THE EFFECTS OF TRANSVERSE MICROTEXTURE ON THE TRANSVERSE COEFFICIENT OF THERMAL EXPANSION IN CARBON FIBERS

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INTRODUCTION

Carbon fibers are one of the most important reinforcements used in composite materials due to its high specific stiffness and specific strength. Extensive research efforts have been conducted on the property-structure relationships in carbon fibers. However, most work in the past focused on the relationships between axial properties and the preferred orientation of the graphite basal planes [1]. Little has been done about the effect of transverse microtexture on the fiber properties, especially the transverse properties due to measurement difficulties. In this study, the effects of transverse microstructure on the transverse coefficient of thermal expansion (CTE) will be studied. The theoretical calculations and the experimental measurements of transverse CTE will be compared. The difference between theory and experiment will be discussed.

EXPERIMENTAL

The experimental setup for measurement of transverse CTE of a single carbon fiber is shown in Fig. 1. Laser diffraction technique was used to calculate the fiber diameter and diameter change. The details of experimental procedures can be found in [2]. It needs to be mentioned that this experimental setup allows the measurement of transverse CTE in two directions perpendicular to each other.

MODEL

The mathematical formulation used to calculate the transverse CTE is based on the work of Avery and Herakovich [3], who followed the treatment of Cohen and Hyer [4] for an orthotropic tube under uniform thermal load. The transverse CTE α_r and α_θ in radial and circumferential directions are defined as

$$\alpha_r = \varepsilon_r / \Delta T \quad \text{and} \quad \alpha_\theta = \varepsilon_\theta / \Delta T$$

where ε_r and ε_θ are strains in the r and θ directions under an uniform thermal load ΔT.

RESULTS AND DISCUSSION

Fig. 2 shows the experimental result of transverse CTE measurements of an Amoco P55x pitch-based carbon fiber which has an oriented-core microstructure. The CTE was measured in two directions perpendicular to each other. CTE anisotropy was observed although the data for the 0 degree position runs show a lot scatter. The CTE for the 0 degree position is about $5.47 \times 10^{-6}/^{o}C$ and the CTE for the 90 degree position is about $13.88 \times 10^{-6}/^{o}C$. The anisotropy ratio is 2.54. Fig. 3 shows the result for a E55 fiber which has about the same Young's modulus as that of P55x but has a radial-folded transverse microstructure. Similar transverse CTEs were obtained from two perpendicular positions which is expected considering the small variation in structure in the different directions.

Fig. 4 and 5 show the theoretical transverse CTE α_r and α_θ in r and θ directions for ideal radial and onion transverse microstructure fibers. The material constants used in the computation is listed in Table 1. As shown in the figures, the transverse CTEs , α_r and α_θ , are a function of radius. It must be mentioned that the singularity in the center of the fiber for the radial structure is not realistic. However, the trend of the curve will be similar. The large variation of CTE across the fiber diameter is a consequence of thermal stresses resulted from the large anisotropy of CTE in the basic structural element.

The numerical studies in Fig. 4 and 5 indicate a much lower effective transverse CTE in the radial direction for a radial structure compared to an onion skin structure. However, the calculation assumes an ideal radial structure, and also neglects the contributions of porosity and internal stresses. For an ideal radial structure, the direction of the basal plane must pass through the center, but in a real structure, misalignment exists. Also, the basal planes are not straight. For the radial-folded structure, the basal planes are corrugated and the CTE is expected to be larger. In fact, as shown in Fig. 3 the experimental result for an E55 fiber which has a radial-folded transverse structure shows transverse CTEs of 9.75 and 10.70×10^{-6} $^{o}C^{-1}$ in two perpendicular directions, which are much larger than that calculated from an ideal radial structure. Contrary to the radial structure, the calculations for the onion structure indicate a large transverse CTE in the radial direction. However, in a real fiber the CTE is expected to be lower due to the deviation from an ideal onion structure. Also, the microcracks between layer planes are likely to reduce the transverse CTE.

CONCLUSIONS

Theoretical calculations and experimental measurements indicate that the transverse CTE of carbon fiber is affected significantly by the transverse microstructure. Anisotropy of transverse CTE was observed for carbon fibers with an oriented-core transverse microstructure.

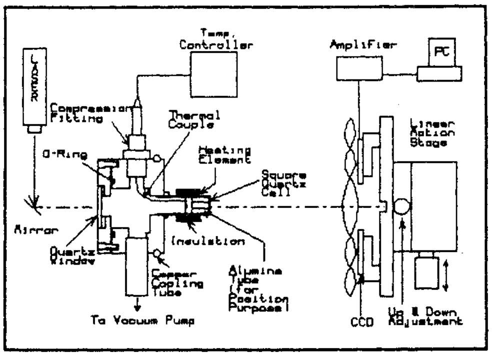

Fig. 1 Experimental Setup for CTE Measurement.

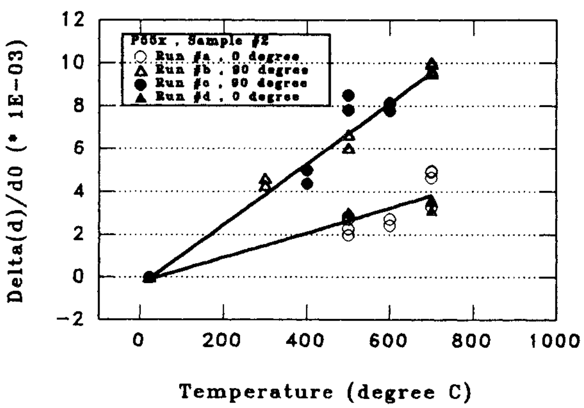

Fig. 2 Transverse Thermal Expansion of a P55x Carbon Fiber .

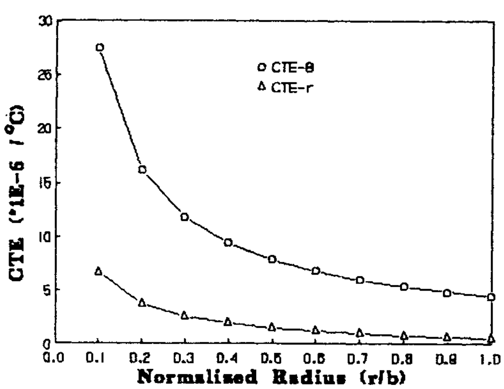

Fig. 4 Transverse CTE Distributions in Radial Structure Carbon Fibers.

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Table 1 Materials Constants

Radial Structure	E_r = 400 GPa	$\alpha_r = 0.25\times10^{-6}$ /°C	$\nu_{r\theta}$ = 0.25
	E_θ = 30 GPa	$\alpha_\theta = 20\times10^{-6}$ /°C	$\nu_{z\theta}$ = 0.25
	E_z = 400 GPa	$\alpha_z = 0.25\times10^{-6}$ /°C	ν_{zr} = 0.25
Onion Structure	E_r = 30 GPa	$\alpha_r = 20\times10^{-6}$ /°C	$\nu_{r\theta}$ = 0.019
	E_θ = 400 GPa	$\alpha_\theta = 0.25\times10^{-6}$ /°C	$\nu_{z\theta}$ = 0.2
	E_z = 400 GPa	$\alpha_z = 0.25\times10^{-6}$ /°C	ν_{zr} = 0.25

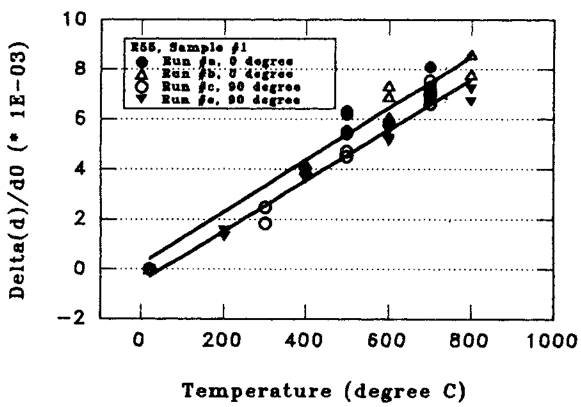

Fig. 3 Transverse Thermal Expansion of an E55 Carbon Fiber.

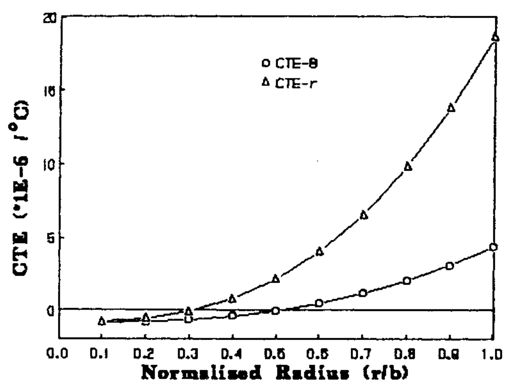

Fig. 5 Transverse CTE Distributions in Onion Structure Carbon Fibers.