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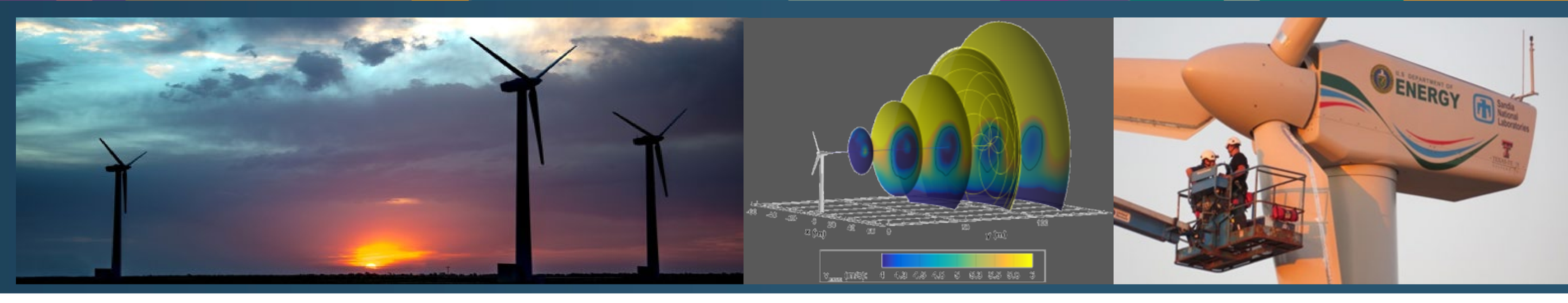

Accurate Modeling of Material Nonlinearities in a Wind Turbine Spar Cap

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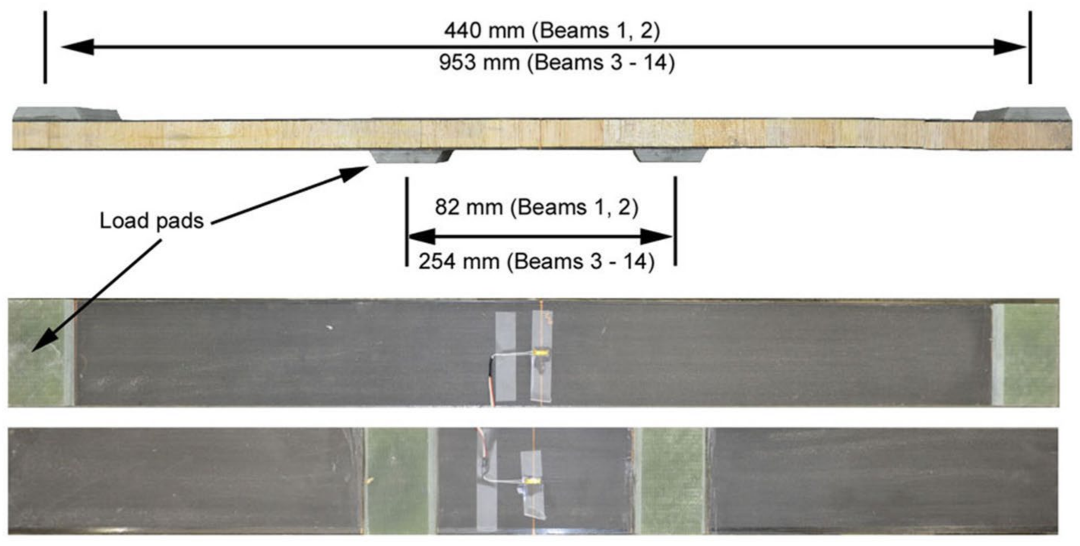
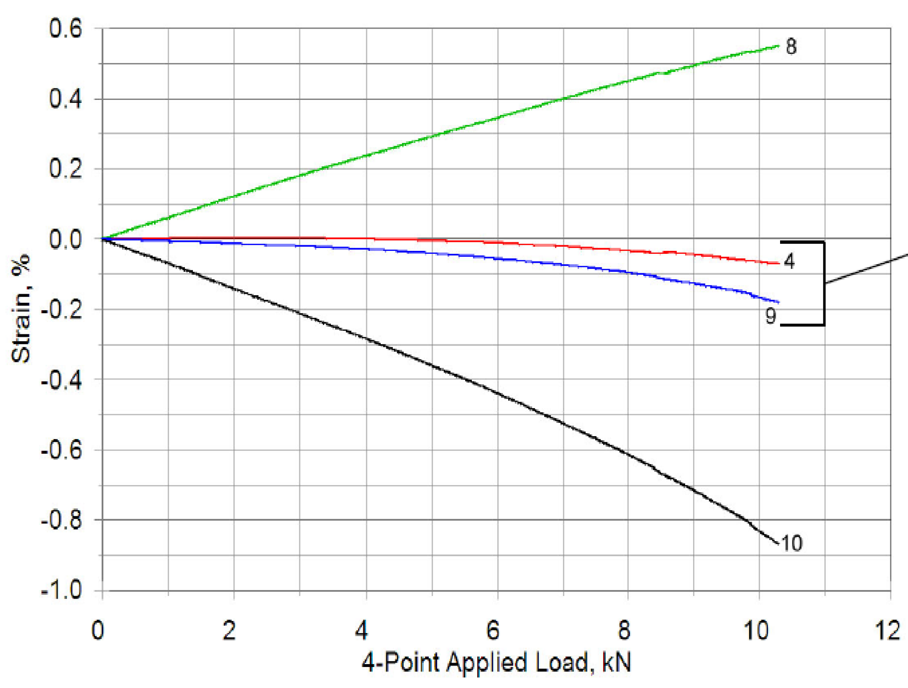
Abstract

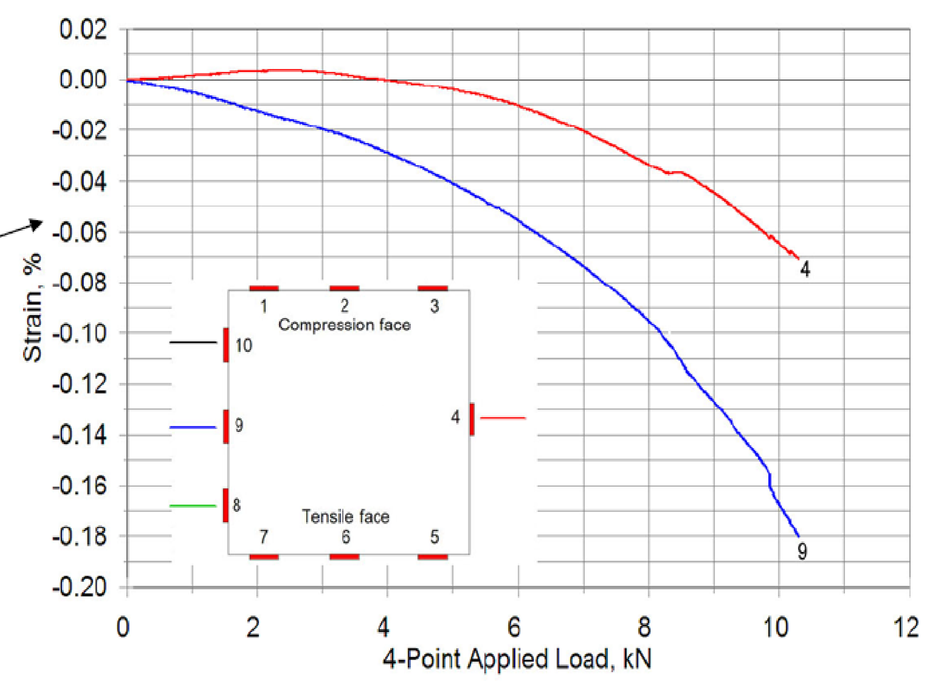
This study presents component-level testing of carbon fiber sandwich beams and the effect of carbon fiber material nonlinearity in its strain response in bending. A simple material model is presented and validated that accurately captures the carbon fiber longitudinal nonlinearity in both the tensile and compressive response. This material model is implemented in a finite element model of the BAR-DRC reference wind blade, a downwind 100-meter rotor blade, and the effects of the nonlinearity on ultimate limit states of the blade are analyzed. The material nonlinearity has negligible effect on the deflection, and material failure predictions. The buckling analysis revealed significant reductions in buckling load factor in the controlling flap direction caused by the material nonlinearity, revealing the importance of including this material model for buckling analyses of wind blade with carbon fiber reinforced spar caps.

Mechanical Testing

Strain load diagram of mid-thickness strain gauges on carbon fiber composite sandwich beams loaded in four-point bending show a non-zero compressive strain response indicating a shifting of the neutral axis towards the tensile (stiffer) side.

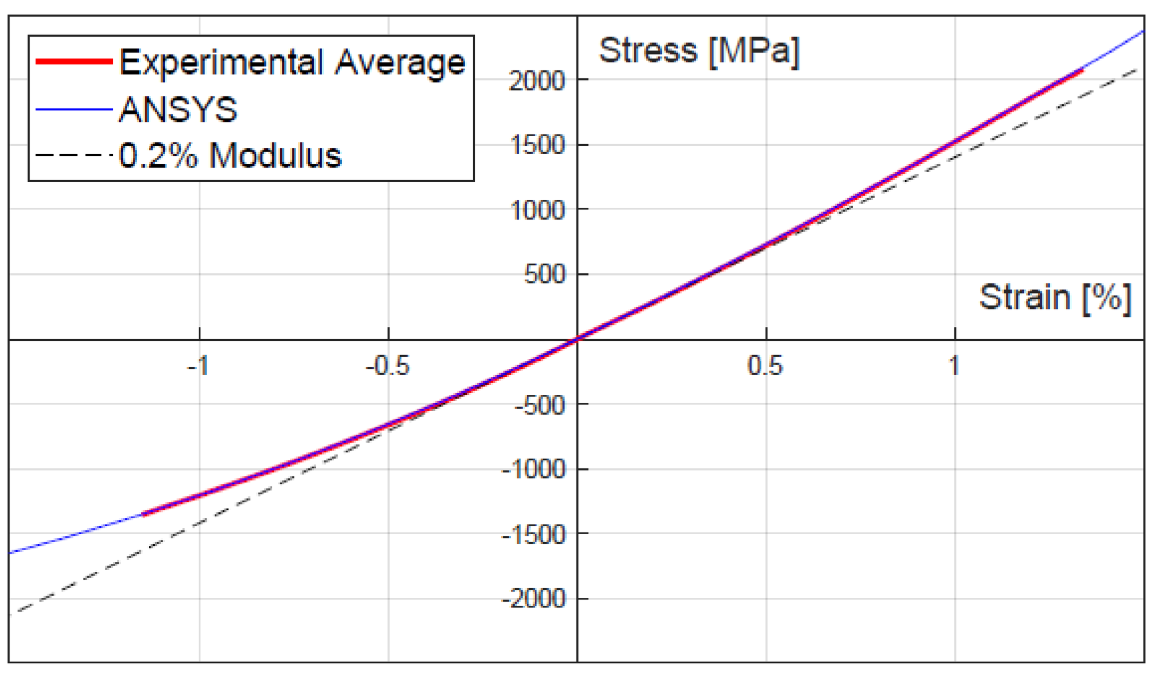


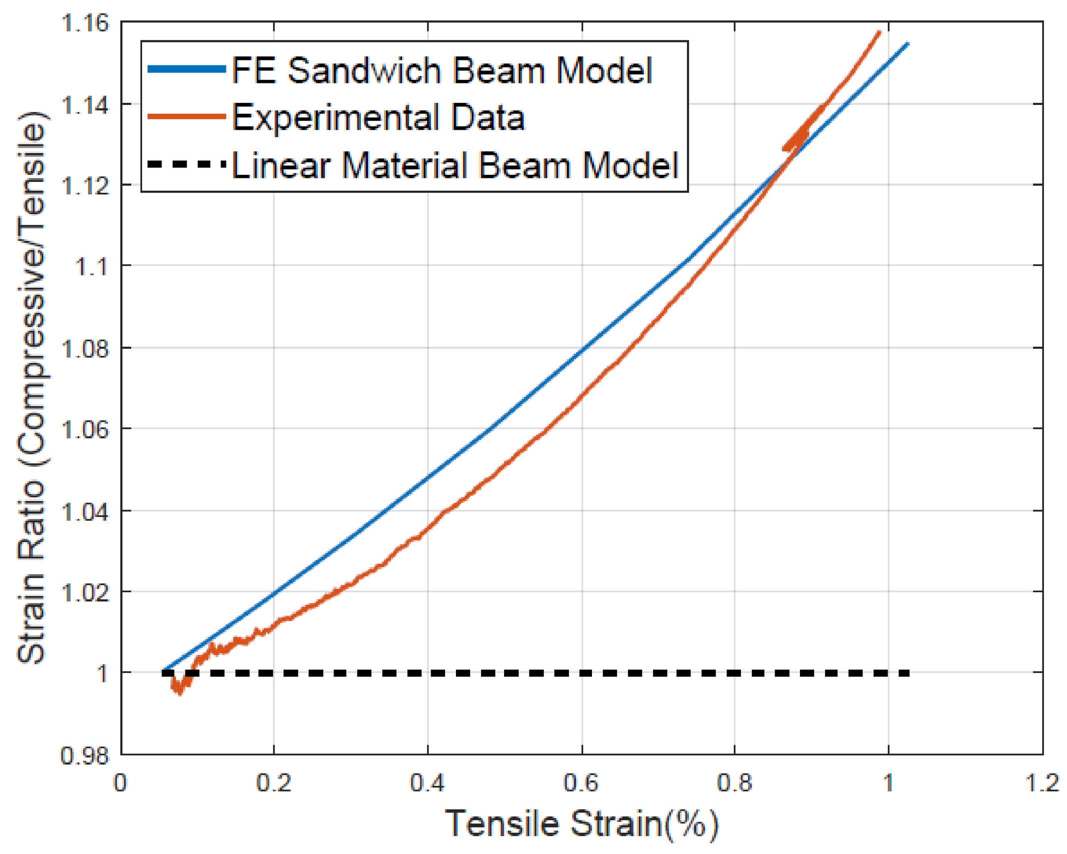




Model Development and Validation

An ANSYS® USERMAT was developed that captured the strain hardening in tension and strain softening in compression behavior of the carbon fiber composite. Model calibration was done using coupon test data and one element tests.

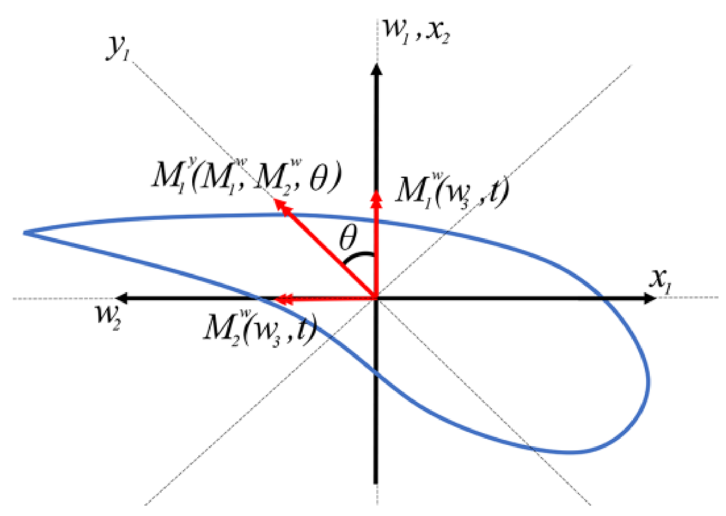




To validate the material model a model of the four-point bend test was developed and the strain ratio of the compressive and tensile faces while undergoing loading was compared to the experimental test. The virtual and experimental response showed good agreement. A linear material model is additionally shown for reference

Wind Blade Comparison Study

Design load directions follow a counter-clockwise direction around cross-section of the blade in increments of 45° [1].



Comparison wind blade studies were done between a 100 meter wind blade with and without material nonlinearity in it's spar cap.
Tip deflection analyses showed minimal differences.

Nonlinear Buckling Results:

Load Direction [°]	Linear Material load factor	Nonlinear material Load factor	Difference [%]
0	13.96	13.84	-0.86
45	0.94	0.99	5.32
90	0.66	0.52	-21.21
135	1.02	0.59	-42.16
180	6.67	6.72	0.75
225	2.09	2.03	-2.87
270	0.80	0.80	0
315	1.34	1.34	0

Maximum Failure Index Results:

Load Direction [°]	Linear Material load factor	Nonlinear material Load factor	Difference [%]
0	0.224	0.224	0
45	2.490	2.678	7.55
90	0.505	0.506	0.2
135	0.187	0.187	0
180	0.131	0.130	-0.76
225	0.196	0.195	-0.51
270	0.125	0.128	2.40
315	0.146	0.146	0

Conclusions

Carbon fiber nonlinear material response appears to have a significant effect on the buckling response of the wind blade in design and should be investigated further.

References

1. Camarena E, Anderson E, Paquette J, Bortolotti P, Feil R and Johnson N 2022 "Land-based wind turbines with flexible rail-transportable blades - Part 2: 3D finite element design optimization of the rotor blades." Wind Energ. Sci. 7 19-35

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