Compressive Deformation of Embedded High-Performance Polymeric Fibers

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A composite sample fabrication technique was designed and demonstrated for applying direct axial compression to high-performance polymeric fibers for studies of fiber microstructure under in situ compression. Two kinds of polymers were involved in the fibers of interest. One is a polymer of rigid-rod molecule; the other is a polymer of extended coil-like molecule. A multifilament fiber bundle was aligned uniaxially and embedded in an epoxy matrix. The composite sample geometry and the Poisson's ratios were analyzed by finite-element computations that suggest that a high modulus matrix is required for inducing high-compressive load and large stress gradient along the embedded fiber. This was verified by optical microscopy on compressed composite samples and facilitated the selection of the epoxy matrix. A compressive strain of 2% was successfully applied to the polymeric fibers resulting in the fiber kink band formations, which are considered a fiber compressive failure, for microstructure studies. Our sample fabrication also indicates that fibers of rod-like polymer have a lower critical compressive strain compared to that of fibers of coil-like polymer. X-ray scattering results are also introduced to show the validity of the prescribed technique for examining the microstructure of fibers under compressive deformation.

Introduction

HIGH-PERFORMANCE polymeric fibers for composite reinforcement earn their title because of their excellent axial tensile properties that are an order of magnitude greater than those of the common textile fibers. The polymeric fiber has other attractive properties, such as superior strength to weight ratio, excellent thermal stability, and low electrical conductivity. A high-performance polymeric fiber is an organic fiber with the strongest molecular bonding aligned parallel to the fiber axis. It usually has a weaker molecular bond in the transverse direction, creating a highly anisotropic material. A critical problem with these fibers, which limits their use in composites, is their relatively low axial compressive strength. Kevlar 49 fiber reinforced composites exhibit axial compressive strengths that are just 20% of their axial tensile strengths.[1]

The demand in the aerospace industry for stronger composites has placed much emphasis on developing better high-performance fibers. The proposed new aerospace vehicles, such as the Advanced Tactical Fighter (ATF) or the Transatmospheric Vehicle (TAV), have placed extraordinary demands on lightweight material technology. These demands, such as a 50% weight-saving requirement, will force major advance in organic (lightweight) fibers.

Recent developments with poly (p-phenylene benzobisthiazole) (PBT) fibers have led to a new class of high-performance polymeric fibers with tensile modulus exceeding 40 Msi. However, their low compressive strength prevents practical applications as the reinforcing fiber in composites or as structural components. Therefore, research efforts are being directed towards developing a high-performance polymeric fiber with both excellent tensile and compressive properties. Toward this end, we need to understand the compressive behavior of high-performance polymeric fibers, their structures and property relationships, and also the effects of fiber processing and post-treatments on compressive strength.

Purpose of Study

The purpose of this study was primarily to design, to analyze, and to demonstrate a viable sample fabrication technique to facilitate the microstructure investigation of the high-performance polymeric fibers subjected to an in situ axial compression. This paper is not to report on the microstructure of the fibers under compression but on an experimental technique that can lead to baseline fiber microstructural information for improving compressive strength. This research is unique in that the microstructural behavior of the fiber under compression had not been successfully determined yet. Only a study by Takahashi et al.[2] has observed a fiber at the molecular level under compression. In the study, a form of microstructural instability known as kink-band formation (see Fig. 1) was observed at very high levels (as high as 40%) of compressive strain. However, most polymeric fibers develop the kink bands at compressive strain less than 2%. Our study was aimed at limiting the fiber compressive strain less than 2%, but also inducing adequate kink band density for microstructure investigation.

The approach developed to study the characteristics of the compressive deformation of the fibers involved an uniaxially oriented fiber bundle embedded in an epoxy matrix. The role of the composite matrix is primarily to support the fiber laterally, allowing only axial compressive stresses to exist within the fiber. A finite-element analysis was performed to aid in understanding the effect of sample geometry on the stress and strain distribution throughout the fiber and in selecting the appropriate epoxy matrix. A direct compressive deformation was imposed axially to the fibers by using a pneumatic device, and its effect on the embedded fibers was examined with an

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optical microscope and compared with the finite-element analysis prediction.

Various morphological methods were incorporated in order to investigate the microstructure of the fiber, such as wide-angle and small-angle X-ray scattering and scanning electron microscopy. The result will be introduced briefly to demonstrate the validity of our sample fabrication technique and then reported more extensively elsewhere.

High-Performance Polymeric Fibers

Two types of fibers with different molecular configurations have been examined under compression. The poly (p-phenylene terephthalamide) (PPTA) and the poly (2,5 benzoxazole) (AB-PBO) fibers consist of extended coil-like molecules. The poly (p-phenylene benzobisoxazole) (PBO) and the PBT fibers consist of rod-like molecules. These rod-like molecules form a paracatenated backbone having flexibility only in the rotation of bonds between alternating phenylene and heterocyclic groups. All of these fibers are spun from anisotropic liquid-crystalline solutions by a dry jet-wet spinning process. Table 1 lists the tensile and compressive properties for each fiber. The compressive strength of the fiber is determined by the stress level of initial kink-band formation and not the failure of the complete fiber.

The PPTA fiber examined is the commercially available Kevlar 49 fiber produced by E. I. duPont de Nemours and Co. Kevlar 49 fiber is an organic fiber with high modulus, tensile strength, and thermal stability, with a low density and electrical conductivity. This fiber was designed for reinforcing plastics in aerospace, marine, electrical, and recreational applications. The structure of Kevlar 49 has been the subject of numerous papers. It has been shown that the fiber is highly crystalline[3] and exhibits a paracrystalline structure.[4] A paracrystalline structure is "a single-phased structure having nearly perfect crystallinity locally but a cumulative statistical lattice disorder over a long range".[5] The fiber has a fibrillar morphology[6] and has weakly bonded sheets oriented along the radial direction, giving it a cylindrically orthotropic symmetry.[7]

The AB-PBO, PBO, and PBT fibers are heterocyclic aromatic polymeric fibers developed through the Air Force Materials Laboratory Ordered Polymers Program. They are cost-effective replacements for aromatic and aliphatic polyamide fibers due to their high strength, superior thermal stability, excellent dielectric properties, and significant weight savings.

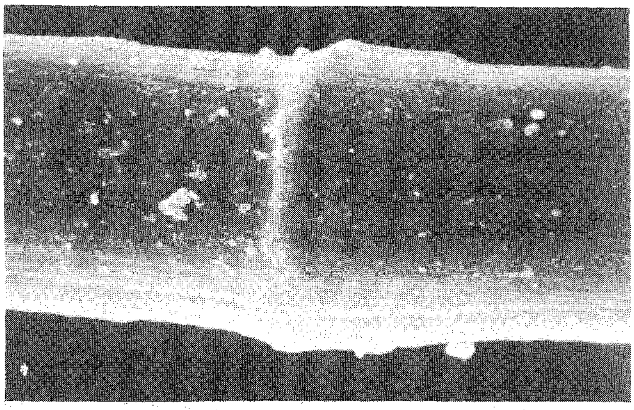

Fig. 1 Kink band in a fiber.

Table 1 Mechanical properties of fibers investigated (units in Ksi)

Fiber	Modulus	Tensile strength	Compressive strength
Kevlar 49	17500	458	60
AB-PBO	7900	442	53
PBO	21500	442	51
PBT	37900	372	55

Matrix of the Composite

The matrix used in this study is diglycidyl ether of bisphenol-A (Epon 828, Shell Chemical Co.), an epoxy resin cured with meta-phenylene diamine (m = PDA, Aldrich Chemical Co.). This matrix, which has viscoelastic properties, was chosen because of its transparency, thus enabling easy observation of fibers under compression. Also, the physical and mechanical properties of this epoxy matrix have been well known from extensive studies conducted by the Air Force Materials Laboratory.

The epoxy resin, Epon 828, is a viscous fluid, having an amber color and an average molecular weight of 380. The curing agent, m-PDA, is a light amber crystalline solid with a molecular weight of 108 and a melting point of approximately 60°C. From the molecular weights, one can calculate an ideal amount of m-PDA for a given amount of Epon 828 for a fully cured epoxy network, based on the reactivity between the two compounds. This proportion between m-PDA and Epon 828 is called the stoichiometric amount and is calculated to be 14.5 parts by weight per hundred parts of resin (phr).

Composite Sample Geometry

Compressive deformation was conducted on fiber/epoxy samples in order to observe and to study kink-band formations in the fibers. A microscope was used to observe the formation and to document the kink-band density with a Polaroid camera. Though it will not be reported in this paper, it should be stated that a complete investigation of the microstructure of fiber samples under in situ compression was carried out, including extensive X-ray scattering of underformed and deformed composite samples.

The composite samples consists of a fiber bundle, or multifilament, embedded in an epoxy network of Epon 828 cured with m-PDA. A multifilament is used so that the average response of all the fibers under compression can be examined using X-ray scattering. The multifilament must be embedded and aligned in a supporting matrix to eliminate the possibility of fibers postbuckling. If postbuckling is present, tension as well as compression will exist so that the compressive behavior of the fiber microstructure cannot be distinguished using X-ray scattering techniques.

The sample geometry, detailed in Fig. 2, can be described as a concavo-concave or flat bow tie configuration that is symmetrically necked towards its center. This geometry, used by Broutman[8] and others for tensile debonding strength studies between fiber and matrix, has typical, dimensions of a length of 0.7 in. with a width of 0.25 in. at the ends decreasing to 0.125 in. at its midpoint. The radius of curvature along the sample edges is 1.0 in. The thickness of the specimen is variable and is determined according to compression requirements.

The sample geometry was chosen so that, under load, a stress variation could be produced along the sample length. The stress becomes a maximum at the sample midpoint and thereby increases the concentration of kink-band formations to facilitate the study of kink-band formation effects on the microstructure of the fiber.

Composite Sample Fabrication

The samples were made by placing a selected amount of continuous fibers into silicon rubber molds. The molds have

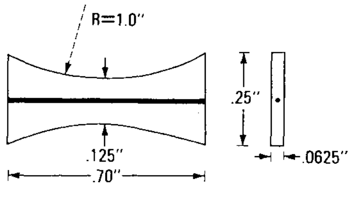

Fig. 2 Composite sample geometry.

sprue slots that center and align the fiber bundle in the mold. Ideally, no visible bending in either the width or thickness direction should exist. The fibers are held into place by applying contact cement to the slots just beyond the ends of each sample.

The properties of an epoxy matrix are known to be dependent on the stoichiometry of its curing agent. Figure 3 contains an experimental curve, developed by the University of Dayton Research Institute,[9] showing how the tensile modulus of the Epon 828 epoxy matrix varies with the percentage (phr) of m-PDA. In order to determine the optimum amount, a few compressive tests were run on the sample to observe its response, starting with an epoxy resin of Epon 828 cured with 14.5 phr of m-PDA.

Epon 828 and m-PDA of specific stoichiometric amount are weighted and placed in an oven at approximately 70°C to melt m-PDA. After m-PDA has completely melted, the two compounds are mixed thoroughly and evacuated at 75°C, for debulking air and gases from the mixture. The debulked epoxy mixture is then molded into samples that are cured for two hours at 75°C followed by two hours at 125°C and cooled to room temperature by ambient condition.

Once the composite samples have reached room temperature, they may be removed from the oven and inspected. The samples are thinned down to the required thickness for compressive deformation and polished for optical microscopic examination.

Compressive Deformation

Axial compression of the embedded fiber is applied by using a pneumatically operated compression device designed by the Air Force Materials Laboratory. First, the sample is placed in a compression holder that has the capability of maintaining a compressive displacement. The compressive holder is placed between a fixed support, on the compression device, and a support that can move forward or backward by the release of pressure into a pneumatic cylinder. The compression device has been adapted for mounting on a microscope observation platform, and a calibrated load cell is placed between the moving support and the pneumatic cylinder, so a continuous load readout can be displayed. The complete sample deformation and optical examination setup is shown in Fig. 4.

When applying the compressive load, the fiber in epoxy is observed through the microscope while also monitoring the load readout. When the fiber contains a heavy concentration of kink bands, the pressure is shut off to maintain the compressive deformation. The load readout is recorded and the kink-band density is photographed using the Polaroid camera attachment on the microscope.

Finite Element Analysis

A two-dimensional finite-element analysis was performed to understand the effects of sample geometry and fiber/matrix properties on axial stress distribution of the fiber when the composite sample is compressed. The two-dimensional analysis assumes that the fiber component has transversely isotropic properties that are believed to be valid for a uniaxially aligned fiber bundle. A numerical model was determined through a convergence study. The objective was to facilitate the selection of the matrix that would achieve the greatest stress in the fiber. This would aid the experimental studies of the fibers under compression. The model consisted of linear elastic plane stress elements.

The symmetry in sample geometry enabled the modeling of one quadrant of the actual sample, shown in Fig. 5. Since the fiber was embedded in an epoxy matrix, the capability of varying the material through the thickness was required for those grid elements containing fibers. This was done by creating a constant strain set of two elements in the same grid location, a fiber element and a matrix element. These elements share the same nodes and have thicknesses that add up to the total thickness of the sample. These two elements are "smeared together" during computation. The individual thickness of each fiber and matrix element depends on the fiber bundle cross-sectional area. Assuming this cross-sectional area is circular, an average thickness in the fiber element can be found, as shown in Sec. a-a of Fig. 5. Then, by subtracting this thickness from the sample total thickness, the thickness of the corresponding matrix element can be found. This procedure was repeated for all grid elements containing fibers.

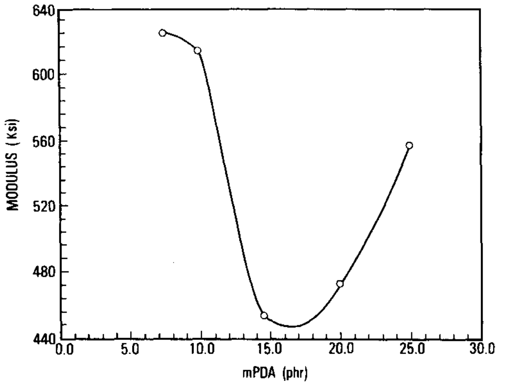

Fig. 3 Variation of epoxy matrix tensile modulus with content of curing agent.

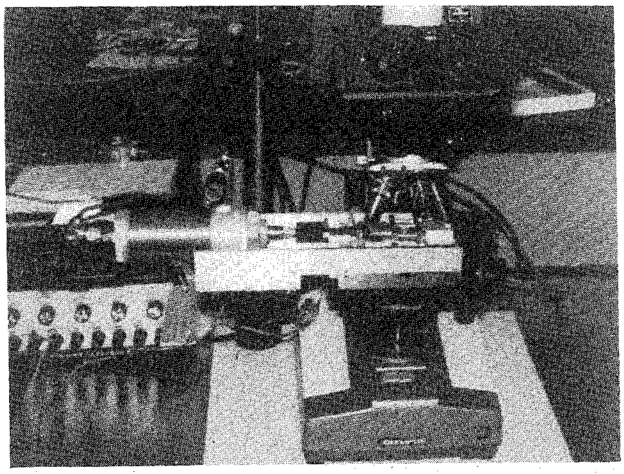

Fig. 4 Compressive deformation and optical examination equipment setup.

The quadrilateral elements, shown in the finite-element model, are subdivided into four constant strain triangles during computation. The triangles were formed by adding a node at the center of each quadrilateral. The interior node is removed by static condensation. Once the stresses and strains, due to a uniform compressive displacement, have been computed for each triangular element, average values are determined from the four triangular elements that make up a quadrilateral element.

The fiber and matrix properties were considered to be individually isotropic, although the fibers are actually highly anisotropic. The main reason this was done is that a linear finite-element analysis was used for a trend analysis only; a highly accurate analysis was not required.

The fiber modulus used varied, depending on which fiber was being modeled. Poisson's ratio, however, was taken to be 0.25 for all fibers, an average value obtained from uniaxial composite data. The matrix modulus incorporated in the analysis was for an epoxy resin cured with 14.5 phr of m-PDA corresponding to 458.0 Ksi. The Poisson's ratio of the epoxy was taken to be 0.35, a value typical of an epoxy matrix.[10]

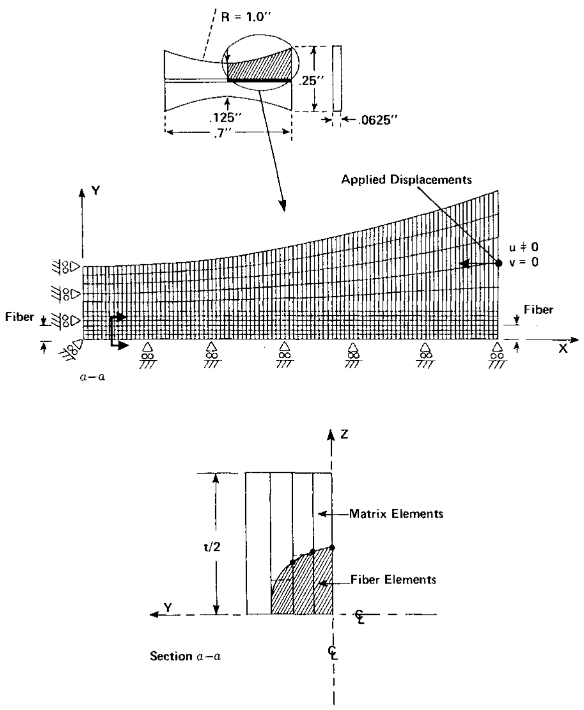

Fig. 5 Finite-element model of the composite sample.

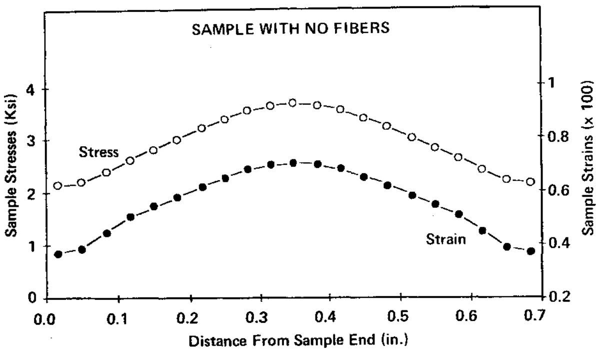

Fig. 6 Axial stress-strain distribution of epoxy matrix with no fiber.

Figures 6 and 7 illustrate the effect of the fiber on the axial stress distribution in the sample. As shown in Fig. 6, if no fiber is present in the sample, the geometry induces a stress increase of 1.72 times at the midpoint compared to that at the sample end (72% increase). Now, when a fiber was added to the sample, this stress increase was no longer present, due to the high stiffness of the fiber. Using a modulus of 21.0 Msi, corresponding to the PBO (or Kevlar 49) fiber, a stress increase of only 20% was obtained (Fig. 7). These results indicate that as the fiber modulus was increased, keeping the matrix modulus constant, the axial stress variation was decreased.

Figures 8 and 9 illustrate the effect of varying the matrix modulus while holding the fiber property constant. Using a modulus of 1.0 Msi for the matrix, the midpoint stress increase in the AB-PBO fiber, with a modulus of 8.0 Msi, was 1.47 times the stress at the sample end. This stress variation is plotted in Fig. 9. Comparing that with the stress increase of 35% obtained with the original matrix (Fig. 8), a 12% increase is obtained. Thus, when the matrix modulus was increased, keeping the fiber modulus the same, the stress variation was increased.

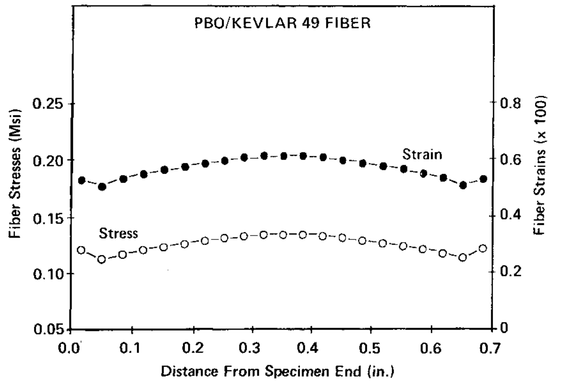

Fig. 7 Embedded PBO/Kevlar 49 fiber axial stress-strain distribution.

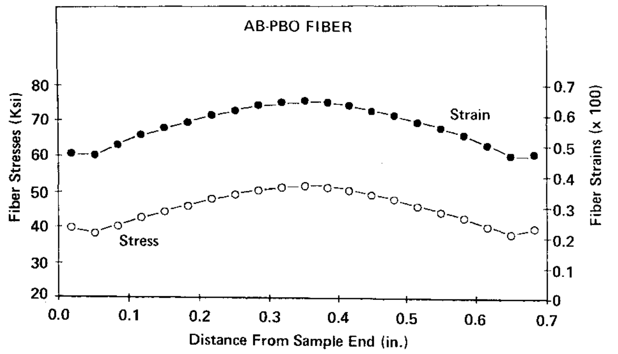

Fig. 8 Embedded AB-PBO fiber axial stress-strain distribution.

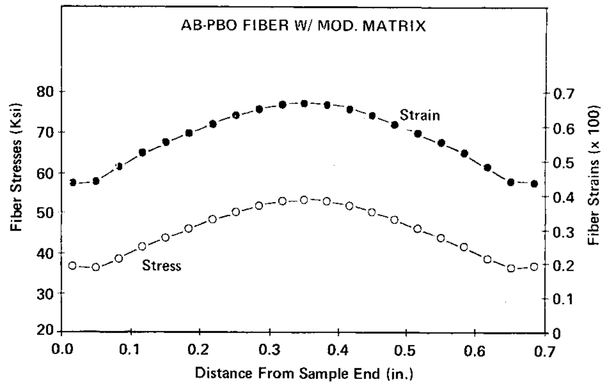

Fig. 9 AB-PBO fiber axial stress-strain distribution with modified matrix.

Possion's ratio was changed for the fiber, varying between 0.0 and 0.45, while holding the matrix properties constant. Only a 2% change in the stress variation between these limits was obtained. Also, by changing the matrix Poisson's ratio between 0.25 and 0.45, holding the fiber Poisson's ratio constant, a 3% change resulted. The combination that results in the largest stress variation is one in which both fiber and matrix Poisson's ratios are the largest, resulting in a 4% increase in stress variation from that of the original values. Thus, changes in Poisson's ratio do not substantially affect the axial stress distribution in the fiber; any isotropic value could be used in the analysis without significant loss of accuracy.

These results for the stress distribution appear to be reasonable. The fibers considered are much stiffer than the epoxy matrix so that the fiber tends to take the most of the load. Therefore, the composite sample is acting as if it has a uniform cross section, with approximately a constant stress distribution in the fiber. The only alternative for increasing the stress variation for a given fiber in the sample is to try to increase the matrix stiffness.

Varying the geometry was considered also. The curvature of the original composite sample was based on a cross-sectional area ratio of 2:1 from the sample end to its midpoint. However, when the finite-element model of the sample was modified for a 4:1 cross-sectional area ratio, only a 10% increase in the stress variation of the fiber could be obtained. As this increase was not large enough to concentrate the compressive deformation of the fiber at the sample midpoint, variation in geometry was not pursued any further.

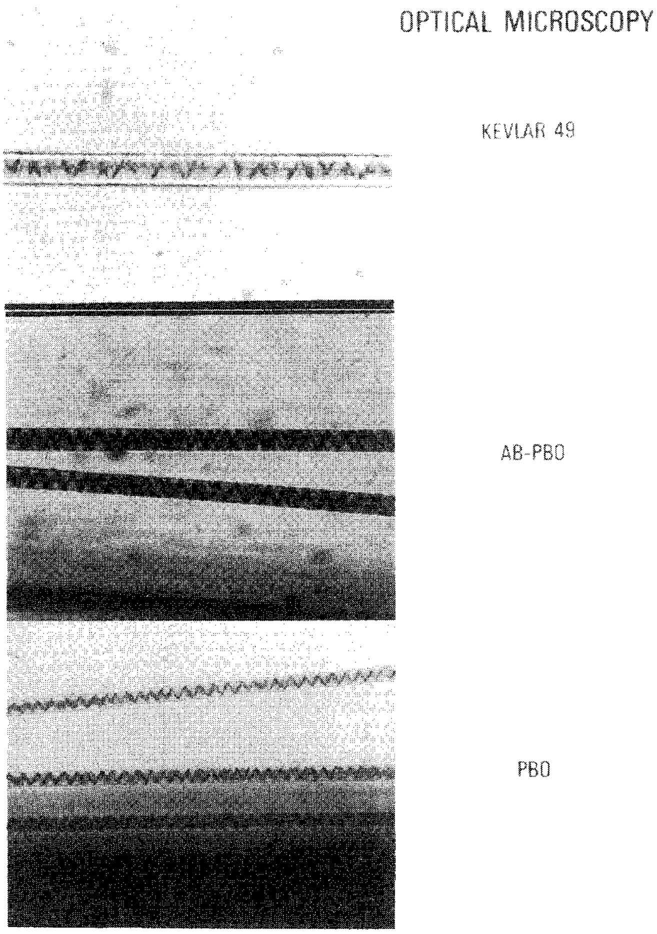

Fig. 10 Optical micrographs of embedded fibers under axial compression.

Results and Discussion

The results of this research can be divided into two parts. The first part, the finite-element analysis, has already been discussed. It was concluded that the axial stress variation in an embedded fiber can be increased when a stiffer matrix is used. However, the results prompted a study of the effects of varying the epoxy matrix stiffness on the sample when it was subjected to an axial compression. Thus, the second part is devoted to an investigation of matrix property effects on compressive deformation and sample fabrication.

Matrix Stiffness and Compressive Deformation

The first composite samples fabricated contained Kevlar 49 fibers and an epoxy matrix of Epon 828 cured with 14.5 phr of m-PDA. Thus, the sample corresponds to the matrix used in the initial finite-element model. During compression of the sample, kink bands were formed uniformly along the fiber length, suggesting that the compressive stress in the fiber is uniform. Thus, the stress distribution seems to be consistent with the results of the finite-element analysis, as shown in Fig. 10. The formation of kink bands in the Kevlar 49 fibers started when the applied load reached 12 lb. They were distributed evenly along the fiber length. As the force was increased, the intensity of the kink bands increased and when the force reached 60 lb, the sample began to bend out of plane, i.e., buckle.

The tendency of the sample to bend under compression is undesirable. When the sample is bent, both compression and tension are present in the fiber; therefore, successful examination of the compressive behavior of the fiber, using X-ray scattering, would not be possible. The main objective during the compressive deformation is to impose only axial compression on the fiber. The axial compression must be of sufficient intensity to generate an adequate density of kink bands in the fibers. This will permit the X-ray scattering to detect the changes in the microstructures of the fiber due to compressive deformation.

In order to increase the load on the sample without having it bend, the matrix stiffness must be increased. This will allow, in turn, a greater concentration of kink-band formations to occur. According to Fig. 3, the highest tensile modulus that can be obtained for the Epon 828/m-PDA matrix is that corresponding to a stoichiometry of 7.5 phr. Assuming that the compressive modulus is equal to the tensile modulus, several Kevlar 49 samples were fabricated with this stiffness matrix. During compression of these new samples, the epoxy matrix was too brittle and fractured. The kink-band density still was not as great as would be desired. However, during the testing it was noticed that the kink-band formations remained in the

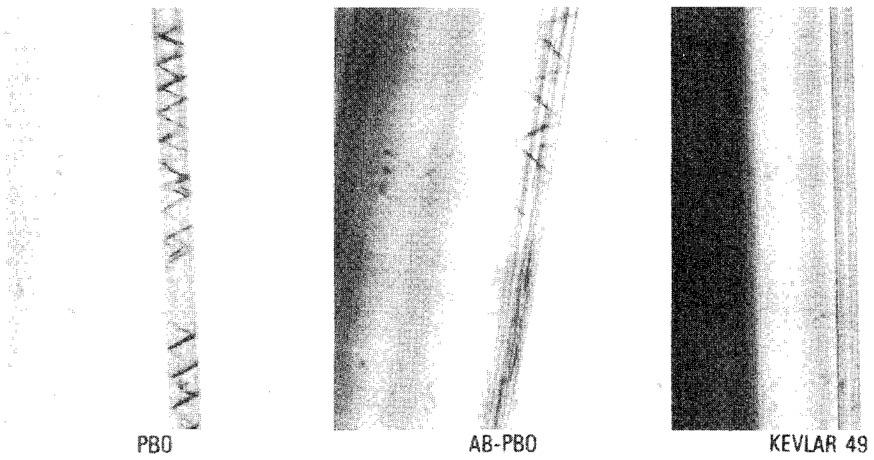

Fig. 11 Optical micrographs of as-cured composite sample.

fiber after the compressive load was removed. This phenomenon did not occur in the sample of 14.5 phr matrix. The 7.5 phr matrix appeared to be maintaining a compression force on the fiber. After about one week, the kink-band formations disappeared in the fiber. Thus, it appears that the kink bands remain in the fiber due to a viscoelastic effect of the matrix. Nevertheless, the epoxy matrix was too brittle.

The next epoxy matrix tried was a 10.0 phr Epon 828/m-PDA mixture. This amount of curing agent in the matrix still results in a matrix with a high modulus, but it was not expected to be as brittle as the 7.5 phr epoxy matrix. During compression of the 10.0 phr matrix sample, containing Kevlar 49 fibers, adequate amount of kink bands was obtained. The sample did not buckle or fracture at loads up to 175 lb. The nominal strain on the sample, measured using the original and compressed sample lengths, was 2% at the maximum loading. Also, the viscoelastic effect of the matrix on the fiber, observed for the 7.5 phr epoxy matrix, was still present. However, the kink bands disappeared sooner, at about three days, for 10.0 phr epoxy matrix. So, the epoxy matrix for the compressive deformation was Epon 828 resin cured with 10.0 phr m-PDA.

Effects of the Matrix During Sample Fabrication

For composite samples containing fibers other than Kevlar 49, it was observed that some kink bands were formed in the fibers during sample fabrication. This was due to the residual thermal stresses that are generated within the sample because of matrix shrinkage. Optical micrographs were taken (using the Polaroid attachment on the microscope) of the fibers within the samples just after fabrication, as shown in Fig. 11. No external loading had been applied to the sample. Observations concluded that the Kevlar 49 fibers have no kink-band formation present. The other fibers—AB-PBO, PBO, and PBT—contain kink-band formations of varying intensity. The intensity of kink-band formations gives an indication of the critical compressive strains of the fibers, relative to one another. The as-spun and heat-treated PBO fibers appear to have the lowest compressive strains among the fibers considered since the kink band intensities are the greatest. This is in good agreement qualitatively with measured fiber critical compressive strain by the bending beam technique. As listed in Table 2, the fiber critical compressive strains for coil-like molecules, such as Kevlar 49 and AB-PBO, is always higher than those of rod-like molecules, such as PBO and PBT.

Initially, the formation of kink bands in the fibers during fabrication caused some concern and attempts were made to eliminate this problem. First, steps were taken to ensure that fiber handling during sample fabrication did not cause the formation of kink bands. This was done by examining the fibers under a microscope at different stages of fabrication up to the point in which the epoxy resin and curing agent mixture is poured into the mold. However, no kink band appeared due to handling, thus alleviating this concern.

Another possible reason for the kink bands forming could be due to the shrinkage of the epoxy matrix during the curing cycle. First, the epoxy matrix is heated to 125°C and expands. After two hours, the matrix is cooled to room temperature (23°C) slowly. During this time the matrix contracts, thereby placing the fibers in compression through the interfacial bond between the fiber and the epoxy matrix. Therefore, the curing cycle was modified to minimize the matrix shrinkage. According to the epoxy resin manufacturer, Shell Chemical Co., the curing cycle causing the least amount of shrinkage is a six hour

Table 2 Critical compressive strain of single filament measured by cantilever beam test[a]

Fiber	Tensile modulus, Msi	Critical compressive strain
Kevlar 49	18	0.0057 ± 0.0002
AB-PBO HT[b] 525°C	19	0.0042 ± 0.0004
PBO		
AS[c](RT)[d]	13	0.0019 ± 0.0002
AS(RT) HT 300°C	17	0.0018 ± 0.0003
AS(RT) HT 415°C	20	0.0019 ± 0.0004
AS(RT) HT 500°C	25	0.0017 ± 0.0002
PBT		
35IV AS(RT)	26	0.0019 ± 0.0004
35IV AS(RT) HT 650°C	39	0.0020 ± 0.0002

[a] Cantilever beam test was preformed by J. F. O'Brian, University of Dayton, Research Institute.
[b] HT = heat-treated at given temperature.
[c] AS = as-spun.
[d] RT = coagulated at room temperature.

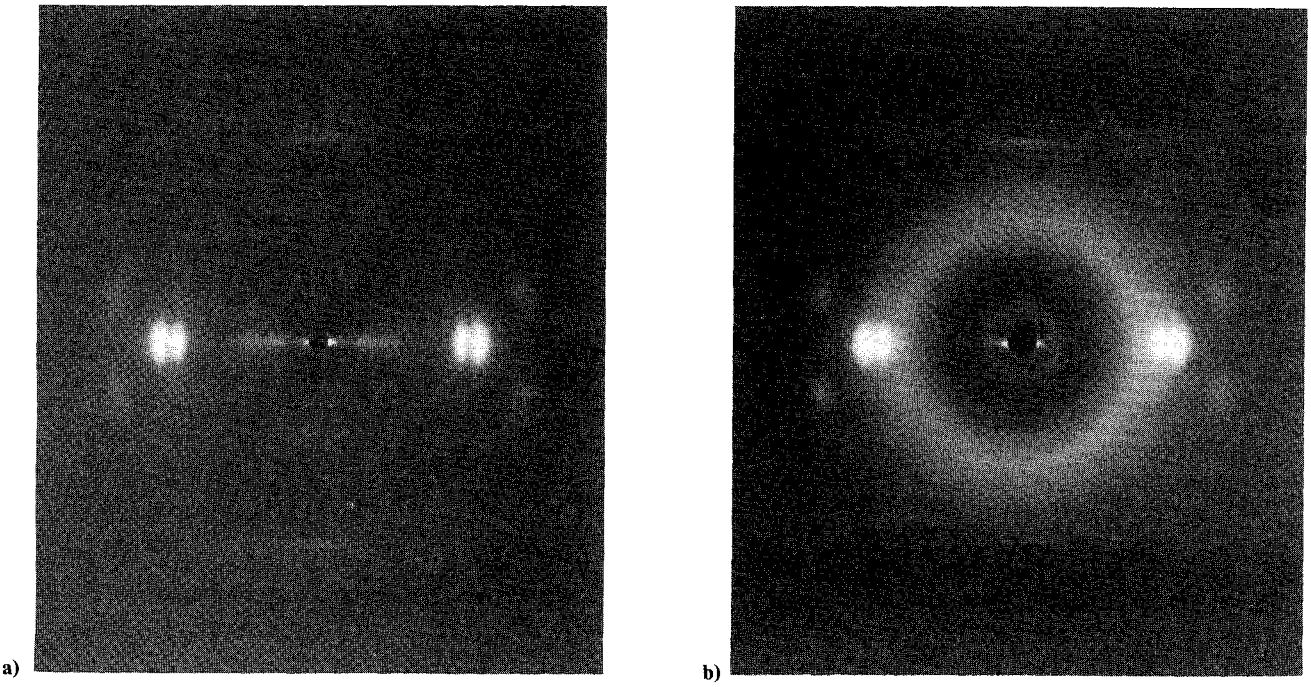

Fig. 12 X-ray scattering patterns of a) Kevlar 49 fiber; b) Kevlar 49 fiber embedded in the epoxy matrix.

cure at 75°C. Samples were made using this cure cycle, but kink bands still formed. The only alternative, then, is to use a different matrix, one that has little or no shrinkage during cure.

The goal of the experimentation, however, is to apply direct axial compression to induce kink bands in the fiber. As long as the molecular structure and long-range order of the fiber has not been altered due to the curing process, loss of the complete deformation process will not change the results when the uncompressed and compressed fibers, embedded in matrix, are examined. The composite sample containing the kinked fibers was examined with X-ray scattering and other morphological means. Figure 12 shows two X-ray scattering patterns on Kevlar 49 fiber alone and embedded in the epoxy matrix. Comparison of the X-ray scattering patterns indicates that the aniostropic scattering patterns from the Kevlar 49 fiber do not alter by embedding in the epoxy matrix. In addition, the epoxy matrix gives an isotropic scattering pattern that can be distinguished easily from the anisotropic scattering pattern of the fiber. This allows studies of microstructure of fiber under compressive deformation by X-ray scattering. This study of the microstructure of the fibers under in situ compression will be reported elsewhere.

Conclusions

The following conclusions can be made as related to the experimentation and analysis used to study the high-performance polymeric fibers under in situ compression:

1) A viable technique has been demonstrated for the study of compressive behavior of fibers. This involved embedding an uniaxially oriented continuous fiber bundle in a transparent epoxy matrix. A direct axial compression can be applied to the fiber; its compressive behavior can be examined by optical microscopy and X-ray scattering. A maximum compressive strain of 2% has been achieved with high degrees of kink-band formation induced in the fiber.

2) Finite-element analyses indicate that the stress gradient along the fiber is insensitive to the composite sample geometry and to Poisson's ratio of the fibers and the epoxy matrix. However, it was found that the stress gradient can be enhanced by using a stiffer matrix, i.e., a matrix of higher modulus. These have been verified by uniform kink-band distribution on the embedded fiber of the compressed composite samples and by the fact that a stiffer matrix of Epon 828 cured with m-PDA can sustain a higher compressive load leading to more kink-band formation.

3) The sample fabrication, using Epon 828/m-PDA matrix, caused kink-band formation for all fibers except Kevlar 49 fiber. The degree of kink-band formation agrees qualitatively with measured critical compressive strains. In addition, it shows that fibers of coil-like molecules have a higher critical compressive strain than fibers of rod-like molecules.

4) The initial kink-band formation from the composite sample fabrication did not, however, affect the subsequent analysis of the fiber. The viscoelastic effect of the matrix on the fibers enhanced the microstructure examination considerably. X-ray scattering on the undeformed composite sample indicates that the microstructure of the fiber is not affected by embedding in the epoxy matrix.

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