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## INVESTIGATING COMPRESSION FAILURE MECHANISMS IN COMPOSITE LAMINATES WITH A TRANSPARENT FIBERGLASS-EPOXY BIREFRINGENT MATERIAL

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INVESTIGATING COMPRESSION FAILURE MECHANISMS IN COMPOSITE LAMINATES  
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by

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**ORIGINAL CONTAINS  
COLOR ILLUSTRATIONS**

INTRODUCTION

To exploit fully the use of composites in aircraft structural components (e.g., wings and fuselages) requires a thorough understanding of the unique failure mechanisms of these materials. An example of such a mechanism is in-plane fiber-matrix shearing recently identified in compression-loaded  $\pm 45^\circ$ -dominated graphite-epoxy laminates with a circular hole (ref. 1). The opaque property of graphite-epoxy laminates prevents direct observation of the mechanisms involved in the initiation and propagation of damage. Although destructive failure assessment methods such as the deply technique (ref. 2) are available, the sequence of failure within the laminate is difficult to determine using these methods. An insitu nondestructive technique is needed to observe failure as it develops and as it propagates within the laminate. One available technique is based on the use of a transparent fiberglass-epoxy composite birefringent material (ref. 3). This material was selected for the present study because both the birefringency and transparency properties of the fiberglass-epoxy material can be used to identify a characteristic failure mode for a particular composite laminate. The fiberglass-epoxy laminate is used to study a failure mode which is also characteristic of a similar graphite-epoxy laminate. The birefringency property allows the laminate stress distribution to be observed during the test and also after the test if permanent residual stresses occur. The transparency property allows visual observation of the location of initial laminate failure and of the subsequent failure propagation.

## SPECIMENS AND TESTS

Two  $[+45_4/-45_4]_{2S}$  fiberglass-epoxy specimens with a single, centrally-located circular hole were tested. The specimens were fabricated from commercially available J. P. Stevens and Co. Style 3733<sup>1</sup> glass cloth with S-190<sup>1</sup> finish preimpregnated with Marlette Corp. Maraset 658/558<sup>1</sup> epoxy resin. Specimens were nominally 6.0 in. long, 3.0 in. wide, and 0.11 in. thick, and the hole diameters were 0.19 in. and 0.50 in. (hole-diameter-to-plate-width ratio of 0.06 and 0.17, respectively). The specimens were tested by slowly applying a compressive end-load to simulate a static loading condition. The specimen ends were machined flat and parallel to permit uniform compressive loading. The loaded edges of each specimen were clamped by fixtures during testing, and the unloaded edges were simply-supported by knife-edge restraints to prevent the specimen from buckling as a wide column. A typical specimen being loaded in the test fixture and being illuminated with polarized light is shown in figure 1. The polarizer and analyzer are oriented at  $+45^\circ$  and  $-45^\circ$ , respectively, to the load axis.

## RESULTS AND DISCUSSION

Experimental results presented in figures 2 and 3 illustrate the value of the birefringent material for observing failure of composite specimens. The specimens shown in figure 2 were loaded and then unloaded. When these unloaded specimens are illuminated with polarized light, the isochromatic fringe patterns on the specimens indicate that plastic deformation has occurred. The pattern on the specimen in figure 2a indicates that high stresses exist in bands oriented at  $\pm 45^\circ$  to the load axis. Using the transformation of stresses for this

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<sup>1</sup>Identification of commercial products and companies in this note is used to describe adequately the test materials. The identification of these commercial products does not constitute endorsement, expressed or implied, of such products by the National Aeronautics and Space Administration.

uniaxially loaded laminate, the inplane shear stress  $\tau_{12}$  is a maximum on elements oriented  $45^\circ$  to the applied load which results in high stresses in the epoxy matrix between fibers. The high stresses in the bands in figure 2a are caused by inplane fiber-matrix shearing in these regions and are identified as matrix-shearing bands in the figure. While the specimen was being loaded, these bands initiated at the hole boundary and grew toward the specimen edges. The specimen shown in figure 2b was loaded further into the plastic range than the specimen shown in figure 2a. This specimen also has matrix-shearing bands, but the isochromatic fringes are not observed in the region of these bands. While the specimen was being loaded, severe internal damage occurred within the bands which disrupted the light path and destroyed the birefringency property. The damage was caused by local delamination and inplane shearing failure mechanisms. When this specimen was illuminated with white light (fig. 3), the damage in the matrix-shearing bands is indicated by the  $\pm 45^\circ$  dark bands. The damage is most severe at the two locations where the hole boundary intersects the horizontal centerline of the specimen, the locations where damage initiated. Closer inspection of the damaged regions reveals a fiber-kinking mechanism that occurs at the boundaries of the matrix-shearing bands. A sketch illustrating this fiber-kinking mechanism in the hole-boundary region is shown in figure 3. The kinking results from a  $+45^\circ$  layer partially restraining the inplane shearing occurring in an adjacent  $-45^\circ$  layer or vice versa. The fiber kinking occurs without fiber breakage due to the flexibility in the matrix provided by extensive shear failures.

## CONCLUDING REMARKS

In summary, the birefringency and transparency properties of the fiberglass-epoxy material permit regions of high stress to be located and the mechanisms of local failure and of failure propagation to be identified within the laminate. This fiberglass-epoxy material may also be useful for studying stress fields and for identifying failure initiation and propagation mechanisms in a wide variety of composite structures problems.

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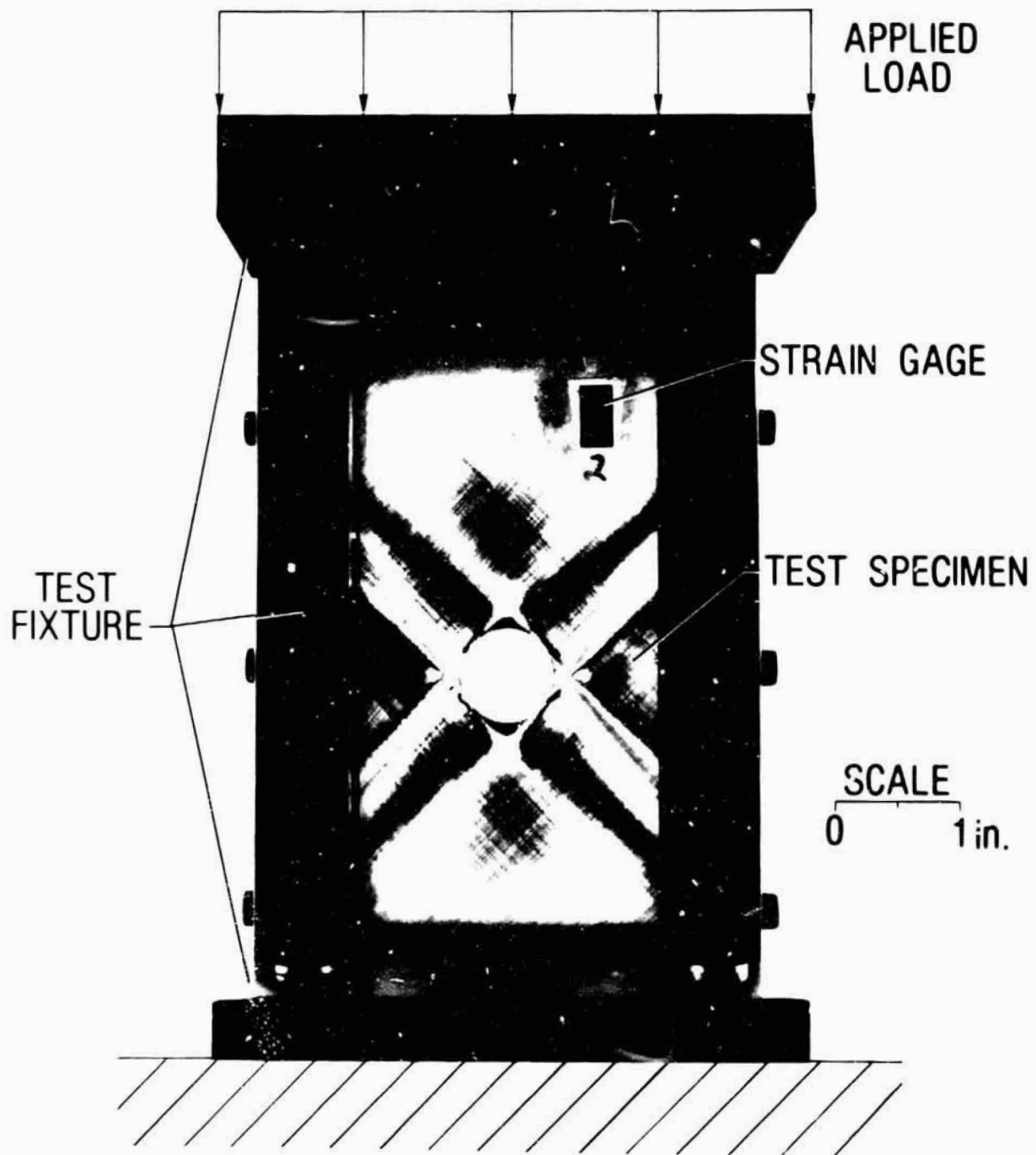
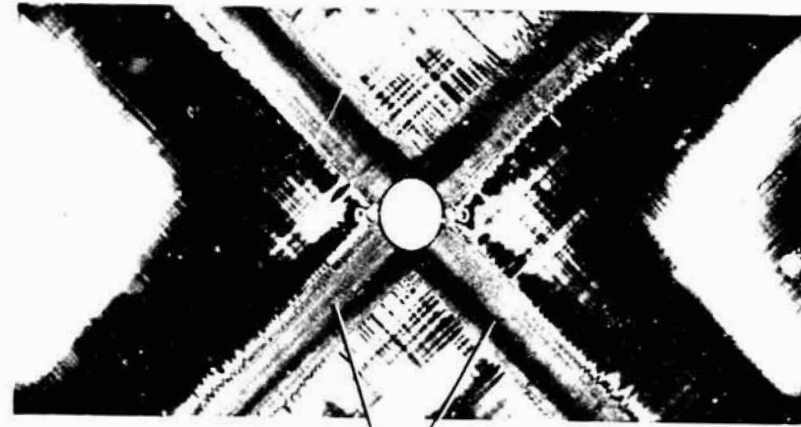


Figure 1. Fiberglass-epoxy birefringent specimen in fixture during test.

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b. specimen with 0.50-in. -  
diameter hole



MATRIX-SHEARING  
BANDS

a. specimen with 0.19-in. -  
diameter hole

Figure 2. Fiberglass epoxy birefringent specimens after being loaded beyond the elastic limit. Both specimens are illuminated with polarized light.

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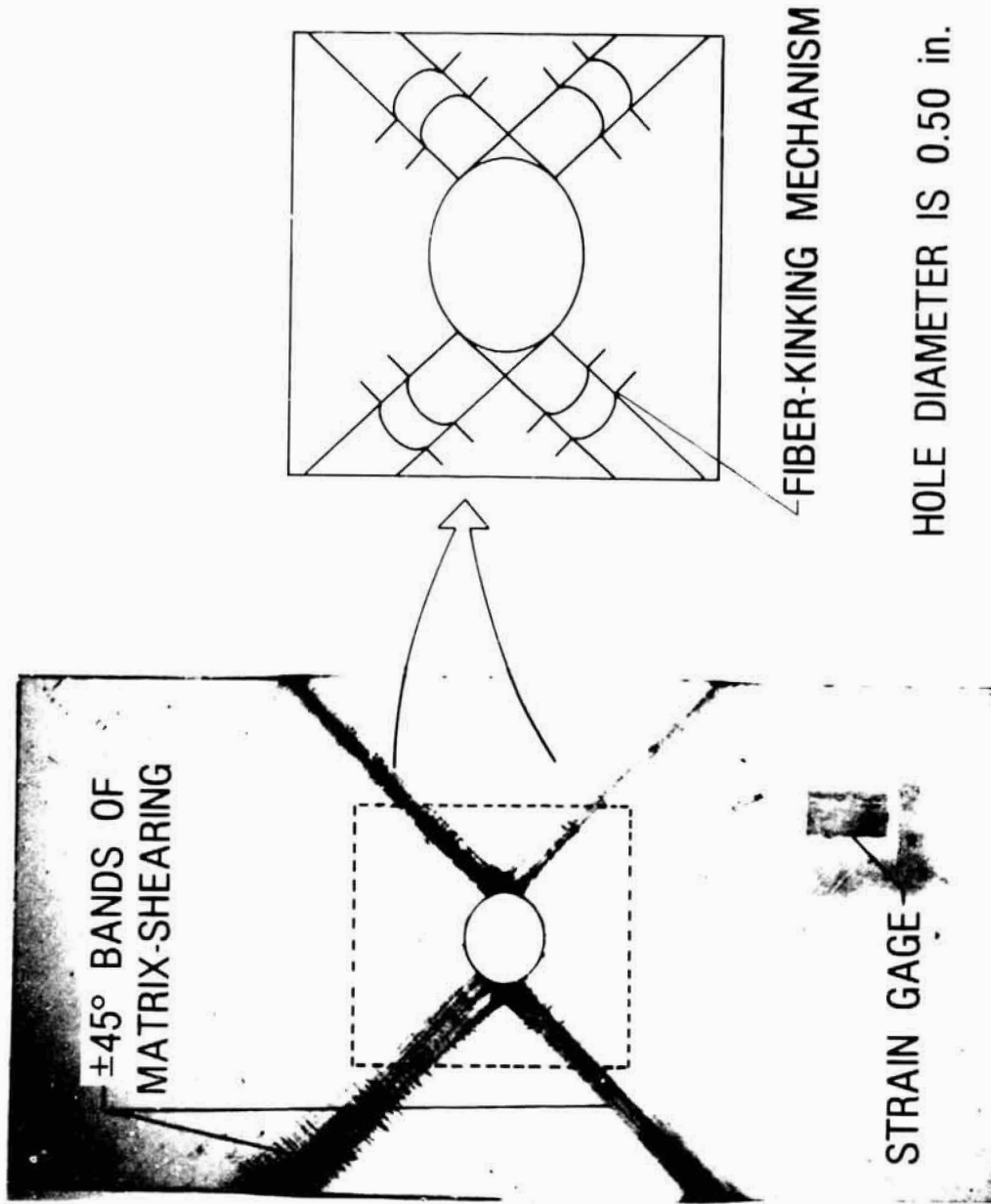


Figure 3. Failed fiberglass-epoxy specimen illuminated with white light.