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Material behaviour

Mechanical behavior of microcellular, natural fiber reinforced composites at various strain rates and temperatures

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ABSTRACT

The mechanical properties of polypropylene (PP) composites with short, wheat straw natural-fiber reinforcements are studied in tension at various temperatures and rates of loading. Specimens of two fiber lengths have been considered with both closed-form, microcellular voids and in solid form. Results of mechanical stress-strain tests are given at static to moderate rates of strain, specifically 0.0005/s, 0.025/s and 14/s. Testing at these strain rates is conducted up to specimen failure at low, room and high temperatures of −30 °C, 22 °C, and 107 °C, respectively. Primary findings suggest that fibers increase the tangent modulus and ultimate stress, while reducing the failure strain, compared to pure polymer. The presence of microcellular voids generally reduces ultimate strength, but does not reduce failure strain. In many cases, the microcellular composites display reduced rate sensitivity that would result in the development of lower stress than solid counterparts during high rate and/or high strain events. The performance difference between the two fiber cases studied here is largest at room temperature and quasi-static strain rates, and in most cases becomes insignificant with increasing or decreasing temperature and increasing strain rates.

1. Introduction

Natural fiber composites (NFCs) can offer advantages over traditional glass fiber composites (GFCs) in cost, performance, noise attenuation [1–3], recyclability, disposal [4], carbon footprint and supply-chain considerations, including worker exposure hazard [3–5]. Additionally, when NFCs with isotropic mechanical properties are needed, fiber can be obtained from low-value agricultural byproducts such as stalks, without competing with food sources [6]. Though often much less stiff than GFCs, NFCs may have an inherent advantage in products such as energy absorption guards or safety equipment, depending on strain rate [1]. Some fibers, notably flax and hemp, have Young's modulus values approaching that of glass, but with lower density and specific tensile strength [2,3], and NFCs may contain larger volumetric fractions of fiber, further reducing cost and environmental impact by displacing petroleum used in the production of conventional fibers.

Although the manufacture and static behavior of natural fiber composites has been studied extensively [1–3,5–10], only a few studies are available of their mechanical rate behavior [7,9,11] particularly for the case of microcellular composites [7]. Works studying temperature and rate dependence do not appear to be available for solid or microcellular cases. The current work investigates strain

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rate and temperature dependencies of natural fiber, solid and microcellular polymeric composites. In both the solid and microcellular cases, two kinds of chopped fiber composites are manufactured and tested, those containing short wheat straw fibers and those containing longer wheat straw fibers. A common injection molding grade polypropylene homopolymer is used as the base polymer in all cases. Tensile stress-strain testing has been conducted at low, high and room temperatures, and at three rates of strain.

2. Materials and experimental methods

2.1. Test system overview

Tensile testing was performed on a test system designed for rate testing and described in [12]. It incorporates a ball-bearing rail device, with features that enable the collection of data via an attached force gage, displacement encoder and accelerometers (Fig. 1). It also provides the means to apply tensile or compressive forces with a high degree of directional accuracy. Once a specimen is mounted in the device, forces may be applied by an appropriate forcing unit. In the present case, the testing forces were applied at low (quasi-static) strain rates by a servomotor force actuator; for moderate strain rates of 14/s, a steel striker piston was driven by compressed air into the striker plate (Fig. 2).

For testing at temperatures above and below room temperature, the testing fixture is fitted with a heating or cooling cylindrical chamber that encloses the specimen and maintains a controlled internal temperature. Fig. 3 shows the cold chamber, which is similar to the hot test chamber. A pair of cylindrical specimen grips extend into the chamber through plastic end caps with about 1 mm diametral clearance. The grips can also be seen in Fig. 4. The cold test chamber consists of an extruded aluminum tube with six internal, longitudinal passages (Fig. 3). The end caps are constructed of ultra-high molecular weight (UHMW) polyethylene plastic, and ported to permit liquid or gaseous nitrogen to travel sequentially, lengthwise, through the internal passages. A simple plastic needle valve is used to manually control the flow through the funnel. The threaded outlet port is used to apply back pressure via the use of a water column. Controlling the back pressure allows easier manual control of temperature.

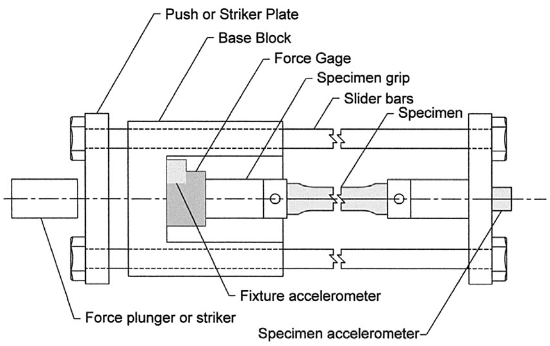

Fig. 1. Tensile test fixture apparatus.

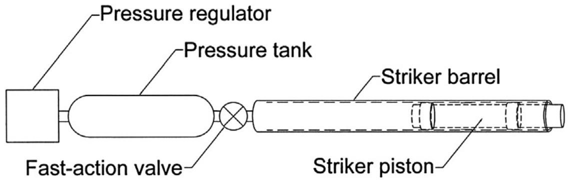

Fig. 2. Air pressure striker device (not to scale).

Heating of the specimen is achieved by a resistance heating wire within the hot chamber, wound in the space between joined coaxial metal tubes. This shields the specimen from direct radiant heating from the wire. Temperature is monitored by a type K thermocouple within the chamber, and is controlled by a solid-state thermal controller.

2.2. Testing procedure

Test specimens were visually inspected for obvious flaws or variation, then drilled at the attachment ends to clear the 1/4-20 screw used in the circular grips. The grips were assembled into the test fixture, and the test specimen was lightly secured in the moveable grip. A toolmaker's surface gage and dial indicator (Fig. 4) were used to verify that the specimen was installed precisely aligned with the direction of the pull (within 0.13 mm over 100 mm gage length), and the holding clamps tightened.

Tests were conducted at three rates of strain: 0.0005, 0.025, and 14/s; and at three temperatures: −30 °C, 22 °C, and 107 °C. The specimen was unconstrained during the heating and cooling periods to prevent thermal pre-loading stress.

For the two lower rates of strain, a servomotor actuator (Test Resources Model 500#) was used to provide steady 3 mm/min and 150 mm/min rates of extension, resulting in strain rates of 0.0005/s and 0.025/s on the 101.6 mm gage length. The force actuator was controlled by a Test Resources Model Q Controller. Time and extension data produced by the actuator were collected and time-synchronized with force data from a Test Resources

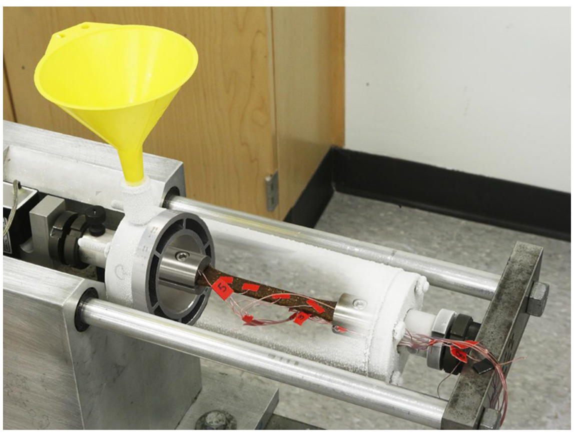

Fig. 3. Cold chamber cutaway, showing coolant passages, round grips and thermocouples.