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Thermal Buckling of Composite Tubes

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ABSTRACT

The object was to design and initiate the use of a fixture capable of testing for pre-buckling deflections in a composite tube under thermal loading. The fixture is to be used on a continuing basis to test three types of composites: (1) glass/epoxy, (2) Kevlar/epoxy, and (3) graphite/epoxy. The course of action chosen was to adapt a fixture designed by Tim Streb and Steve Fulkerson in the spring of 1991. The fixture was completed, and one test was performed. An added responsibility was to initiate a course of action such that the volumetric percentage of fiber in the composite may be determined.

INTRODUCTION

A composite consists of a fiber and a matrix. The combination of a strong fibers with a dense matrix gives composites properties unlike any pure material. The objective of the assignment was to design and initiate the use of a fixture capable of measuring axial and lateral deflections when thermally loaded. The fixture needed to be capable of handling temperature up to 400 degrees Fahrenheit and remain rigid. Also, the fixture needed to be capable of supporting measuring equipment for future mechanical loadings. A secondary objective of the research was to determine the best method of finding the fiber volume fraction of cured composites. This involved investigations into organic chemistry and high magnification viewing devices. The thermal test conducted used ten strain gages, a ten band bridge, a strain indicator, two thermocouples, a thermometer, and four dial indicators. A Stabil-Therm Recirculating Utility Oven was used for the thermal environment. The equipment was to allow for measuring induced load on the composite in addition to finding when pre-buckling deformations occurred. Buckling in axially loaded tubes has been theoretically predicted and experimentally shown to occur by axisymmetric ripples [1]. The purpose of this research was to measure such a rippling effect.

DESIGN AND RESULTS

Procedure for Fiber Volume Fraction

Three distinct procedures were investigated to determine the fiber volume fraction of the material. The initial procedure used for the glass composite was to insert a small section of a completed tube in a test oven and burn off the epoxy matrix. Knowing the initial and final weights as well as the density of each material allowed a calculation of the fiber volume fraction of the original sample. However, when this procedure was suggested for the Kevlar and graphite epoxy, several chemists and ceramic engineers suggested using some alternative method. Since Kevlar and graphite are organic compounds, they would burn off at temperatures required to burn off the epoxy.

The next method suggested was to chemically remove the epoxy with nitric and/or sulfuric acid. This technique was outlined in an ASTM standard [2]. However, the supplier of the Kevlar composite material objected to such a procedure. The supplier said such tests were inaccurate and that other methods should be investigated.

As it was necessary to measure for air voids in the composite for related research by M. Farhadinia [3], it was suggested that the two assignments be combined. Farhadinia found that the university possessed an optical device capable of achieving both goals. A typical cross-section of the cured composite was cured into a surrounding matrix. This cylindrical unit was then highly polished, and high resolution photographs were taken and processed by a computer. The computer calculated the void and fiber percentage as a function of cross sectional area. When the results from the glass burnout test were compared to the optical method, a high correlation was present. Therefore, the technique chosen was the optical method.

Fixture Design

The fixture designed for the experiment involved the adaptation of a previously designed fixture by the author and T. Streb [4]. The original fixture was designed to measure thermal and mechanical loading of composite tubes. Alterations necessary included the attachment of four deflection dial indicators in a plane normal to the axis of symmetry. The dial indicators were to be placed every ninety degrees around the midpoint of the composite and be capable of measuring the horizontal deflections of axial loading. Photographs of the original design may be seen in figures 1 and 2. Figure 1 shows the setup for thermal loading. Four bars with strain gages mounted in the center restrain the composite from axially expanding. The strain gages allow for the measuring of the induced load created by the elevated temperatures (after correcting for the thermal expansion of the fixture). Figure 2 shows the setup for mechanical loading. The bottom plate is fixed. The top piece is attached to the moving head of an MTS machine. An intermediate plate allows for the adjustment of the angle of compression to ensure uniform loading around the perimeter of the composite. A sketch of the final design for thermal loading may be seen partially assembled in figure 3. The design required parts capable of being attached to an end plate for thermal loading and to the intermediate plate for mechanical loading. Four identical parts attach to the plate around the composite. Each L-shaped piece holds one dial indicator.

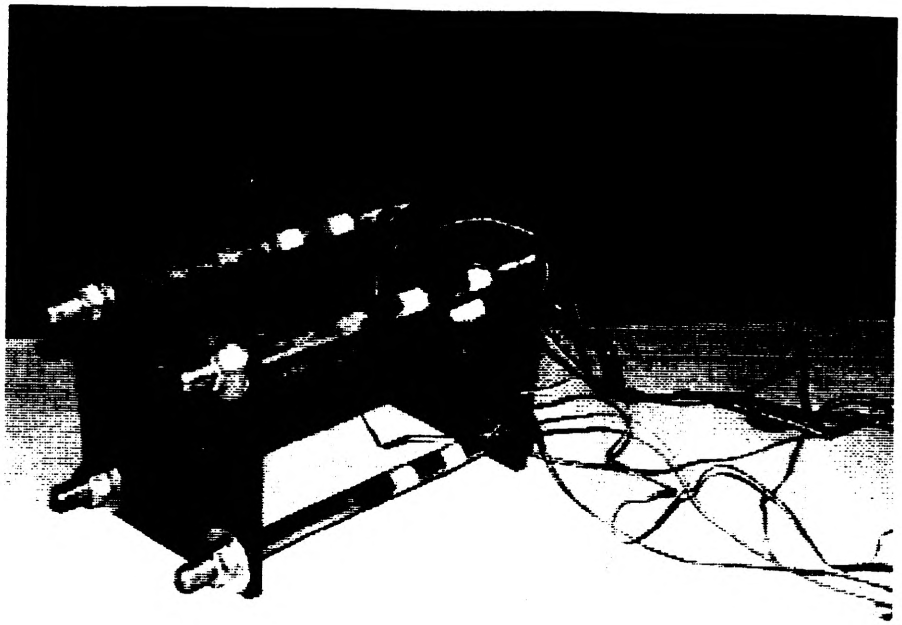

Figure 1. Fixture for Thermal Loading

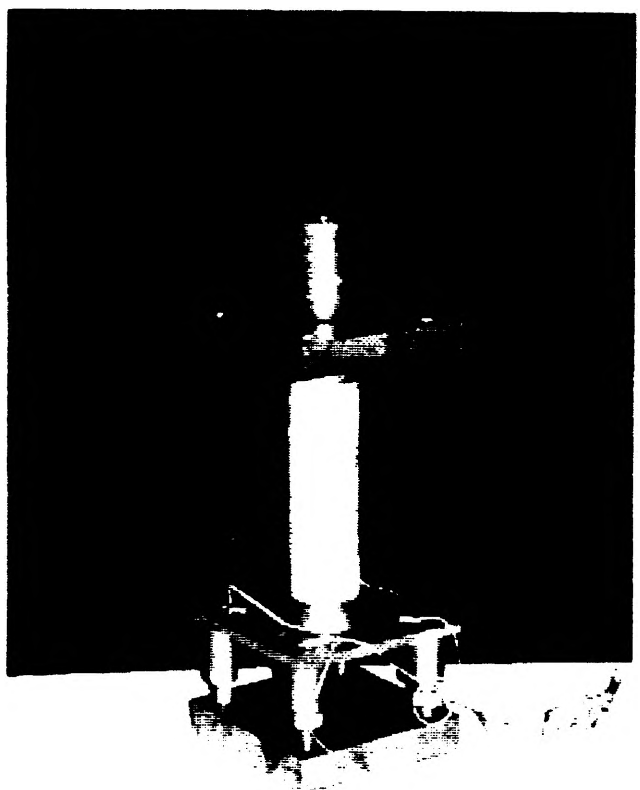

Figure 2. Fixture for Mechanical Loading

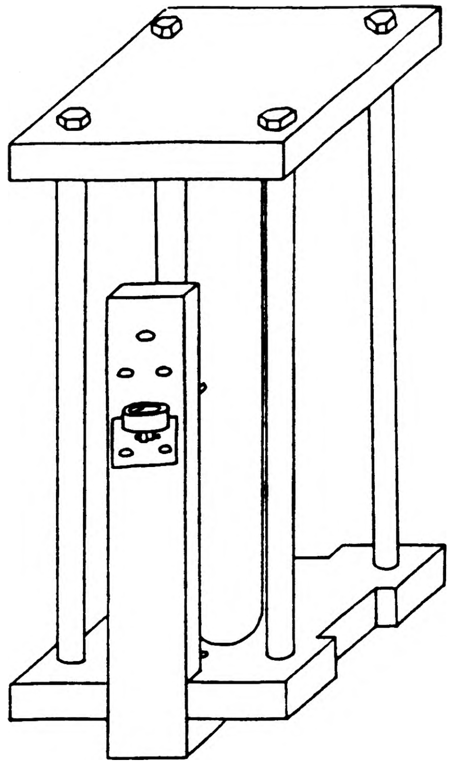

Figure 3. Partially Assembled Fixture for Thermal Buckling Test

Testing

For testing, a three layer, glass/epoxy sample was selected. Its fibers were parallel to the axis of symmetry. Four strain gages were glued to the vertical bars and six strain gages were fixed. Four deflection dial indicators were mounted, and two thermocouples were attached to the apparatus. A calibration was performed to find the natural effect of the elevated temperature on the involved systems. This was performed with no load. Finally, testing was initiated. The four bolts were tightened to a "snug" fit. The strain was zeroed, and it was assumed the induced force was negligible. The fixture was placed in the oven and heating was commenced.

RESULTS

The results were poor. No induced load was measured in the test. This was disappointing since significant loading was seen for previous tests with the fixture sans the added equipment. When testing was performed in April 1991, loads surpassed 20 kN for a similar temperature range. However, the sample tested then was a five layer Kevlar composite with circumferential fibers. Also, the previous sample was noticeably stiffer. Figures 4, 5, and 6 display the measured strain in three of the four vertical bolts versus temperature for both the calibration and experimental runs. Little difference is seen between the two curves. This clearly indicates no load was induced. An apparent error was made in the calibration curve of the remaining bolt. Though the source of the error is unknown, it can easily be remedied by simply running another calibration of the gage. Strain results for the gages attached to the sample indicated similar trends in the failure to measure induced loads.

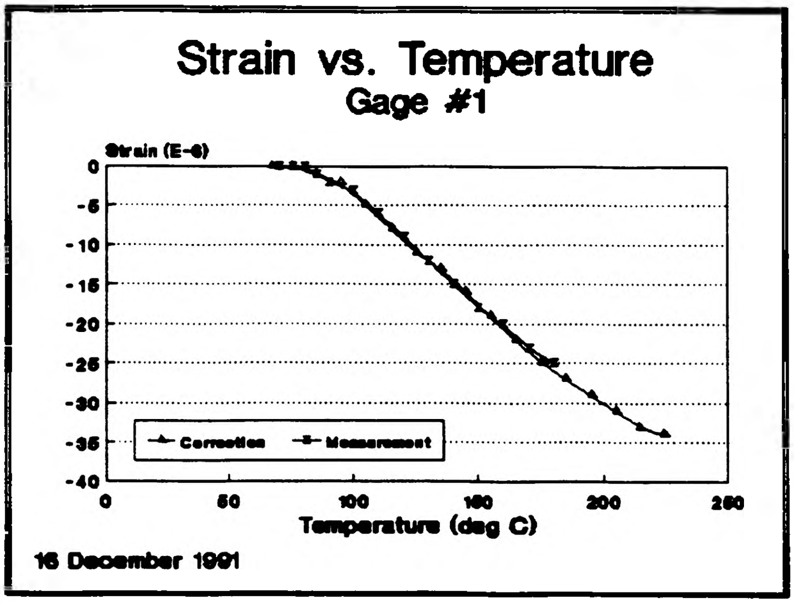

Figure 4. Strain versus Temperature for Vertical Support #1 in Thermal Buckling Test

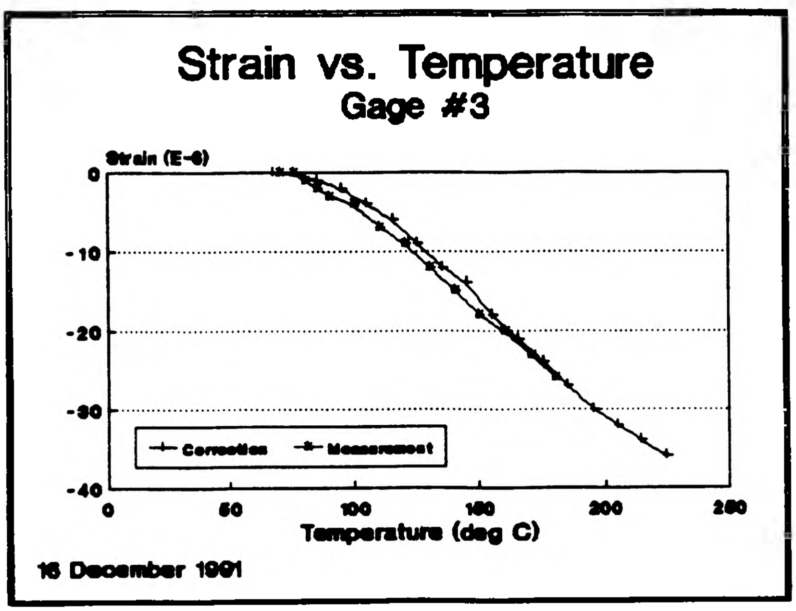

Figure 5. Strain versus Temperature for Vertical Support #3 in Thermal Pre-Buckling Test

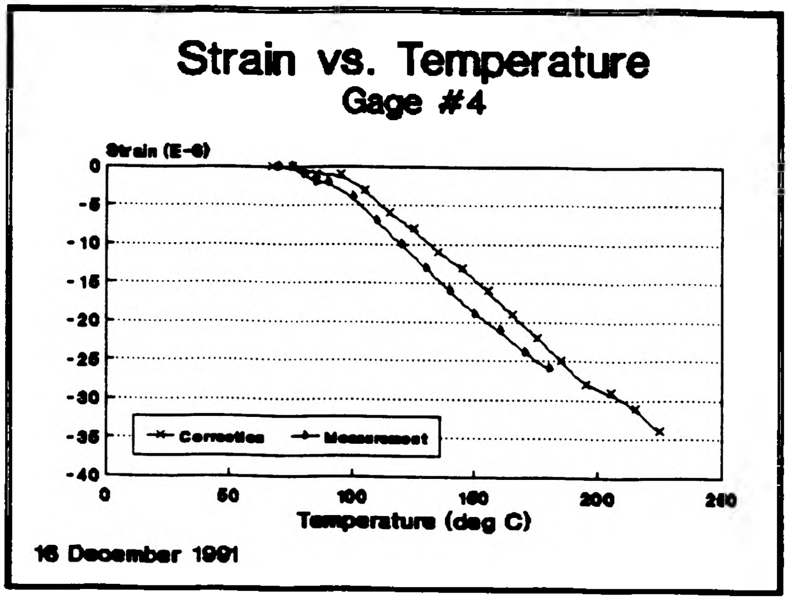

Figure 6. Strain Versus Temperature for Vertical Support #4 in Thermal Pre-Buckling Test

Several possible causes exist for the lack of successful results. One suggested cause is that the bars were too stiff for the sample measured. Glass composites are inherently weaker than Kevlar composites, so to expect similar result ranges may be unreasonable. Another possible cause is that the bolts may not have been securely fixed to the ends. The planned method of solving the problem is to utilize the dial indicator supports to fix the two plates together. This would allow for an exact parallel alignment and secure joining of the two plates. However, the author's concern is in the difficulty of measuring the induced load. Clearly, loads are difficult to compute when strain indicators are attached to a rectangular cross section with several holes drilled through its cross section. Also, unless new supports are made, small extensions are necessary to span the extra distance to the top plate. If the induced load is of any interest, the author suggests using bolts with a smaller cross section rather than opting for joining the plates with the gage supports.

CONCLUSION

While only one test was performed, the information acquired will certainly help future students at the University of Missouri-Rolla. A fixture was designed for current and future use and a simple method of determining percentage by volume of fiber in composites was found. Overall, the author feels grateful that he was able to continue his senior design project as it allowed for good experience with a rapidly expanding field.

REFERENCES

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