RESEARCH
in Progress

Advanced Housing
Research Center
Forest Products Laboratory
Madison, Wisconsin

Viscoelastic Response of Natural Fiber Composites

Six-axis test machine developed at FPL for evaluation of multi-axis strain-stress relations.

Natural fiber–thermoplastic composites with high fiber loading (greater than 50% fiber) are rapidly making their way into the structural applications market. These products are typically manufactured by mixing a natural fiber, such as wood, jute, or sisal, with a common household thermoplastic, such as polyethylene, polypropylene, or polyvinyl chloride, and small amounts of other additives to aid in processing or increase durability. This mixture is heated and formed into shapes under pressure by either extrusion or injection molding. The rapidly increasing interest in natural fiber–thermoplastic composites is due in part to a "market pull" driven by concerns over preservative treating of wood and the perception of increased durability of fiber–plastic composites. However, relatively little has been published to validate this perception of increased durability, especially in the area of serviceability due to the viscoelastic (particularly long-term or creep) properties of this class of materials.

Background

Because these materials are relatively new and most are proprietary, not much information is available in the literature about their viscoelastic, particularly long-term or creep, response. Knowledge of viscoelastic response is critical for computing the creep behavior of these materials. Companies are bringing products to market without much engineering analysis in this regard. Most of the studies have focused on one technique, either dynamic mechanical analysis (DMA) or creep testing, to investigate viscoelastic behavior. Very few researchers have reported whether the time–temperature–superposition principle held for these materials by conducting both DMA and creep tests. Building codes require that fiber–thermoplastic composite lumber products be subjected to a 48-h creep test at design load and a 90-day creep–rupture test at two times the design load. No data exist as to whether these tests will provide a safe product in 10 years or beyond. Furthermore, these tests fail to recognize the influence of degradation of these materials by ultraviolet or water on their viscoelastic behavior.

Objective

A set of standardized experimental and analytical tools must be developed to aid producers and code agencies in developing and validating, respectively, structural products fabricated from natural fiber–plastic composites. The objective of this research is to understand the time-dependent behavior of fiber–plastic composites from fundamental mechanics of materials principles in order to provide the experimental and analytical tools needed by producers and regulatory agencies.

Approach

Dynamic mechanical analysis will be compared with small coupon and full-scale structural member creep behavior to establish practical models that relate the viscoelastic response of small coupon specimens to full-scale structural members, such as deck boards and guardrails. Additionally, samples will be subjected to ultraviolet radiation or moisture, or both, to see how these environmental factors influence viscoelastic response. All procedures involving small coupons will be conducted with both unexposed and exposed material.

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A comprehensive testing regime will be established to systematically evaluate the natural fiber composites. Initial small coupon testing will involve five repetitions from each of 15 formulations (five from the Forest Products Laboratory, three from Teel Global Resources, Inc., two from Washington State University, and five from commercial producers).

Task 1: Establish quasi-static baseline properties—The initial quasi-static mechanical behavior must be known before the influence of time can be measured. These baseline quasi-static mechanical properties will be established by mechanical testing following standardized ASTM procedures. The small coupon testing will involve three basic tests—compression, tension, and flexure. Tension tests will follow ASTM D 638 Tension Test Method Type I (for thickness less than 0.28 in.) and Type III (for thickness greater than 0.28 in. and less than 0.55 in.). Compression tests will follow ASTM D 695 Test Method. Flexure tests will follow ASTM D 790 Test Method-I with a span of 16 times the depth. Additionally, spans of 5, 10, and 20 times the depth will be used to determine a shear modulus in flexure. These standardized ASTM tests will help set load limits for the creep tests. These quasi-static procedures will be repeated for exposed samples.

Task 2: Quasi-static testing of full-scale structural components—Full-scale testing is required to establish the mechanics of materials models for quasi-static material properties measured in Task 1 and to provide a baseline response for full-scale creep tests. Complex interactions may occur in a full-scale test member that may not be readily apparent from small coupon data. These interactions need to be determined before analyzing time-dependent data. The test condition will represent loading that the structural component would experience in service.

Task 3: Complete six-axis quasi-static material mechanical property evaluation—Small coupons will be tested in a six-degree-of-freedom test machine being developed at the Forest Products Laboratory. This test machine allows for the assessment of multi-axis states of strain–stress not achievable by standard test methods currently employed for material evaluation. These multi-axis states of strain are more representative of conditions seen in service than are the standardized ASTM test methods. Specimens will be sized to the specifications of ASTM D 638 Tension Test Method. The maximum principal strain will be set to correspond to the maximum strain rate as specified in ASTM D 638 Tension Test Method. All unique quadrants of strain space will be tested to develop a three-dimensional material behavior space.

Task 4: Dynamic mechanical analysis and creep testing—Dynamic mechanical analysis (DMA) is a tool that can be used with the concept of time–temperature–superposition to rapidly determine the viscoelastic properties of a material. For the objectives of this research, DMA can be used to accelerate the evaluation of creep behavior of fiber–plastic composites. This is accomplished by cyclically loading, at different frequencies and temperatures, small coupons. The load–displacement behavior at these different frequencies and temperatures are combined into a master curve that is used to extrapolate time. These experiments will be repeated with exposed specimens.

Creep testing will be done on small coupons in compression, tension, and flexure (following ASTM methods) and on full-scale structural components. These tests will provide two important results. First, deformation over time will be compared with the master curve models developed by DMA. Second, the ability of small coupon creep data to predict full-scale creep behavior by fundamental mechanics of material models will be verified. The small coupon tests will be repeated with exposed specimens.

Expected Outcomes

Expected outcomes of this research will include recommendations for a suite of experimental and analytical tools to understand the viscoelastic behavior of natural fiber–thermoplastic composites. The experimental tools will be beneficial to establish standards for evaluating the creep response of this class of materials. The analytical tools will aid material producers in creating components based upon a rational design methodology.

Timeline

This project will begin in October 2003 and end September 2005.

Contact Information

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