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Tension and Compression Creep Apparatus for Wood–Plastic Composites

ABSTRACT: Design of structural members made of wood-plastic composites (WPC) is not possible without accurate test data for tension and compression. The viscoelastic behavior of these materials means that these data are required for both the quasi-static stress-strain response, and the long-term creep response. Their relative incompressibility causes inherent difficulties in creating effective clamping devices that do not preload the specimens. In order to conduct repeats of both test modes at multiple stress levels for at least 90 days, uni-axial test apparatuses must be economical and mass producible. Further, all tests must be conducted in an environment that is moisture and temperature controlled, creating space constraints. This paper describes economical apparatuses for both tension and compression creep testing that do not preload the specimens, require a minimum of floor space, and are easy and safe to load and unload. The operation and typical data for the tests are presented to demonstrate the apparatuses.

KEYWORDS: creep, wood-based products, test fixtures, duration of load, tension, compression

Introduction

Wood–plastic composite (WPC) products have become more prevalent in residential decking over the past decade due to their perceived low maintenance and “green” appeal. They have not yet been used substantially as structural members, presumably because of concerns about low stiffness, load-duration failure, and creep. Creep is defined as a time-dependent deformation under a constant load [1]. Recently, several standards have been put in place to ensure that these decking products perform satisfactorily under time-dependent and exposed conditions. ASTM 7032 [2] describes the procedures to establish a performance rating of WPC deck boards and guard rails, which is used in conjunction with an International Code Council performance specification in order to approve particular products. This ASTM standard is effective in approving new or established products, but little information about the material properties is gained from the process. Other standards, such as ASTM D6108 [3], ASTM D6109 [4], ASTM D6112 [5], and ASTM D7031 [6], establish methods to evaluate the mechanical or creep performance of WPC products. None of these standards; however, address creep in tension, and all of them evaluate the response of the total cross section of the products, not the material with which they are shaped. This means that each profile must be evaluated as a new “material,” which is analogous to conducting a full evaluation of every steel W section before it can be used. Evaluating the full cross section also requires that the testing apparatus be proportional to the size of the product, which may be difficult when testing large members.

Unlike sawn lumber and wood composites, thermoplastic products can be extruded in a wide variety of cross sections, although most are currently solid rectangles. In order to truly engineer WPC members, the uni-axial and shear behavior of the material must be determined over both short and long time scales. This information would allow the optimization of a product cross section based on its material properties, which is not currently possible.

Guidance for testing general plastic coupon specimens in tension and compression is given in ASTM D638 [7] and ASTM D695 [8], respectively. These standards describe the specimen sizes and shapes that are acceptable and there is some description of the apparatus that might be used in a quasi-static, constant strain-rate test. Quasi-static tension or compression tests on WPC specimens have been conducted by Haiar [9], Kobbe [10], Pooler and Smith [11] and Carroll et al. [12]. Kobbe and Pooler and Smith also conducted creep tests for 100 and 1000 min, respectively. These creep tests were conducted with servomechanical or servohydraulic universal test machines. Lee et al. [13] used a clamping system, which was not described, and weights for a 6 h tension creep tests, whereas Marklund et al. [14] did a similar test for varying times, the longest of which was 48 h. In order to evaluate WPC material properties according to ASTM 7031 [6], multiple repetitions of creep tests (typically 28) with a duration of 90 days or more at several stress levels must be conducted simultaneously, making a universal test machine uneconomical. Specialized clamping and loading equipment that can be easily replicated are more practical for this task. This equipment must be small enough to fit in an environmentally controlled space, which also limits use of large weights when testing a large number of specimens.

Another method that has been used for creep testing is commercially produced dynamic mechanical analyzer (DMA) machines, which allows for precisely controlled temperature and humidity conditions. These machines are generally limited in their size and load capacity and can only test one specimen at a time.

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This means that tests are usually conducted on very small specimens for short durations. Tajvidi et al. [15] and Nunez et al. [16] used DMA machines to test creep in small WPC specimens for less than 30 min.

One study that included an apparatus description for both tension and compression was by Benham and McCammond [17]. This study was conducted on several pure polymers, not a WPC. They used serrated bushings and fork-end members to grip the specimens, but more detail was not given. The compression apparatus used linear motion bearings, which we have found to be too expensive when producing a large number of apparatuses. Benham and McCammond used their apparatus for tests with duration of 11 days, which allowed them to reuse the equipment multiple times.

The objective of this work is to develop long-term load apparatuses for tension and compression creep testing of WPC coupon specimens that (1) have a relatively simple and quick mounting process, (2) do not apply axial force to the specimen during the mounting process, (3) can be used with various load application methods, and (4) are easy and economical to fabricate.

Description of the Tension Apparatus

A creep test is defined as a constant stress test, but it is generally unnecessary to account for dimensional changes, making it acceptable to maintain a constant load throughout the test [18]. This load is applied as quickly as possible from an initial state of zero stress. The viscoelasticity and relative incompressibility of filled thermoplastics makes constructing a simple clamping mechanism challenging. As squeezing force is applied by the clamping mechanism, the specimen must be allowed to expand in the axial direction; otherwise substantial internal axial compressive prestress will develop due to the relative incompressibility of the thermoplastics. This stress initiates a complex combination of creep and relaxation. Relaxation is defined as the decrease in stress over time in a viscoelastic material due to a constant applied strain [1]. Our initial attempts to construct a clamping mechanism with grips that were fully fixed during the mounting process created axial compression stresses as high as 50% of the ultimate tensile strength of the material. If this prestress was present for several minutes during the mounting process, the specimens begin to creep and relax opposite the tensile test direction, which greatly affects the subsequent test results. A system was sought that eliminates unwanted forces during the test (such as bending), allows axial expansion during mounting, and is simple enough to mass produce economically.

The successful tension apparatus involved a hook and ring system attached to the specimen with serrated clamps at each end, as shown in Fig. 1. This system conceptually releases all degrees of freedom except those required for tension. Two 63.5 mm × 31.5 mm × 6.4 mm (2.5 × in. 1.25 × in. 0.25 in.) aluminum blocks, each serrated on one face, were secured to the specimen at its ends by tightening a 6.3 mm (1/4 in.) unified national fine thread machine bolt through a hole in the blocks and the specimen. This required holes to be drilled at each end of the specimens along its centerline. The bolts were tightened to 6.8 N·m (60 lbf in.) of

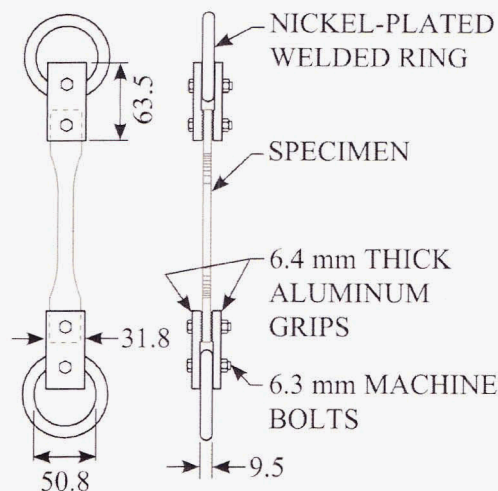


FIG. 1 — Tension creep ring-grip assembly for WPC coupons, dimensions in mm.

torque using a mechanical torque wrench, which produced a compressive “squeezing” force on the ends of the dog bone that was calculated to be approximately 4.5 kN (1000 lbf). The other end of the aluminum blocks were bolted to a 9 mm thick × 50 mm (3/8 in. × 2 in.) inside diameter welded steel ring using the same size bolts. The rings and bolts were zinc-plated to avoid corrosion in the testing environment. The clamp system, which requires holes in the specimen, was chosen because it is lightweight and easy to construct. The weight of the clamp system is an important consideration because the specimens must support it during the mounting process, before the full load is applied.

When desired, a load cell was secured between the aluminum blocks and a threaded eye-bolt, which replaced the steel ring. Locating the load cell between the specimen and the hinge joint ensured that the load measurements were of the applied axial forces only. Mounting the specimens to the clamp system was conducted on a specially constructed loading jig that ensured that all four bolts, the specimen’s centerline, and the ring centers were collinear in both axes (in- and out-of-plane). This guaranteed that the specimen would be loaded in its major axis direction only and would not experience bending. Only one end of the specimen assembly was secured at a time during clamping, allowing axial expansion and eliminating any pre-load. The jig firmly secured the aluminum blocks with a steel crossbar to ensure that the tightening torque did not apply stresses within the specimen’s gauge length.

Three different methods were used to apply the creep load to the tension specimen assemblies. In each method, the nickel-plated rings were connected to rigid open hooks that supported up to 4.5 kN (1000 lbf) without permanent deformation. These hooks were made with 9.5 mm (3/8 in.) steel bar, which was bent into a curved shape with an inside diameter of 19 mm (3/4 in.). The first load method applied force to the specimen simply by hanging weights from it. The top assembly ring was hung from a rigid hook and weights were applied with a hook on the bottom ring. The loading procedure is simple and quick for forces up to about 200 N (50 lbf). Using weight for higher loads requires more space

and becomes increasingly less safe for laboratory personnel. A lever arm system, as described by Findley et al. [18] may be used to increase the load created from dead weight. This was not done, however, in order to conserve room in the environmentally controlled space. Two pneumatic systems were developed for larger loads, a single-specimen apparatus and a two-specimen apparatus, described in the following. The pneumatic systems require precisely maintained air pressures, which were provided for each test using electropneumatic regulators. The regulators use an electronic feedback control system, which accurately maintains the specified pressure despite minor system leaks. In the event of a power failure, the regulators maintain their pressure and have a battery backup. A backup air tank with one-way valves was also provided to supply compressed air in case of an air system failure.

The force on the single-specimen pneumatic system was provided by a 100 mm (4 in.) diameter dual-action diaphragm-type pneumatic cylinder capable of “pulling or pushing” on its piston rod. A steel reaction frame was constructed and the rigid hooks were attached to the frame and rod as shown in Fig. 2(b). The welded rings on the specimen assemblies were secured to the hooks during mounting and air pressure was applied to initiate loading. With 400 kPa (60 psi) of pressure, more than 2.7 kN (600 lbf) of force can be applied to the specimen. The two-specimen system used a larger 150 mm (6 in.) diameter bladder-type pneumatic cylinder that is only capable of “pushing” on its piston rod. For this system, the force was transferred from the piston rod to each specimen through a loading arm, as shown in Fig. 2(a). The loading arm was attached to the piston rod with a bearing pin allowing the arm to rotate so that the force is equally distributed to the two specimens, regardless of the creep response. This system can apply over 3.5 kN (800 lbf) to each specimen with 400 kPa (60 psi) of air pressure. A rigid crossbar is also provided to

stop the piston rod in the event of a specimen failure. The loading arm was suspended from the crossbar with small wires to support its weight, allowing the specimens to hang freely prior to loading. Pneumatic cylinders are commercially produced in a variety of sizes and are both more economical and easier to assemble than hydraulic systems. Various cylinder sizes and air pressures can be used to provide the necessary forces.

Description of the Compression Apparatus

Haier [9] found through compression testing of full cross sections of WPC products that the failure mode was local crushing near the ends, possibly caused by the boundary conditions. To reduce the localized stresses at the loading faces, and to ensure that the intended stress was being experienced in the region at which the strain measurements were taken, a compression dog bone was developed. Using a finite-element analysis (FEA) technique similar to one presented by Garrell et al. [19], dog-bone specimens were examined with inside radii of 12, 24, and 36 mm. It was found that the maximum stress experienced by the specimens with the largest radius was 18% lower than those with the smallest radius. However, unlike tension coupons in which fracture may limit the recorded strength, maximum localized stress is not the primary concern in compression coupons. Instead, uniform stress in the gauge length and unbraced length are important to determine accurate strains and prevent buckling. FEA analysis showed that the stresses in the zone of strain measurement, the specimen gauge length, differed by less than 3% of the nominal stress for all three radii. As the shorter radius significantly reduced the out-of-plane buckling length of the coupon specimen, a radius of 12.5 mm was chosen. The specimen dimensions are shown in Fig. 3.

The compression specimens were mounted vertically with a pneumatic cylinder below as shown in Fig. 4. The imposed force was transferred to the specimen through end-bearing using C-shaped steel brackets. The stationary top bracket was secured with a support frame, whereas the moveable bottom bracket was attached to the cylinder piston rod. The sides of each steel bracket were penetrated and threaded to accept 16 mm machine bolts, which were used to immobilize the specimen and prevent buckling in the minor direction. Attached to the machine bolts on the bottom bracket were serrated swivel pads, whereas the top bolts were fitted with zinc plated jam nuts, which have a smooth face. The bottom bolts were hand tightened to secure the specimen,

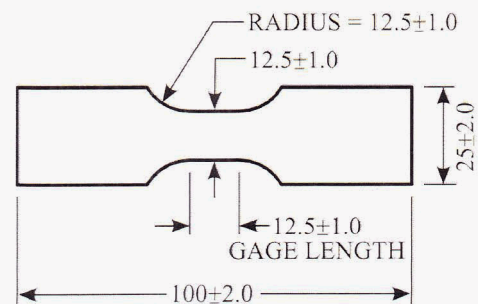
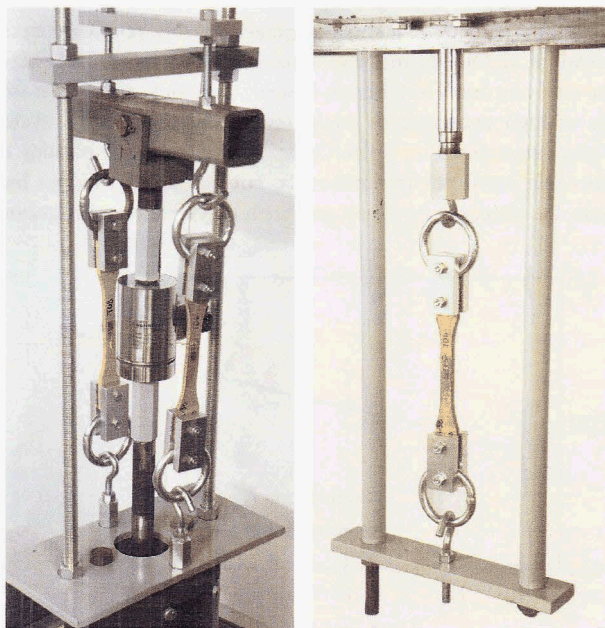


FIG. 3 — Compression dog-bone specimen, dimensions in mm.

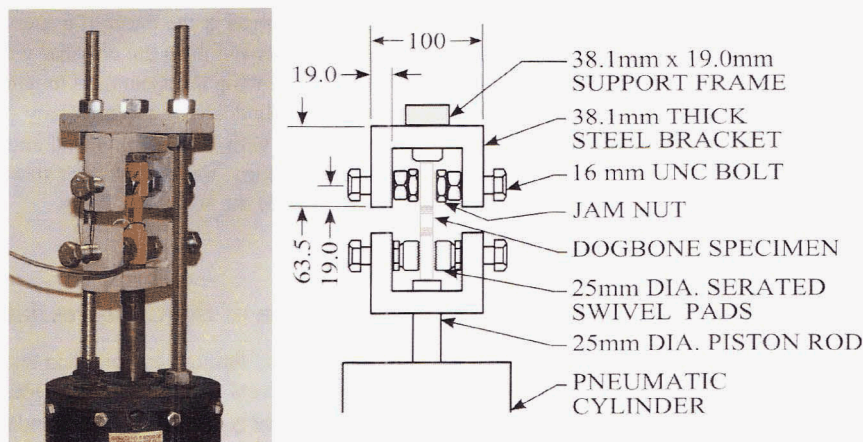


FIG 4 — Compression creep apparatus: photograph and (b) schematic, dimensions in mm.

whereas the top bolts were adjusted so that they just touched the specimen. This allowed the specimen to slide vertically through the jam nuts during loading, while still being braced against out-of-plane buckling. The two brackets were connected with wire loops to support the weight of the bottom bracket prior to loading. Once the pneumatic cylinder was engaged, the specimen was moved upward ~5 mm until the top bearing face contacted the top bracket, initiating loading.

Test Data and Discussion

Twelve tension ring-grip assemblies and 12 compression apparatuses were built. The tension assemblies were used with all three loading systems for up to 180 days at temperatures from 25°C to 50°C. Axial strains in the specimens were measured with strain gauges mounted on two faces of the gauge length. Load, strain, and environmental data were recorded every second at the start of the test until 10 min and then every 5 min thereafter. Typically, the strain measurements began prior to the clamping and/or mounting processes to ensure that these processes did not cause strains in the specimens. The strain responses of a two tension specimens are shown in Fig. 5. Figure 5(a), which shows the loading of the creep tests, demonstrates that specimens did not experi-

ence any unwanted strain during the clamping or mounting processes. Applying the clamp assembly to tension specimens required only a few minutes for one person, and mounting the assembly into the loading apparatus took only a few seconds. Results from 90 day tests using the single-specimen tension apparatus are shown in Fig. 5(b). Results of the other two loading methods were similar. Equally successful results were obtained using the compression apparatus as shown in Fig. 6.

The two-specimen tension configuration was created because it increases the number of specimens that can be conducted in a given time and space. The larger “bladder”-type cylinders were found to have a slower leak rate and provided a steadier load level than the cylinders with a diaphragm and seal. The single-specimen apparatus, however, can measure the strain at rupture of every specimen, whereas the two-specimen test must be stopped after the first specimen fails.

The ring-grip system was designed for WPCs, but it can be used for any material that is comparatively soft, relatively incompressible, and highly sensitive to loads applied immediately before the start of a creep test. Plastic lumber, thermoplastics, and materials at high temperatures could also be used with this system. These apparatuses may also be used with thermoset plastics and fiber-reinforced polymer materials, but due to their higher hardness, the clamping force and grip teeth may require modification.

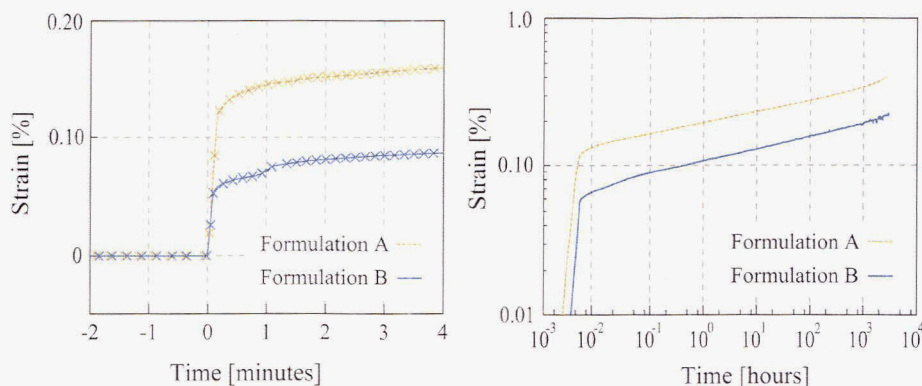


FIG. 5 — Strain responses of WPC coupon specimens loaded in tension: (a) at loading and (b) for 90 day test duration.

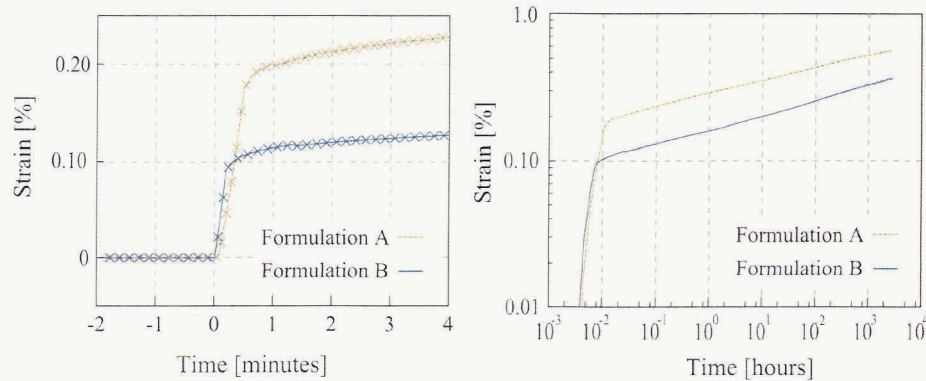


FIG 6 — Strain responses of WPC coupon specimens loaded in compression (a) at loading and (b) for 90 day test duration

Summary

The creep loading apparatus was constructed using standard machine design and off-the-shelf parts. The parts and machining was simple and relatively inexpensive. The creep test system shown in this paper is an improvement over fixed grip systems, universal test machines, and DMA machines for these reasons:

- Does not apply a prestress to the specimen

- Can be loaded by one person without special lifting apparatus.

- Construction of the apparatus is relatively simple and inexpensive.

- A large number of tests can be conducted simultaneously in a relatively small space.

- Provides flexibility in load application method.

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References

- [1] Lakes, R. S., *Viscoelastic Solids*, CRC Press, New York, 1999.
- [2] ASTM-D7032, 2007, "Standard Specification for Establishing Performance Ratings for Wood-Plastic Composite Deck Boards and Guardrail Systems," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA.
- [3] ASTM-D6108, 2003, "Standard Test Method for Compressive Properties of Plastic Lumber and Shapes," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA.
- [4] ASTM-D6109, 2005, "Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastic Lumber and Related Products," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA.
- [5] ASTM-D6112, 2005, "Standard Test Methods for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber Shapes," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA.
- [6] ASTM-D7031, 2004, "Standard Guide for Evaluating Mechanical and Physical Properties of Wood Plastic Composite Products," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA.
- [7] ASTM-D638, 2002, "Standard Test Method for Tensile Properties of Plastics," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA.
- [8] ASTM-D695, 2002, "Standard Test Method for Compressive Properties of Rigid Plastics," *Annual Book of ASTM Standards*, ASTM International, West Conshohocken, PA.
- [9] Haiar, K. J., 2000, "Performance and Design of Prototype Wood-Plastic Composite Sections," Masters of Science, Washington State Univ., Pullman, WA.
- [10] Kobbe, R. G., 2005, "Creep Behavior of a Wood-Polypropylene Composite," Masters of Science, Washington State Univ., Pullman, WA.
- [11] Pooler, D. J. and Smith, L. V., "Nonlinear Viscoelastic Response of a Wood-Plastic Composite Including Temperature Effects," *J. Thermoplastic Compos. Mater.*, Vol. 17, 2004, p. 427.
- [12] Carroll, D., Stone, R., Sirignano, A., Saindon, R., Gose, S., and Friedman, M., "Structural Properties of Recycled HPE Plastic Lumber Decking Planks," *Int. J. Polym. Mater.*, Vol. 52, 2003, pp. 709–724.
- [13] Lee, S., Yang, H., Kim, H., Jeong, C., Lim, B., and Lee, J., "Creep Behavior and Manufacturing Parameters of Wood Flour Filled Polypropylene Composites," *Compos. Struct.*, Vol. 65, 2004, pp. 459–469.
- [14] Marklund, E., Varna, J., and Wallstrom, L., "Nonlinear Viscoelasticity and Viscoplasticity of Flax/Polypropylene Composites," *J. Eng. Mater. Technol.*, Vol. 128, 2006, pp. 527–536.
- [15] Tajvidi, M., Falk, R. H., and Hermanson, J. C., "Time-Temperature Superposition Principle Applied to a Kenaf-Fiber/High-Density Polyethylene Composite," *J. Appl. Poly. Sci.*, Vol. 97, 2005, pp. 1995–2004.
- [16] Nunez, A. J., Marcovich, N. E., and Aranguren, M. I., "Analysis of the Creep Behavior of Polypropylene-Wood-flour Composites," *Polym. Eng. Sci.*, Vol. 44, 2004, pp. 1594–1603.
- [17] Benham, P. B. and McCammond, D., "Studies of Creep and Contraction Ratio in Thermoplastics," *Plastics Polym.*, Vol. 39, 1971, pp. 130–136.

- [18] Findley, W. N., Lai, J. S., and Onaran, K., *Creep and Relaxation of Nonlinear Viscoelastic Materials, With an Introduction to Linear Viscoelasticity*: North-Holland, Amsterdam, 1976.
- [19] Garrell, M. G., Shih, A. J., Lara-Curzio, E., and Scattergood, R. O., "Finite-Element Analysis of Stress Concentration in ASTM D 638 Tension Specimens," *J. Test. Eval.*, Vol. 31, 2003, pp. 52–57.