C. Low-Cost Test Methods for Advanced Automotive Composite Materials; Creep Compression Fixture

John M. Henshaw
The University of Tulsa
600 South College
Tulsa, OK 74104
(918) 631-3002; fax:(918) 631-2397; e-mail: john-henshaw@utulsa.edu

Kenley McQueen
The University of Tulsa
e-mail: kenley-mcqueen@utulsa.edu

Ronald P. Cooper
The University of Tulsa
e-mail: ronald-cooper@utulsa.edu

ACC Project Contact: Dan Houston
Ford Motor Co.
20000 Rotunda Dr., MD 3182 SRL, P.O. Box 2053
Dearborn, MI 48121-2053
(313) 323-2879; fax: (313) 323-0514; e-mail: dhousto2@ford.com

Technology Area Development Manager: Joseph A. Carpenter
(202) 586-1022; fax: (202) 586-1600; e-mail: joseph.carpenter@ee.doe.gov
Field Technical Manager: Philip S. Sklad
(865) 574-5069; fax: (865) 576-4963; e-mail: skladps@ornl.gov

Contractor: U.S. Automotive Materials Partnership
Contract No.: FC26-02OR22910

Objectives

- Design and develop low-cost, reliable fixtures and methods for the characterization of compression creep behavior of automotive composites with and without environmental exposure. Confirm results generated by the new fixture with those from conventional testing systems.
- Incorporate the fixtures and methods in the above objective into industry-standard test methods for automotive composites.
- Using results of short-term tests, develop predictive models for lifetime property degradation.
- Investigate the fundamental damage mechanisms in polymer-matrix, carbon-fiber, and E-glass composites as a function of specific, varied mechanical loading with concurrent environmental exposure.

Approach

- Design and develop a compact compression creep test fixture system and confirm its performance.
- Use the new fixture system to develop a compression creep database.
- Develop a standard procedure for compression creep testing using the new system.

Accomplishments

- Developed and fabricated third-generation fixture prototype.
- Conducted extensive, varied testing of third-generation prototype that shows validity of design concept.
- Documented minor suggested improvements.
- Implemented new Data Acquisition System.

Future Direction

- Complete design and fabrication of third-generation prototype fixture. Evaluate fixture performance; determine if fixture modification is required.
- Conduct compressive creep evaluation of candidate composite materials using final creep compression fixture.
- Establish project end date: December 31, 2005.

Introduction

Because of insufficient information on the long-term durability of lightweight composite materials, reliable methods and models requiring relatively short-term tests are essential to composites achieving their full potential in the automotive industry. The purpose of this project is to develop simple, low-cost fixtures and methods for the creep and creep-rupture characterization of automotive composites and confirm the in-situ creep test fixture results with those obtained using conventional testing methods.

Initial Design Concept For The Compression Creep Fixture

Several design specifications were targeted when developing the initial prototype fixture during the first year of this project. The creep compression fixture must simulate in-service loading conditions by allowing the specimen to be exposed to various automotive environments. The fixture must also be lightweight, compact, relatively inexpensive, and portable compared to industry-standard dead weight creep testing fixtures. Lastly, the data generated by the fixture should be of design quality while comparing favorably to Oak Ridge National Laboratory (ORNL) and literature data. A successful fixture will also be corrosion-resistant, capable of testing American Society for Testing and Materials (ASTM) standard compression coupons, and exhibit no signs of specimen buckling.

Prototype 3 Design Details

The third-generation prototype currently under development utilizes a four-pin design where the specimen fits inside two compression blocks that are pressed toward each other by load reversing pins (Figures 1 and 2). The ends of the pins are threaded into a connecting bracket that, in turn, mounts to either a clevis joint on a spring-loaded moment arm or into a standard load frame (Figure 3). Prototype 3 is capable of testing compression specimens that are 5 in. long, which is near the recommended ASTM D3410 standard length. Earlier prototypes utilized an undersized specimen.

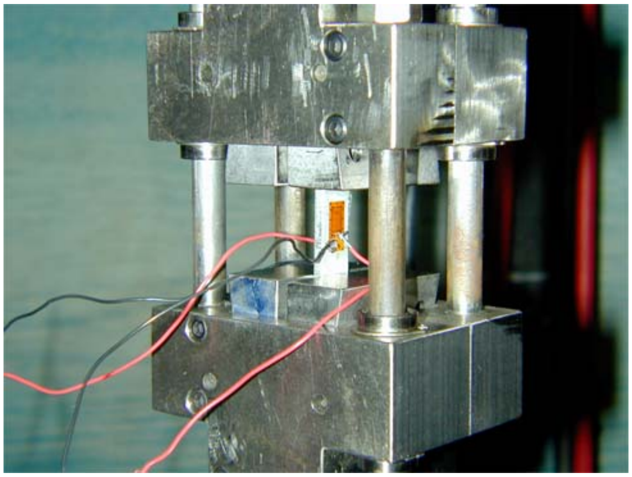

Figure 1. Third-generation creep compression prototype shown during a compression test.

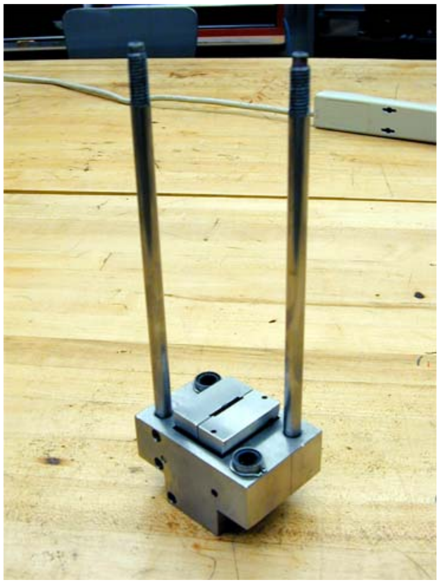

Figure 2. Disassembled creep compression fixture showing load block, load reversing pins, and slot for inserting specimen.

Figure 3. A creep compression test using the third-generation prototype. For this test, the fixture is pulled in tension in a standard load frame.

Prototype 3 Test Results

Initial testing of P4 (Programmable Powdered Preform Process) manufactured glass-reinforced polymer-matrix composite with the first-generation prototype showed compression creep behavior very similar to the compression creep curves generated by ORNL. Results of these tests were included in the 2003 annual report. As noted in that report, a problem with the earlier prototype was the difference in strain levels between opposite sides of the specimen. Such a strain difference indicates a bending load being induced on the specimen. ASTM requires compression tests to exhibit less than 5% bending. Because bending loads were frequently excessive on the old prototype, a new design was required.

The second-generation prototype, whose design was detailed in the 2003 annual report, showed improved test results, but several more modifications were desired, resulting in a third-generation prototype (as shown in Figures 1–3).

Test results with the new prototype (third-generation) have been extremely encouraging. The results of a typical test are described below and shown in Figures 4–7. For these tests, a standard-sized aluminum compression specimen (5 in. long by 1 in. wide by 1/8 in. thick), strain-gaged front and back, is loaded into the fixture, which is then pulled in tension in a standard MTS load frame (Figure 3). Various tests have been performed using this setup as part of the fixture development and prove-out process. One such test, the results of which are shown in Figures 4–7, consists of cycling the fixture from zero load to a maximum load (about 950 lb in this case) and back to zero. For the test described herein, this load cycle was performed ten times, as shown in Figure 4. (The maximum load of 950 lb was chosen in this case because that represents a typical maximum load for a carbon-fiber automotive composite tensile test.)

During these loading cycles, strain on both sides of the specimen is measured continuously. Figure 4 shows both the load in pounds during the test (compression loads are shown in pounds on the positive y-axis of the graph). Figure 4 also shows the compressive strain (in microstrain on the negative y-axis) for the same ten loading cycles. Two strain channels, for both sides of the creep-compression specimen, are shown in Figure 4. Because the two channels of strain data are so similar, they cannot be distinguished in Figure 4.

Thus, Figure 5 shows the variation in strain, expressed as the percent difference between the front and back of the specimen vs time. Figure 5 has the same time scale (x-axis) as Figure 4 to show that the percent difference is greatest at the beginning and end of each load cycle—that is, when the loads are the smallest.

Figure 6 replots the data for all ten load cycles as percent strain difference vs load; thus, all ten load cycles are superimposed on each other. Figure 6

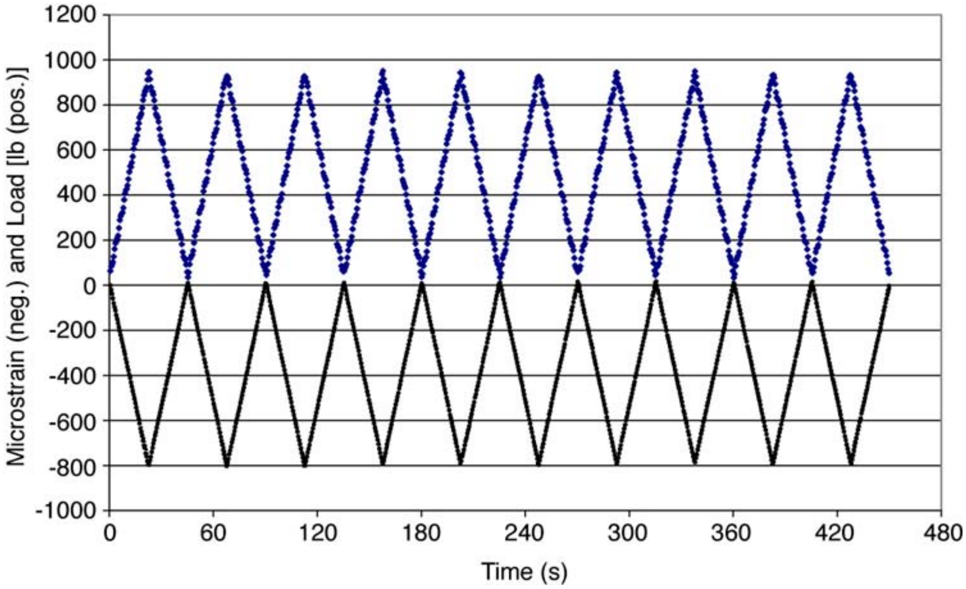

Figure 4. Load and strain for a typical creep-compression fixture development test. Ten load cycles (from zero to about 950 lb and back to zero) are shown. For each load cycle, two channels of strain (front and back of specimen) are shown. The strain data channels lie on top of one another and cannot be distinguished in this graph (see Figure 5).

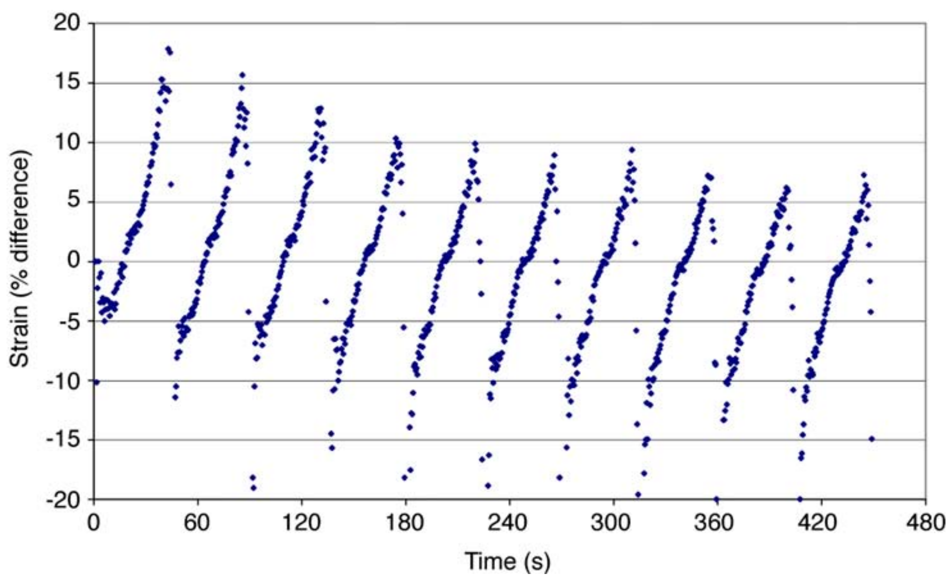

Figure 5. The percent difference in strain measurements, vs time, for the two channels of strain shown in Figure 4. Note that the percent differences are small (within ±5%) except for the beginning and ending of each load cycle, when the loads (and strains) are also small.

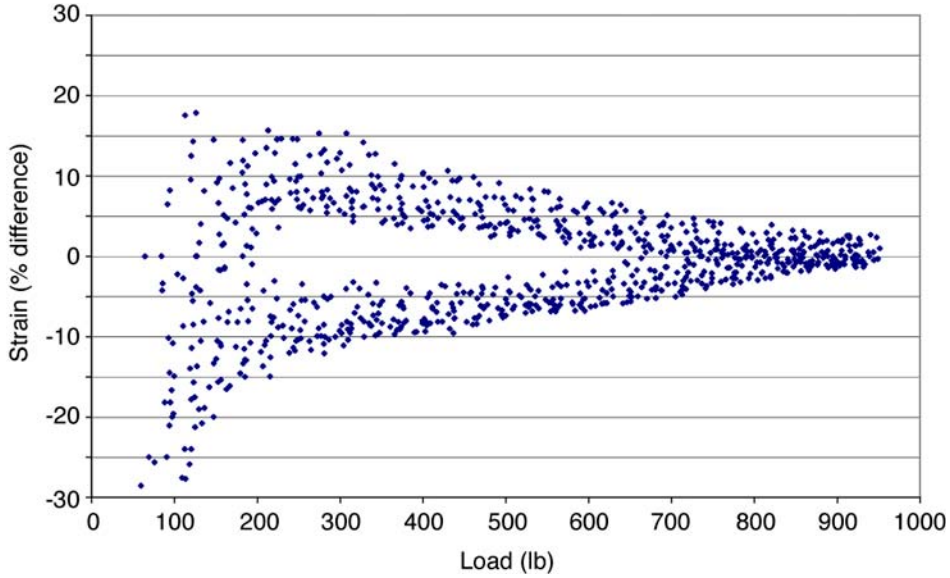

Figure 6. The data from Figures 4 and 5 plotted as percent difference (between the two sides of the creep compression specimen) vs load. Data from all ten loading cycles are superimposed.

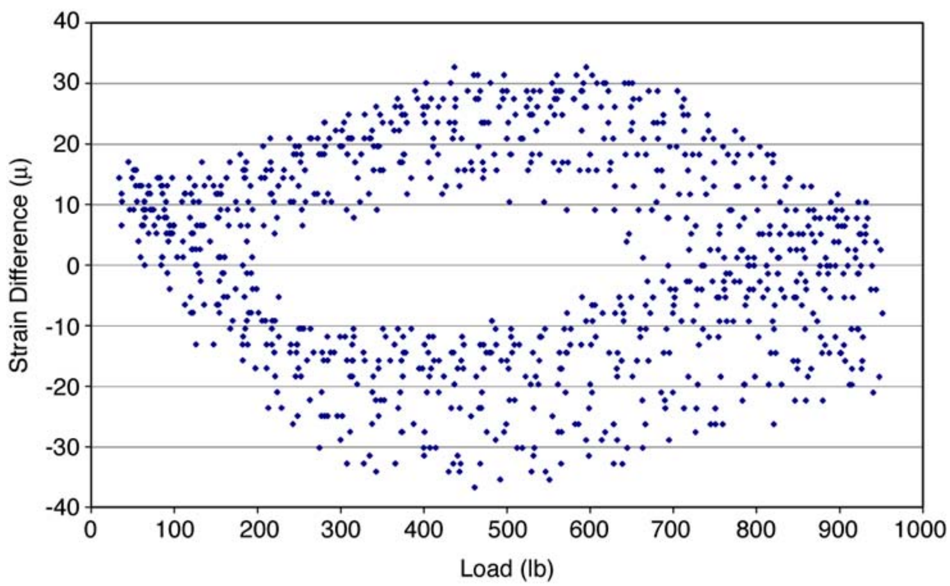

Figure 7. Data from Figure 6 replotted as the absolute strain difference in microstrain (between the two sides of the creep compression specimen) vs load for all ten loading cycles.

shows clearly that the percent strain difference decreases as load increases and that the percent difference is below the ASTM limit of 5% for loads above about 600 lb.

That the percent difference in strain is above 5% for lower loads may be at least partially explained by the low absolute strain levels at those low loads (the maximum strain levels for these tests, at applied loads of about 950 lb, are about 800 microstrain; at lower loads the strains are proportionally lower). At the lower strains, the absolute difference in strain can thus be relatively small and still result in a percent difference greater than 5%. As shown in Figure 7, the absolute difference in strain for all ten loading cycles is always below 40 microstrain.

Another important aspect of this creep compression fixture is its ability to transfer load to the specimen. Test results show that the third-generation fixture consistently transfers over 90% of the load from the load frame to the specimen, for loads in excess of about 300 lb. From these results it is concluded that the efficiency of the fixture is acceptable and that the new fixture will be able to be successfully adapted to spring-loaded, in-situ fixtures developed in earlier projects.

Test results for the third-generation creep compression prototype, as exemplified by those shown reported herein, are thus extremely encouraging.

Prototype 3 Improvements

Several minor improvements to the third-generation creep-compression fixture are envisioned. These involve design details intended to further simplify the specimen loading procedure and to further reduce specimen bending, especially at low loads.

Other Ongoing/Future Work

Continued evaluation of prototype 3 performance through short-term tests using composite and aluminum specimens is ongoing.

The minor design modifications noted above are being incorporated into a final prototype able to meet all design requirements and criteria. This will be followed by fabrication of that final prototype.

Fabrication of several such compression fixtures will then allow statistical evaluation, by researchers at several facilities, of creep compression properties of polymer composite material systems.

Conclusions

1. A third-generation compressive creep prototype has been designed, fabricated, and extensively tested.
2. Test results with this prototype are extremely encouraging, in terms of (a) the ability of the fixture to minimize the percent difference in strain from one side of a specimen to the other, and (b) the ability of the fixture to efficiently transfer load to the specimen.
3. Cyclic loading of specimens in the fixture shows excellent repeatability: the difference in front-to-back strain is below 5% for loads more than about 600 lb.
4. The fixture easily and repeatedly achieves maximum design loads of about 950 lb.