THERMAL EXPANSION OF GRAPHITE-EPOXY BETWEEN 116 K AND 366 K

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STUDY OBJECTIVES

The dimensional stability of materials used in large space structures must be established at both low and high temperatures. The Moire interferometer system, ref. 1, developed and currently used at the NASA Langley Research Center is limited to making thermal expansion measurements above room temperature. The objective of the present study was to develop and demonstrate an interferometer technique to measure small thermal strains associated with graphite-epoxy (Gr/Ep) composites over the temperature range of 116 K to 366 K. A series of tests was conducted to determine the effects of variability within a set of specimens on the thermal strain of Gr/Ep. Since specimen edge effects may be important for quasi-isotropic laminates, the effects of specimen width on thermal strain were investigated. All work was sponsored by NASA under Cooperative Agreement NCCI-15.

- DEVELOP A DEVICE TO MEASURE THE SMALL THERMAL STRAINS ASSOCIATED WITH Gr/Ep AND OTHER LOW EXPANSION MATERIALS BETWEEN 116 K AND 366 K
- CONDUCT A TEST PROGRAM TO:
  - DEMONSTRATE RANGE AND RESOLUTION OF THE DEVICE
  - DETERMINE VARIABILITY WITHIN A SAMPLE OF Gr/Ep SPECIMENS
  - COMPARE THERMAL RESPONSE OF 0.6 cm AND 2.5 cm WIDE Gr/Ep SPECIMENS

Figure 1

MEASUREMENT OF SMALL THERMAL STRAINS

The composite laminates used in structures where dimensional stability is critical will have coefficients of thermal expansion approaching zero. Therefore, any dilatometer used to characterize the dimensional stability of these composites must detect strains on the order of one microstrain (1 $\mu\varepsilon$).

In the present study, a laser Priest interferometer was chosen as a practical approach to meet the measurement and testing requirements. A comparison of the features of the Priest interferometer with the ideal measuring device is shown in figure 2. For the Priest interferometer, measurement resolution is $\lambda/10$ (λ is the wavelength of the laser); flat, rectangular specimens are cut to length; specimen ends are rounded to provide two-point contact only; and thermal strain is measured with respect to a reference.

MEASUREMENT OF SMALL THERMAL STRAINS

- IS CRITICAL TO AN EXPERIMENTAL PROGRAM FOR DIMENSIONAL STABILITY RESEARCH
- MEANS DETECTING STRAINS ON THE ORDER OF 1 $\mu\varepsilon$
- REQUIRES A MEASURING DEVICE WITH FEATURES SUCH AS:

IDEAL	PRIEST INTERFEROMETER
INFINITE RESOLUTION	$\lambda/10$ RESOLUTION
CONTACTLESS	TWO POINT CONTACT
UNRESTRICTED SPECIMEN GEOMETRY	FLAT, RECTANGULAR SPECIMEN
NO SPECIMEN PREPARATION	SPECIMEN CUT TO LENGTH
ABSOLUTE STRAIN MEASUREMENT	REFERENCE TO NBS STANDARD

Figure 2

PRIEST INTERFEROMETER

A Priest interferometer measures the displacement of an unknown specimen relative to two parallel rods of a known reference material. A schematic of the laser, Priest interferometer developed in this study is shown in figure 3. The interferometer was enclosed in a chamber in which the temperature of circulating air was controlled by a resistance heater and liquid nitrogen. A helium neon laser illuminated the interferometer through a window in the top of the chamber. The fringe pattern was recorded by a camera.

The specimen displacement with respect to the reference rods is proportional to the inclination, θ, of the top optical flat. For two nearly parallel optical flats, $\theta = n\lambda/2L_g$ where n is the number of fringes across the gauge length, L_g, and λ is the laser wavelength. A change in the relative displacement of the specimen from one temperature to the next, is equal to $(n-n_o)\lambda/2$ where n and n_o are the number of fringes at the new and old temperatures, respectively. The relative thermal strain, ε_r, is obtained by dividing the displacement by the specimen length, L_s. The total absolute specimen strain is obtained by adding ε_r to the known displacement of the reference rods, ε_q.

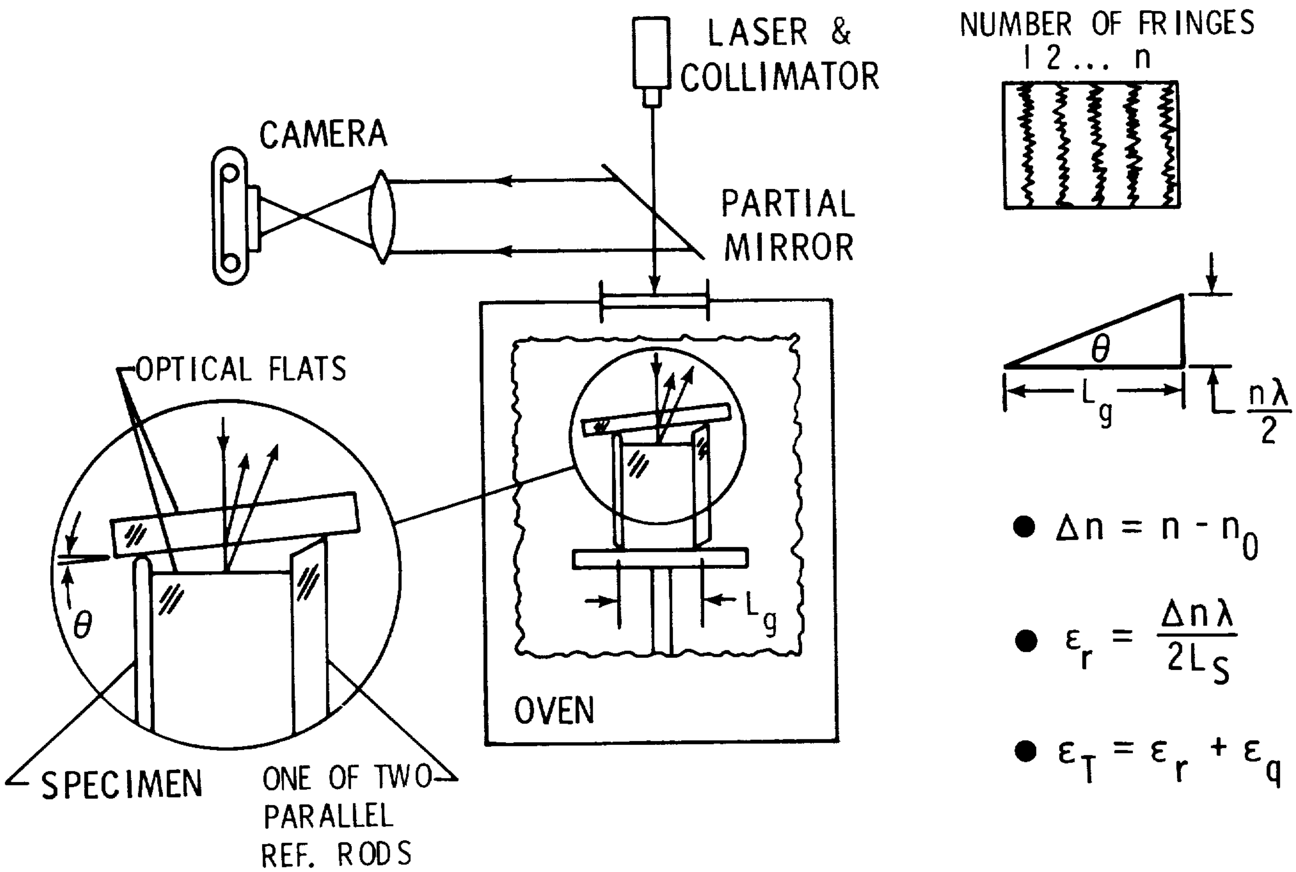
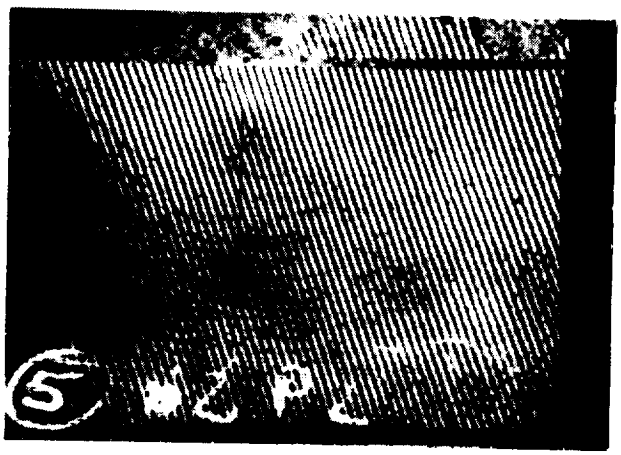


Figure 3

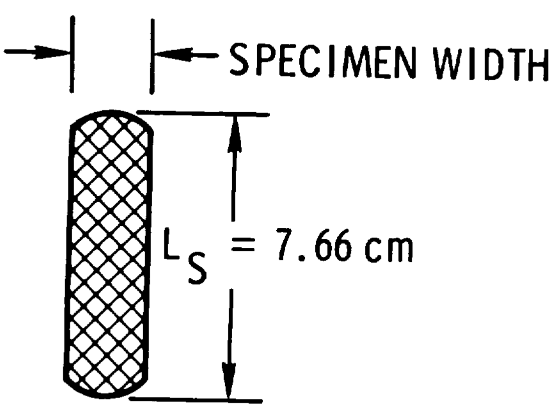
TYPICAL FRINGE PATTERNS

Typical fringe patterns at two different temperatures are shown in figure 4 with sample calculations for the thermal strain. The relative specimen strain, ε_r, was calculated with the equation from figure 3. The total absolute specimen strain was obtained by adding $\varepsilon_r = 37\ \mu\varepsilon$ to the strain of the reference rods, $\varepsilon_q = 13\ \mu\varepsilon$. The strain of the reference rods was obtained from manufacturer's calibration data.



$n_0 = 55,\ T = 300\ K$

$n = 64,\ T = 325\ K$



$$\varepsilon_r = \frac{(64-55)\,(63 \times 10^{-6}\ \text{cm})}{2(7.66\ \text{cm})} = 37\,\mu\varepsilon$$

$$\varepsilon_T = 37 + 13 = 50\mu\varepsilon$$

Figure 4

TEST PROGRAM

The test program used in this study is shown in figure 5. The range and resolution of the Priest interferometer were determined with molybdenum and composite specimens. The effects of material variability on the thermal strain within a set of specimens taken from the same panel were determined with composite specimens. The effects of specimen width on thermal expansion were also determined with composite materials. Specimens widths of 0.6 cm and 2.5 cm were selected since these two are commonly used, respectively, with dilatometers and in mechanical tests.

Each specimen was thermally cycled three times from room temperature to 366 K, cooled to 116 K, and reheated to room temperature. Expansion data were taken at 28 K increments after equilibrium had been reached at predetermined temperatures. The composite specimens were dried at 395 K to constant weight prior to testing.

- DEMONSTRATE RANGE AND RESOLUTION OF APPARATUS
  - $[0_8]$ T300/5208, Gr/Ep, MOLYBDENUM TESTS
- DETERMINE VARIABILITY OF Gr/Ep SPECIMENS
  - CYCLING OF 2.5 cm WIDE SPECIMENS
  - COMPARISON OF "IDENTICAL" SPECIMENS
- CONDUCT A COMPARATIVE STUDY OF WIDTH EFFECT
  - COMPARISON OF RESULTS FROM TESTS ON 2.5 cm AND 0.6 cm WIDE Gr/Ep SPECIMENS

I. D.	SPECIMEN TYPE	# OF TESTS
M	2.5 cm MOLY	3
①	2.5 cm $[0/\pm 45/90]_S$	3
②	"	6
③	"	3
④	"	3
⑤	0.6 cm $[0/\pm 45/90]_S$	3
⑥	"	3
⑦	2.5 cm $[0_8]$	3

Figure 5

RANGE AND RESOLUTION

The operating range and resolution of the Priest interferometer were assessed with a molybdenum specimen and an 8-ply unidirectional graphite-epoxy specimen. Over the temperature range of 116 K to 366 K, the thermal strain can be resolved to within about 1με over a total strain range of as much as 1500 με.

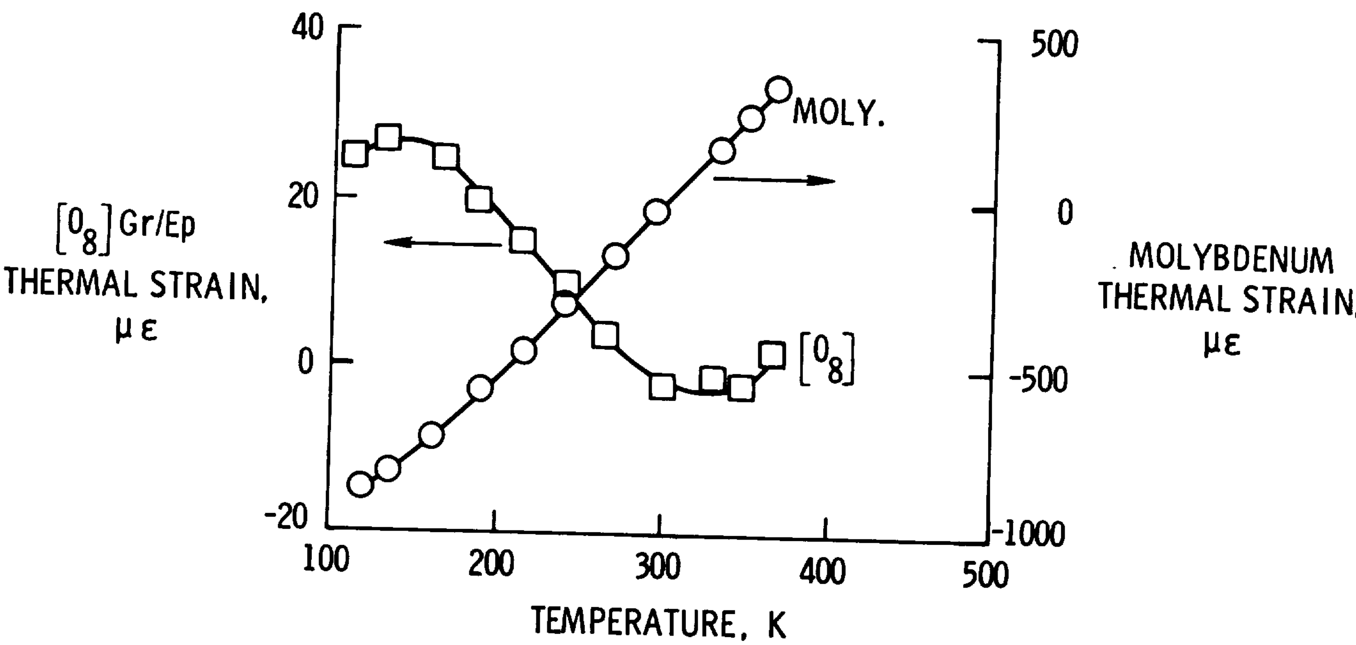


Figure 6

CYCLING REPEATABILITY

Figure 7 shows the thermal strain during each of three thermal cycles on the same quasi-isotropic, graphite-epoxy specimen. Each cycle resulted in essentially the same thermal strain. The data do not indicate any residual strain or hysteresis which has been reported for graphite-epoxy by other investigators. The absence of hysteresis in this study may be a result of stress relaxation which may have occurred during aging at room temperature.

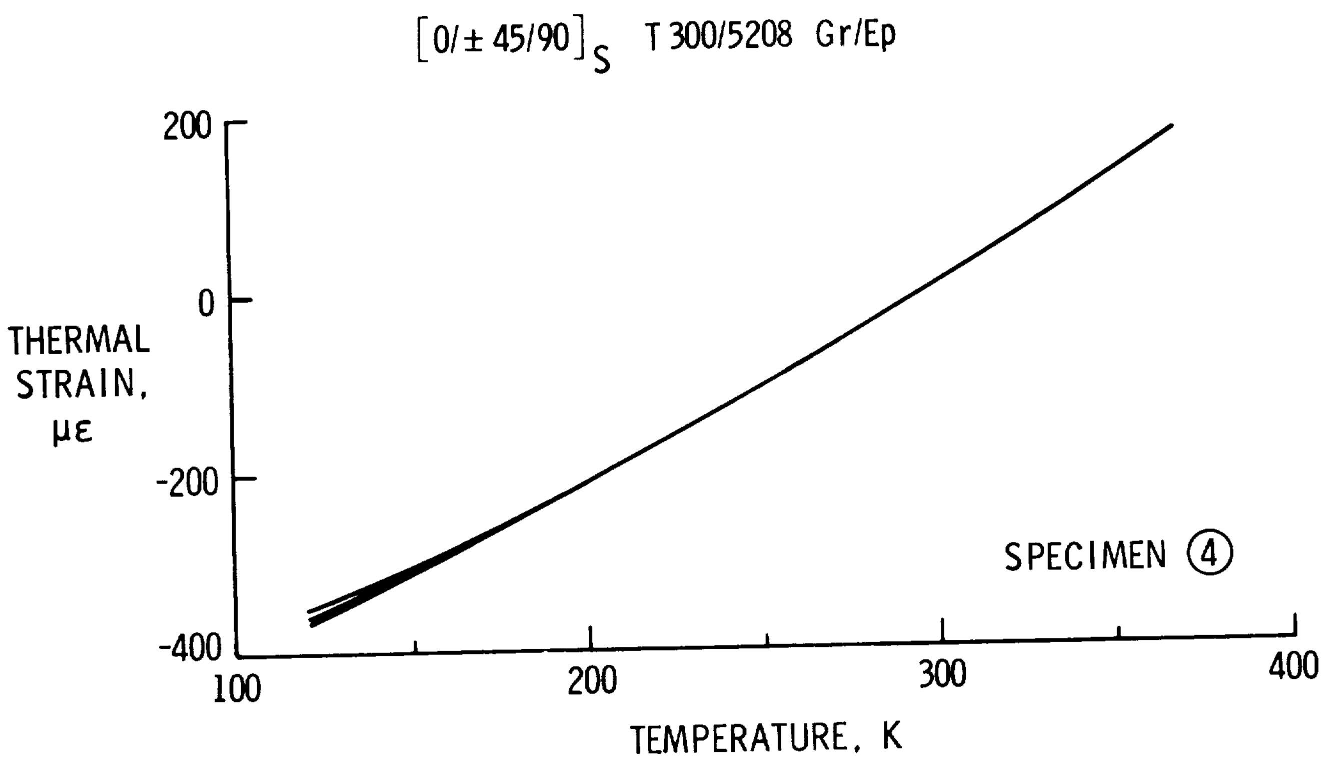


Figure 7

SPECIMEN VARIABILITY

The thermal strains of three quasi-isotropic composite specimens cut from the same panel are compared in figure 8 to evaluate the effects of specimen variability on thermal response. Each curve represents the average thermal strain for three thermal cycles. There were no significant differences in the response of two specimens. The thermal strain of a third specimen differed from the other two by about 10% and 20% at the high and low temperatures, respectively.

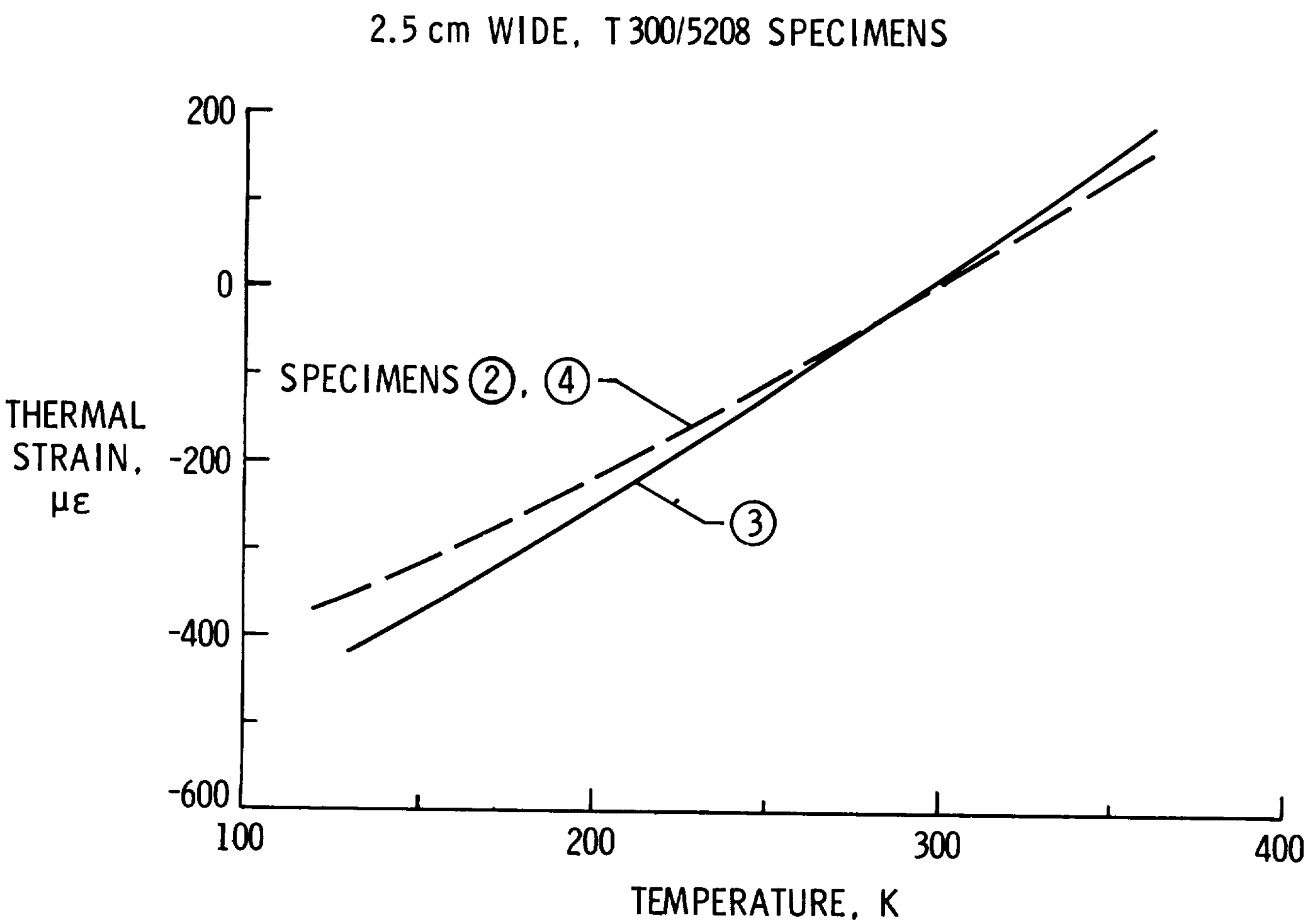


Figure 8

SPECIMEN WIDTH EFFECT

The thermal responses of specimens 0.6 cm and 2.5 cm wide are compared in figure 9. The dashed lines show the data scatter band for the 2.5 cm wide specimens (figure 8). The response of one of two 0.6 cm wide specimens falls within the scatter band for the 2.5 cm wide specimen. The response at elevated temperature of the second 0.6 cm wide specimen also fell within the scatter band. However, at low temperatures the response of this specimen was very different from the 2.5 cm wide specimen. Therefore, there appears to be a significant width effect at low temperatures. Since only two 0.6 cm wide specimens were tested, the results are inconclusive.

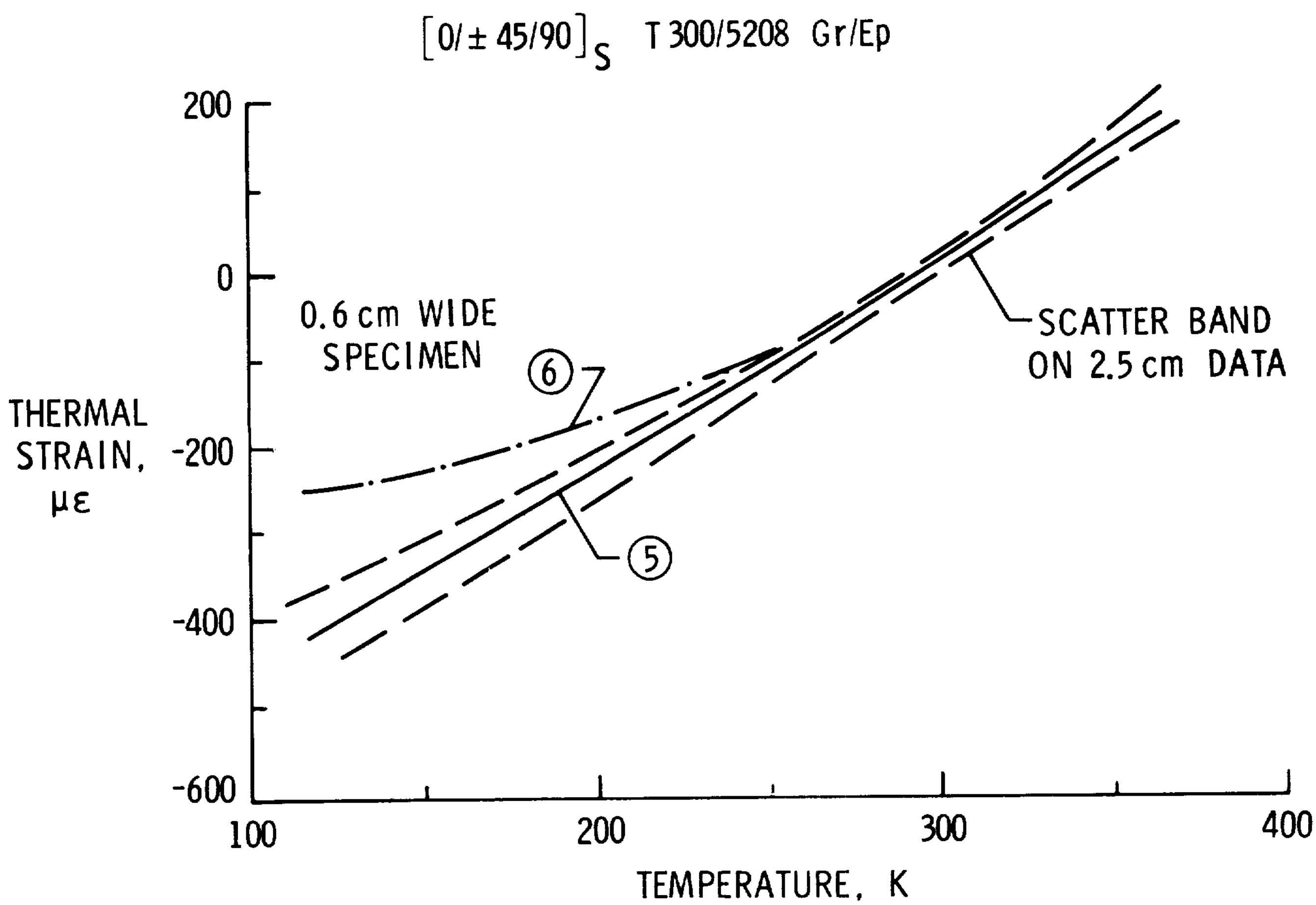
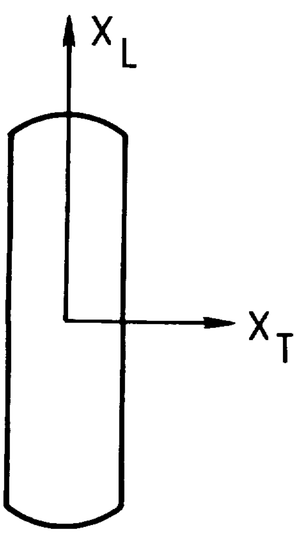


Figure 9

COEFFICIENT OF THERMAL EXPANSION

The coefficients of thermal expansion (CTE) determined in this study for two different laminate configurations at two temperatures are shown in the table. For the unidirectional laminate, the CTE varies significantly over the temperature range. For the isotropic laminate, the CTE is about constant over the temperature range. The values of CTE are similar to those reported by other investigators.

T300/5208 Gr/Ep LAMINATE



LAYUP	α_L AT 200 K	α_L AT 350 K
$[0_8]$	-0.13 $\frac{\mu\varepsilon}{K}$	0.17 $\frac{\mu\varepsilon}{K}$
$[0/\pm 45/90]_S$	2.0 $\frac{\mu\varepsilon}{K}$	2.5 $\frac{\mu\varepsilon}{K}$

Figure 10

SUMMARY

A Priest laser interferometer has been developed to measure the thermal strain of composite laminates. The salient features of this interferometer are that (1) it operates between 116 K and 366 K, (2) it is easy to operate, (3) minimum specimen preparation is required, (4) coefficients of thermal expansion in the range 0-5 με/K can be measured, and (5) the resolution of thermal strain is on the order of 1 με. The thermal response of quasi-isotropic, T300/5208, graphite-epoxy composite material was studied with this interferometer. This study showed that (1) for the material tested, thermal cycling effects are negligible, (2) variability of thermal response from specimen to specimen may become significant at cryogenic temperatures, and (3) the thermal response of 0.6 cm and 2.5 cm wide specimens are the same above room temperature.

REFERENCE

1. Bowles, D. E.; Post, D.; Herakovich, C. T.; and Tenney, D. R.: Moire Interferometry for Thermal Expansion of Composites. Experimental Mechanics, vol. 21, no. 12, Dec. 1981.