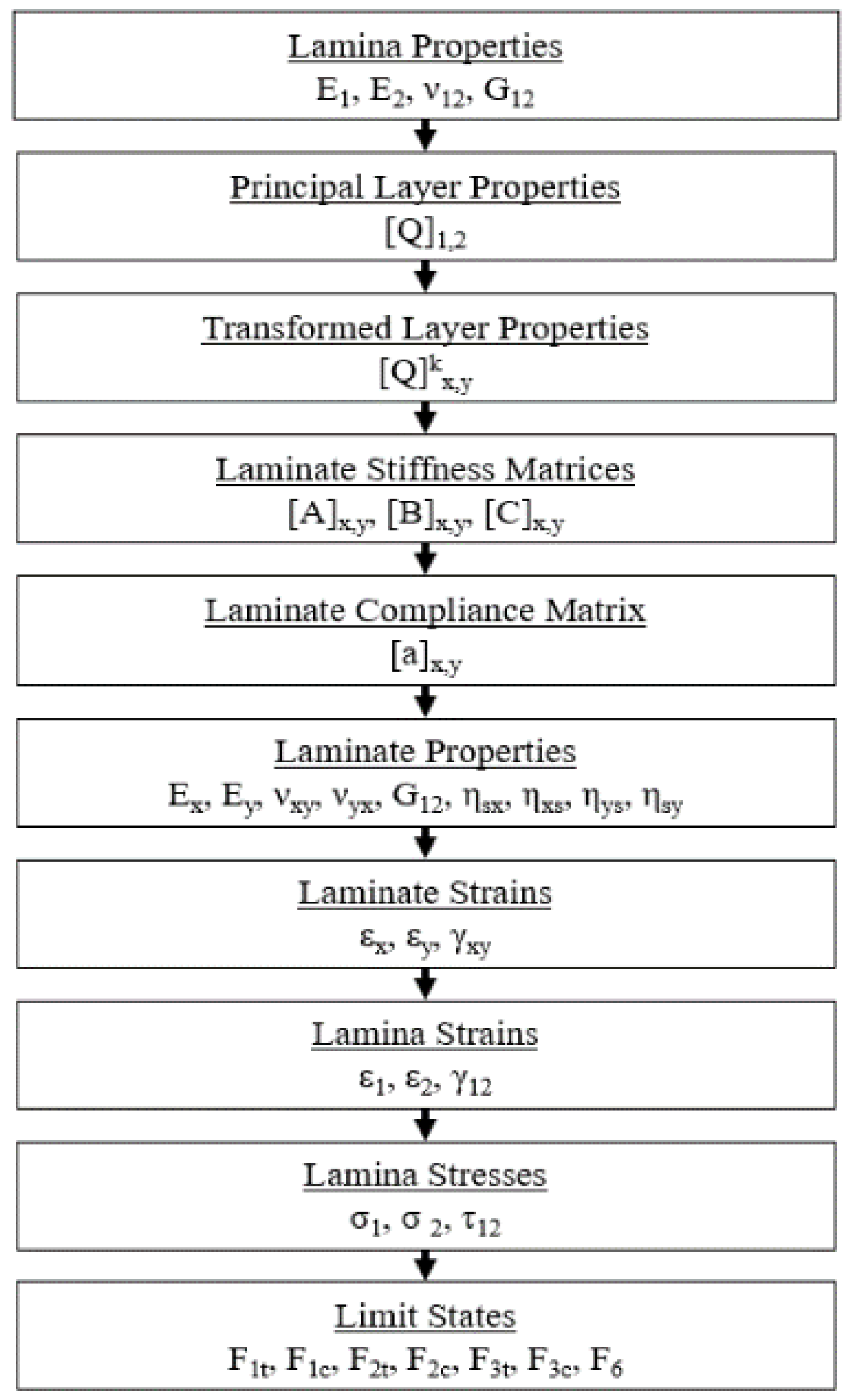
Facesheet Properties

To determine in-plane properties of the composite, the following mechanical properties of the lamina must be found: E_{L1}, E_{L2}, G_{L12}, ν_{L12}, ν_{L21}, z (lamina thickness), k (number of lamina in the laminate), and θ_k (angle between the laminate global principal axis and the lamina principal axis (figure 2).



Design Methodology

Carbon fiber reinforced plastic prepreg sheets come in a variety of different configurations and an infinite number of stacking sequences. The procedure outlined below derives mechanical properties for sandwich plate from mechanical properties of the core and lamina given a predetermined stacking sequence. After sandwich plate properties are determined, mechanical loading can be applied and individual layer stresses and strains in the facesheets can be determined.



Lamina Properties
$E_1, E_2, \nu_{12}, G_{12}$

Principal Layer Properties
$[Q]_{1,2}$

Transformed Layer Properties
$[Q]^k_{x,y}$

Laminate Stiffness Matrices
$[A]_{x,y}, [B]_{x,y}, [C]_{x,y}$

Laminate Compliance Matrix
$[a]_{x,y}$

Laminate Properties
$E_x, E_y, \nu_{xy}, \nu_{yx}, G_{12}, \eta_{sx}, \eta_{xs}, \eta_{ys}, \eta_{sy}$

Laminate Strains
$\varepsilon_x, \varepsilon_y, \gamma_{xy}$

Lamina Strains
$\varepsilon_1, \varepsilon_2, \gamma_{12}$

Lamina Stresses
$\sigma_1, \sigma_2, \tau_{12}$

Limit States
$F_{1t}, F_{1c}, F_{2t}, F_{2c}, F_{3t}, F_{3c}, F_6$

- Determine principal layer stiffness matrix for the lamina $[Q_L]_{1,2}$ and core $[Q_C]_{1,2}$
- Transformed lamina stiffnesses, $[Q_L]_{x,y}$, must be found if lamina axis vary from the principal axis of the sandwich plate.
- Principal and transformed core stiffness matrices remain equal.
- Sandwich stiffness matrices [A], [B], and [D] are functions of geometric parameters of the core and lamina and are calculated from the transformed lamina stiffness matrices.

Matrix	Applied Force	Internal Property
[A]	In plane loads	In-plane strains
[B]	In-plane curvatures, moments	In-plane strains
[D]	Moments	Curvatures

- Sandwich plate material properties are determined using the following equations:[2]

$$E_x = \frac{1}{ha_{xx}} \qquad E_y = \frac{1}{ha_{yy}} \qquad G_{xy} = \frac{1}{ha_{ss}} \qquad \nu_{xy} = -\frac{a_{yx}}{a_{xx}} \qquad \nu_{yx} = -\frac{a_{xy}}{a_{yy}}$$

$$\eta_{sx} = \frac{a_{xs}}{a_{ss}} \quad \eta_{xs} = \frac{a_{sx}}{a_{xx}} \qquad \eta_{ys} = \frac{a_{sy}}{a_{yy}} \qquad \eta_{sy} = \frac{a_{ys}}{a_{ss}}$$

- These properties can be used to determine strains and stresses
- Mid-plane strains and curvatures are defined from applied unit forces and moments.
- Strains at any point in the sandwich plate can be found from the mid-plane strains through the following matrix:[2]

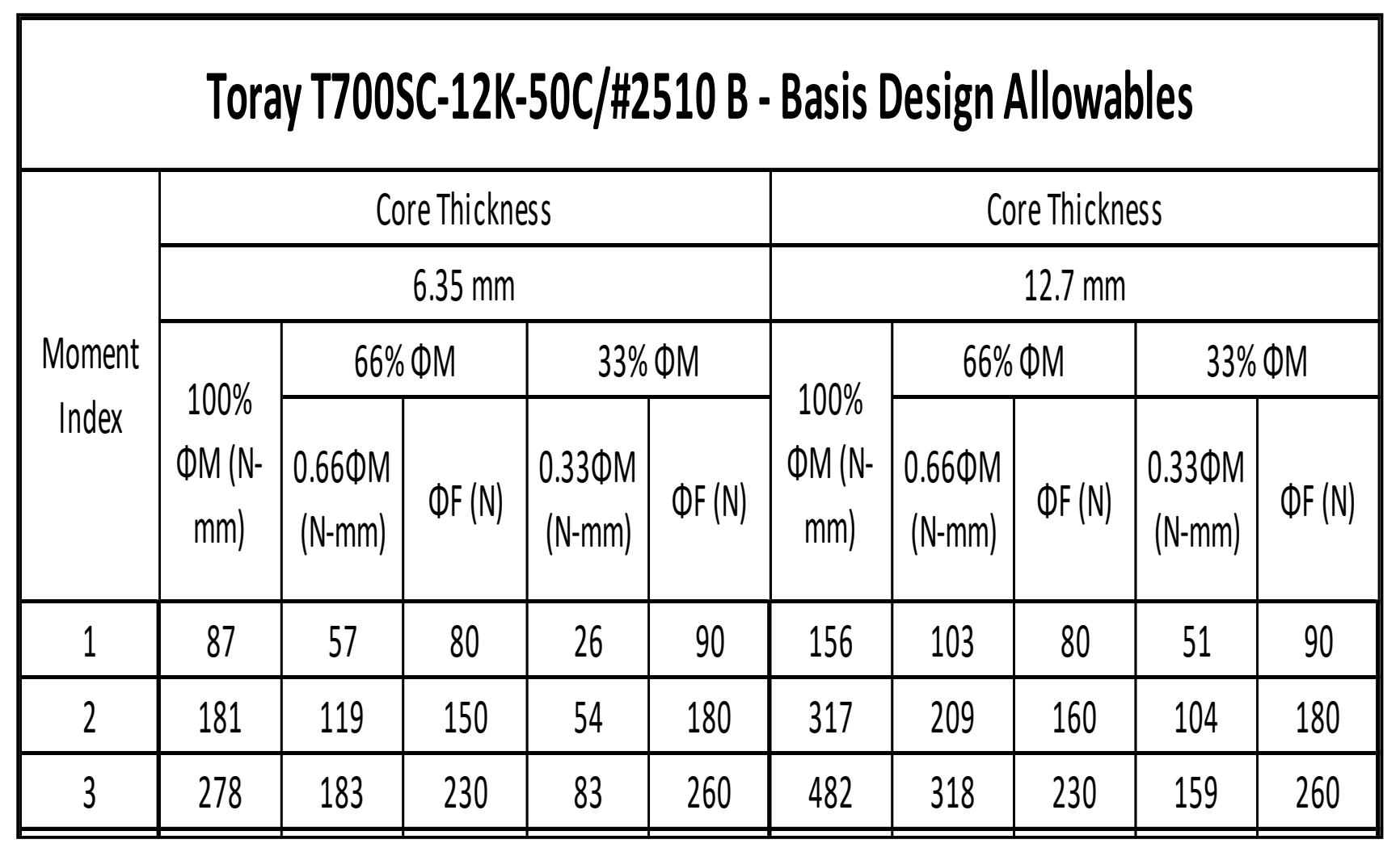
$$\left|\begin{matrix}\varepsilon_x \\ \varepsilon_y \\ \gamma_s\end{matrix}\right| = \left|\begin{matrix}\varepsilon_{x,mp} \\ \varepsilon_{y,mp} \\ \gamma_{s,mp}\end{matrix}\right| + z\left|\begin{matrix}\kappa_x \\ \kappa_y \\ \kappa_s\end{matrix}\right|$$

- Strains in the lamina principal direction are used with the Lamina stiffness matrix to calculate lamina stress.[2]

$$\left|\begin{matrix}\varepsilon_x \\ \varepsilon_y \\ \gamma_s\end{matrix}\right| = \left|\begin{matrix}\varepsilon_{x,mp} \\ \varepsilon_{y,mp} \\ \gamma_{s,mp}\end{matrix}\right| + z\left|\begin{matrix}\kappa_x \\ \kappa_y \\ \kappa_s\end{matrix}\right|$$

Design Charts

The analytical methods described above were used to create design charts to determine composite configuration for specified conditions. Design charts are used to determine the number of plies, stacking sequence, core thickness, and core density of the sandwich composite; a sample of a design chart is shown in the chart to the left.



Toray T700SC-12K-50C/#2510 B - Basis Design Allowables

Moment Index	Core Thickness					Core Thickness				
	6.35 mm					12.7 mm				
	100% ΦM (N-mm)	66% ΦM		33% ΦM		100% ΦM (N-mm)	66% ΦM		33% ΦM	
		0.66ΦM (N-mm)	ΦF (N)	0.33ΦM (N-mm)	ΦF (N)		0.66ΦM (N-mm)	ΦF (N)	0.33ΦM (N-mm)	ΦF (N)
1	87	57	80	26	90	156	103	80	51	90
2	181	119	150	54	180	317	209	160	104	180
3	278	183	230	83	260	482	318	230	159	260

Physical Testing

The design methods proposed were verified with physical testing of composites with stacking sequences considering up to 10 plies per facesheet.[5]

Two failure modes occur in physical testing: core shear (Figure 1) and combined core shear and factsheet yielding (Figure 2); the previous only occurs when large Moment Index numbers are present.

Figure 1: Core Shear

Figure 2: Combine Core Shear and Facesheet Yielding

Shear strength values were tested with two loading conditions: non-standard and standard four-point bending (Figure 3, Figure 4). The maximum shear stress occurring in the composite at maximum flexural strength is reached gives the shear strength value.

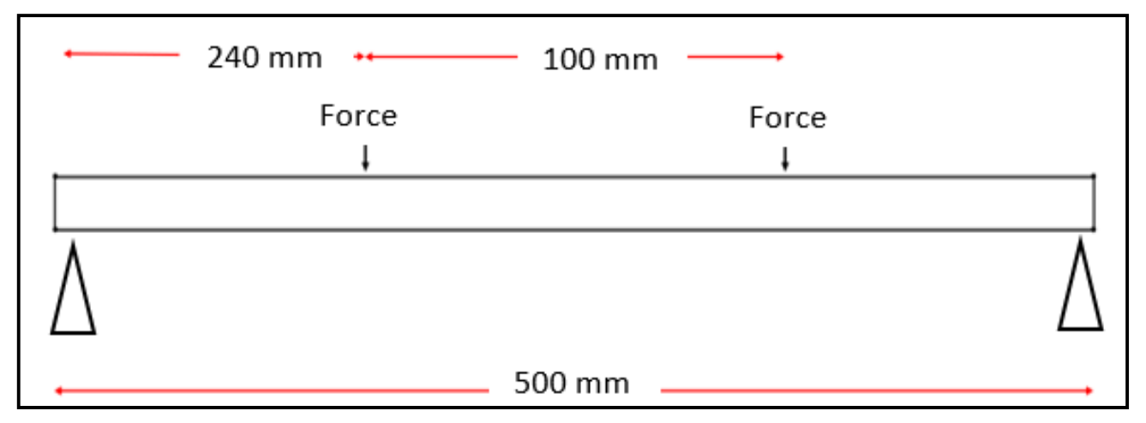


Figure 3: Four Point Bending

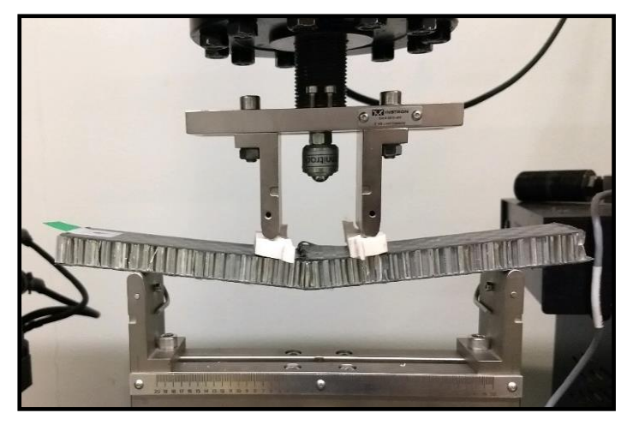


Figure 4: Four Point Bending Test

Data obtained from physical testing was analyzed and closely supported the proposed design charts.

Figure 5 displayz testing results of a composite with a 129 kg/m^3 core density.

The design charts specify that failures will transition from facesheet yielding to core shear at a moment index number of 12; when core shear occurs the composite cannot support a larger moment index. .

This is exemplified in Figure 5, as the unit moment capacity decreases growth starting at a moment index of 12.

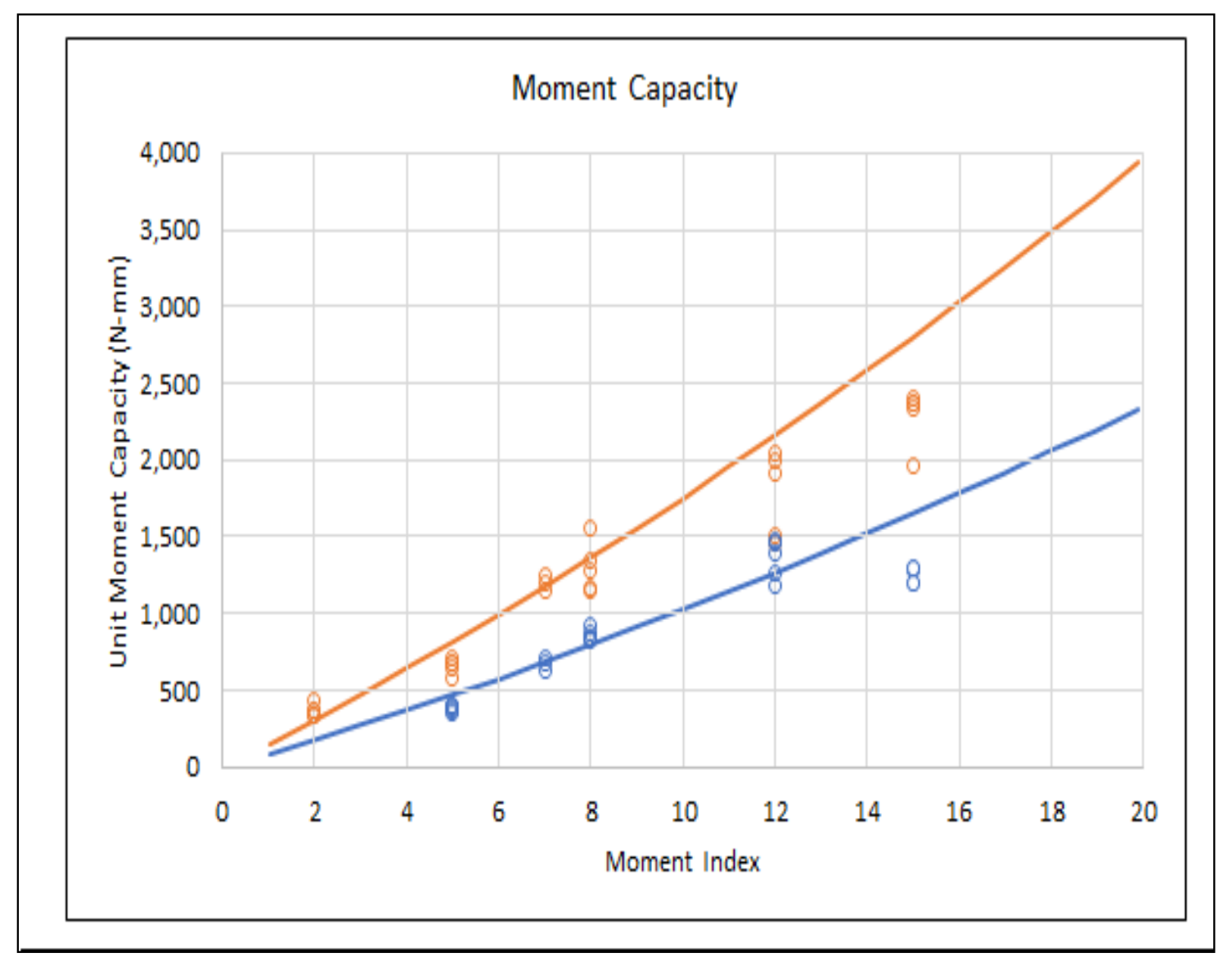


Figure 5: Physical Testing results of 129 kg/m^3 composite. Core shear begins at a moment index number of 12 as proposed in the corresponding design charts.

Literature Cited

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[4] Cho. J. U., et al. “Experimental Study of the Impact Characteristics of Sandwich Composites with Aluminum Honeycomb Cores.” *International Journal of Automotive Technology*, vol. 14, no. 3, 2013, pp. 415-421.

[5] *Standard Test Method for Facing Properties of Sandwich Constructions by Long Beam Flexure*. ASTM International, 2012.

Acknowledgments

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