SAND2014-1794P

COMPOSITE MATERIALS DATABASE

2014 Wind Peer Review

Brian Naughton

Sandia National Laboratories, Wind Energy Technologies | bnaught@sandia.gov

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy | WIND AND WATER POWER PROGRAM

1. INTRODUCTION

As new blades designs have increased in length, the need for tighter design margins has increased to avoid a rapid increase in mass which equates to high costs (fig 1). Building a blade with tighter design and manufacturing margins requires multi-scale data and trends on material behavior subject to the realistic loading conditions blades experience in operation. This project aims to test new and existing wind blade materials using standard, and where necessary, non-standard test protocols to better understand material behavior under realistic loading conditions. Partnering with material suppliers and blade manufacturers this project identifies the critical materials issues facing the industry, tests blade materials to better understand their performance, and disseminates the results through reports, conferences and a public database, supporting the development of lower cost-of-energy wind turbine blades.

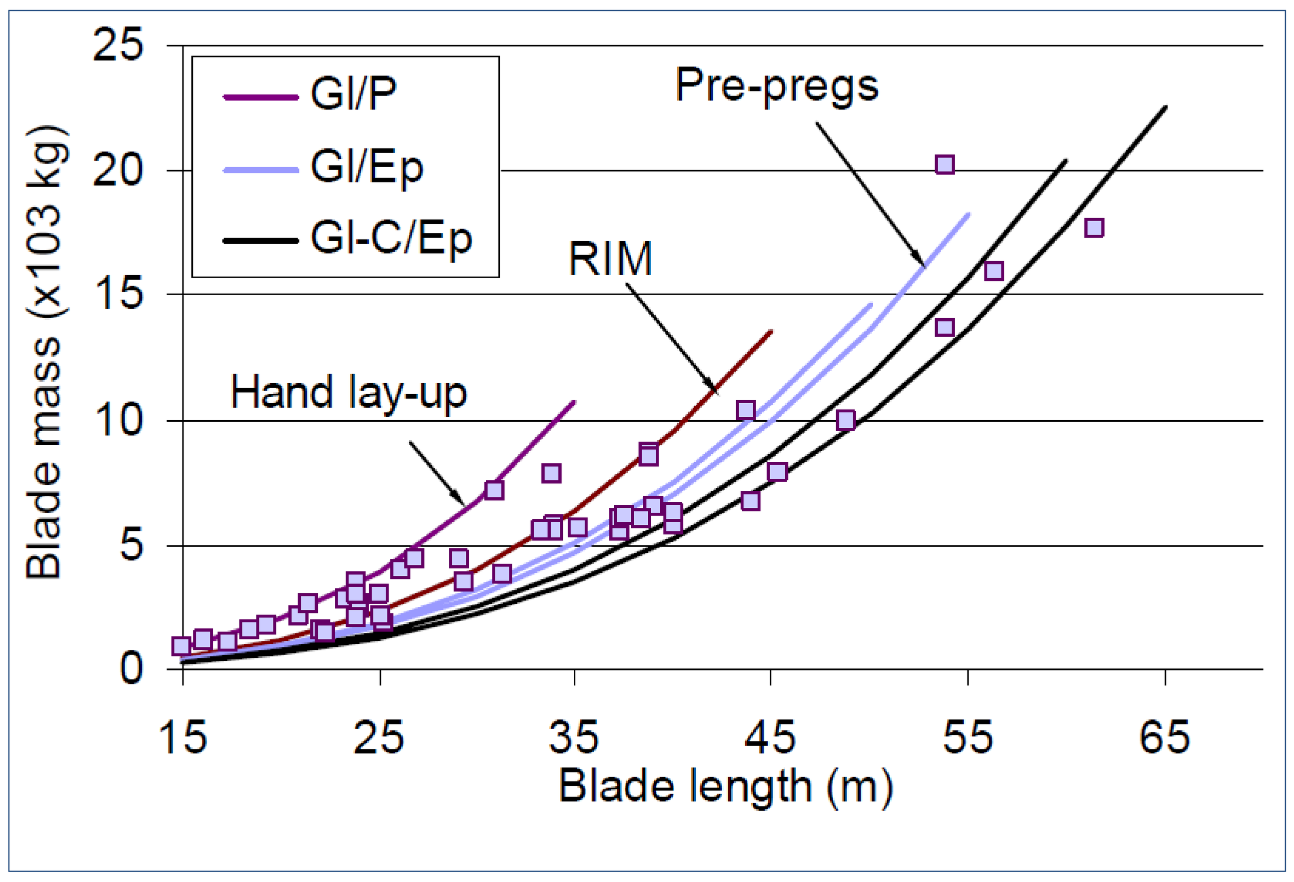

FIGURE 1- BLADE MASS INCREASES CUBICALLY WITH LENGTH LEADING TO HIGH COSTS. THE APPLICATION OF NEW MATERIALS AND MANUFACTURING METHODS ARE USED TO KEEP BLADE MASS DOWN. GL/P IS GLASS FIBER POLYESTER BLADES: GL/EP IS GLASS FIBER EPOXY BLADES; GL-C/EP IS GLASS AND CARBON FIBER EPOXY BLADES. RIM IS RESIN TRANSFER MOLDING, A MANUFACTURING METHOD. PLOT ADAPTED FROM UPWIND PROJECT.

2. METHODS

The technical approach of the project is to test static and fatigue characteristics of new and existing wind blade materials including:

- resins
- fabrics
- adhesives
- core materials
- substructure elements (adhesive bonds, ply drops)

FIGURE 2- A COMPOSITE COUPON BEING SUBJECTED TO FATIGUE LOAD CYCLES IN ONE OF THE MONTANA STATE UNIVERSITY TENSILE TEST MACHINES

Annual testing plans are prioritized based upon:

- Suggestions from blade/turbine manufacturers
- Experience of program participants at MSU and SNL in composites and composite structures
- Requests from materials suppliers to test specific materials for inclusion in database (under program guidelines)
- Needs to complete datasets for parametric studies, etc., like resin or fabric structure effects

3. RESULTS

Many materials are tested during the year with testing equipment running 24 hours a day, 7 days a week. Three recent accomplishments are selected below to represent:

- A basic research project (Biaxial laminate study)
- A direct industry support project (Epoxy vs urethane resin study)
- New testing capabilities (Substructure test fixture)

BIAXIAL LAMINATE STUDY

- Prompted by industry observation of damage initiation in biaxial materials progressing into other primary structures
- More common in larger, heavier blades that experience more edgewise gravity fatigue loading
- Biaxial laminates in the panels carry associated shear loads
- Very little research has been performed on biaxial laminates

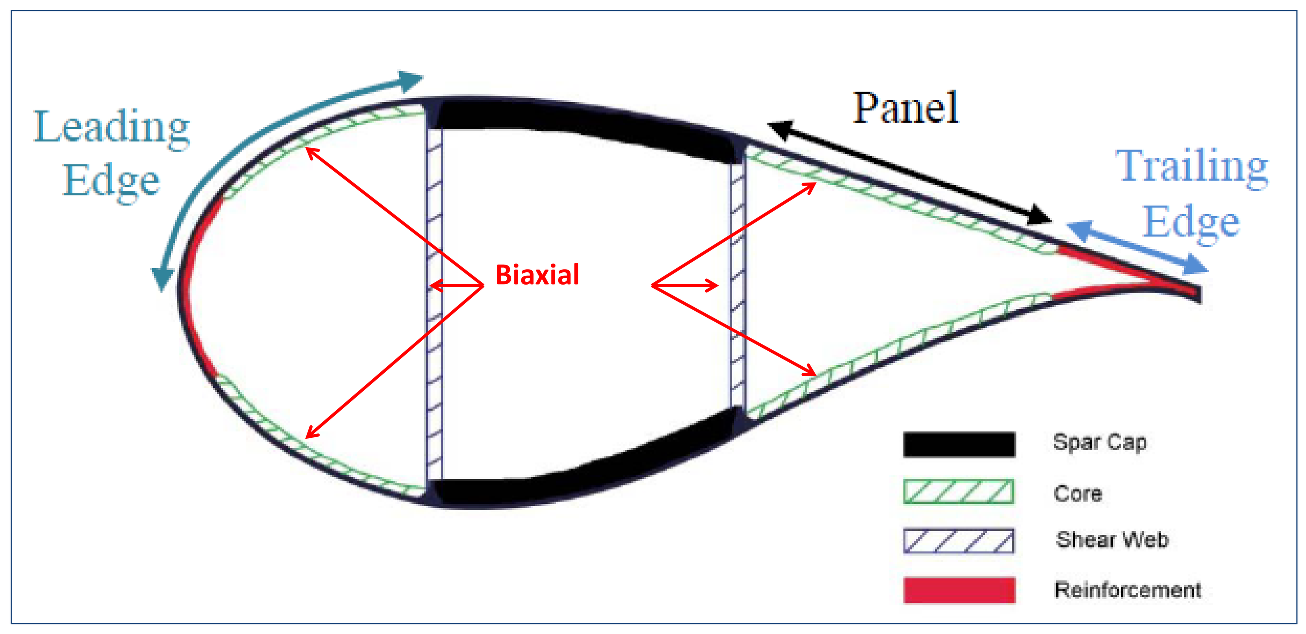

FIGURE 3 – A BLADE CROSS-SECTION SHOWING THE HASHED LOCATIONS WHERE BIAXIAL LAMINATE MATERIALS ARE USED. BIAXIAL LAMINATES ARE TYPICALLY GLASS FIBERS ORIENTED AT +/- 45 DEGREES FROM THE BLADE SPAN

Biaxial laminates were tested under a constant load (creep test) and a cyclical load (fatigue test) and it was found that The controlling parameter in determining the fatigue lifetime for off-axis (biaxial) laminates is cumulative time under load, not stress cycles as is the case with unidirectional laminates most commonly studied.

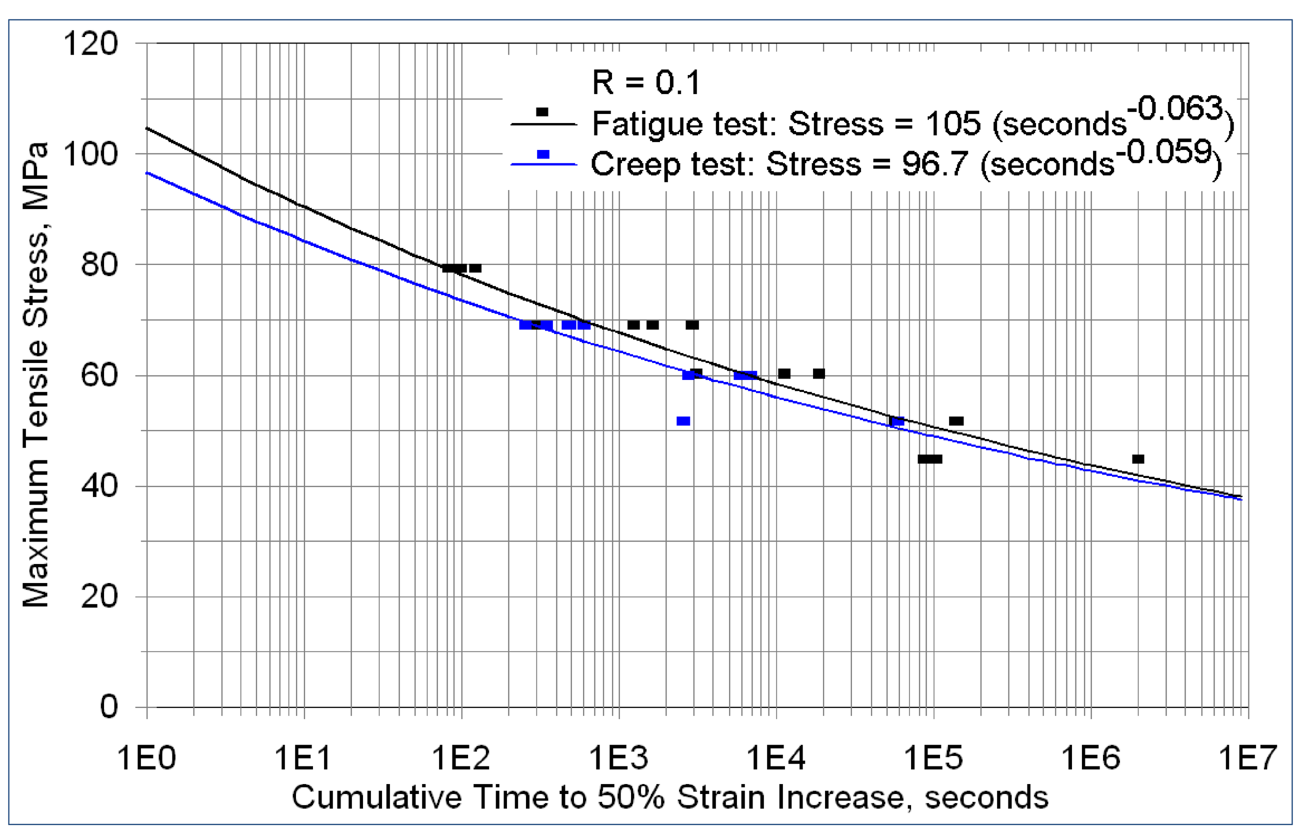

FIGURE 4 – IN TENSILE AND COMPRESSIVE FATIGUE (R = 0.1 AND 10) THE CUMULATIVE (SINE-WAVE) TEST TIME TO 50% STRAIN INCREASE CORRELATES WITH THE CORRESPONDING VALUE FROM CREEP TESTS AT THE SAME MAX STRESS [1].

The loading case where there is zero alternating stress is the creep loading case. Results of this test have been added to existing constant life diagrams that present comprehensive material test data that is both unique and critical to the wind industry to design new blades. And example chart is shown below in figure 5.

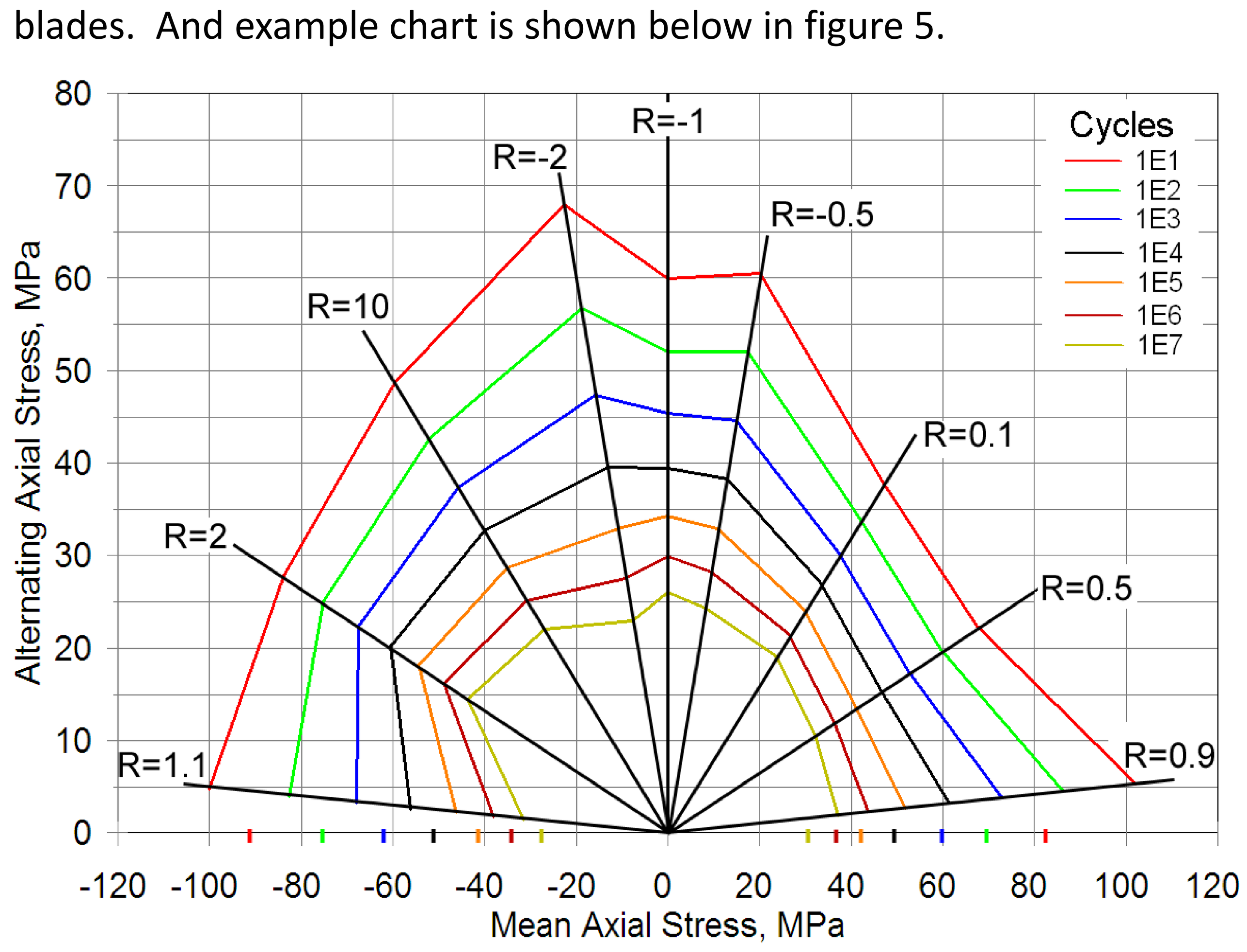

FIGURE 5 – CONSTANT LIFE DIAGRAM OF AXIAL STRESS STATES AND MEASURED LIFETIME IN CYCLES OF A BIAXIAL LAMINATE. CREEP VALUES ARE ADDED ON THE BOTTOM AXIS FROM THIS STUDY. THESE CHARTS REPRESENT HUNDREDS OF TESTS CONDUCTED OVER THOUSANDS OF HOURS.

URETHANE VS EPOXY STUDY

Laminates were tested consisting of the same glass fabrics infused with different resins, urethane and epoxy in order to compare the static and fatigue properties. Urethane has some potential cost and manufacturing process advantages over epoxy. It was demonstrated that while the urethane biaxial materials have reduced strength, stiffness and creep resistance as compared to epoxy, the unidirectional urethane laminates performed as well or slightly better than epoxy as shown in the figure below.

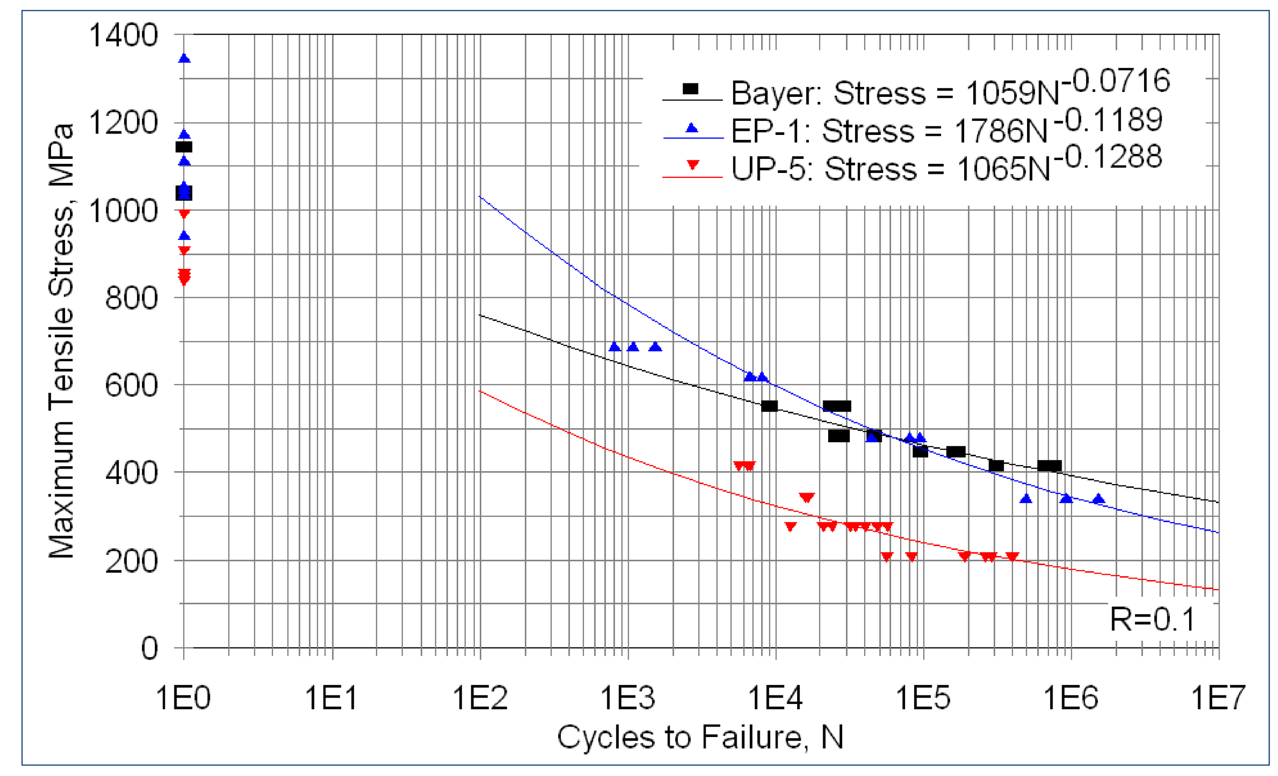

FIGURE 6 – TENSILE FATIGUE RESULTS FOR UNIAXIAL GLASS LAMINATES INFUSED WITH URETHANE (BLACK), EPOXY (BLUE) AND POLYESTER (RED). AT HIGH CYCLES, THE URETHANE OUTPERFORMS THE EPOXY.

SUBSTRUCTURE TEST FACILITY

A new test frame funded through a separate task was completed in FY13 at Montana State University. The new test frame will enable testing of more representative blade structures under more representative loading conditions. This will reduce uncertainty in extrapolating coupon-scale tests up to full blade designs. A new standard test specimen has also been designed as depicted below.

FIGURE 7 – THE SUBSTRUCTURE TEST FRAME (LEFT) WILL BE USED TO TEST NEW SUBSTRUCTURE TEST SPECIMENS (RIGHT) IN ORDER TO PROBE MATERIAL BEHAVIOR IN SHAPES AND LOADINGS THAT CANNOT BE DONE AT A COUPON SCALE.

4. SUMMARY OF RESULTS AND FINDINGS

- Creep behavior was demonstrated in biaxial materials under typical loading conditions that large blades would be subject to. The total time under load rather than number of cycles determines the damage progression and lifetime of the material.
- Urethane resin infused in unidirectional glass fibers has demonstrated similar fatigue strength to epoxy, but with potential cost and processing advantages. This could lead to a new commercial product reducing blade costs.
- A new substructure test facility was completed along with a standard specimen design. This will enable testing of more realistic blade material structures and complex loads reducing the uncertainty in extrapolating coupon-scale properties to full blade designs.
- Testing results have been added to the DOE/MSU Fatigue Database for Wind Blade Materials available here: www.coe.montana.edu/composites/

5. PROPOSED FUTURE WORK

A 2-year effort to investigate the techno-economic feasibility of incorporating low-cost carbon fibers developed at Oak Ridge National Laboratory for wind blade applications was begun in FY14. This will provide baseline public data and cost models of carbon fiber composites used in wind applications.

Oak Ridge National Laboratory | Montana State University