

Magnetic Field Alignment of Carbon Composite Matrix

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Introduction

The fracture behavior of the matrix of carbon-carbon composites from pitch precursors has been shown to be controlled by the disclination structures present.^{1,2} Cracks are diverted or altered depending on the type and structure of the disclinations. Improvement in composite properties may be accomplished by optimization of these disclination structures. Alignment of the carbonaceous mesophase by a magnetic field offers this potential. Thus, the objective of this research on magnetic field effects was to determine how the disclination structures could be controlled or altered to improve the properties of the resulting carbon-carbon composite.

The polynuclear aromatic molecules of the carbonaceous mesophase consist of several fused benzene rings, giving the molecule a disklike shape. This aromatic molecule is diamagnetic and is oriented by a magnetic field and tends to align parallel to the magnetic field. However, the molecular orientation is not uniquely defined. With the use of the normal to the disklike molecule to define its orientation, the normals to the molecules in the magnetic field lie anywhere in the plane perpendicular to the magnetic field.

Previous research on the effect of a magnetic field on the carbonaceous mesophase has centered on demonstration of the orientation of the mesophase by a magnetic field and the use of a magnetic field for preparation of well-oriented samples for measurement of diamagnetic susceptibility. Initial work by Singer and Lewis³ showed that the spherules of the carbonaceous mesophase were oriented by a magnetic field. The polar axes of the spherules aligned to lie in the plane perpendicular to the magnetic field. A higher degree of orientation was obtained when the sample was rotated about an axis perpendicular to the magnetic field. The mesophase spherules were all oriented with their polar axes parallel to the axis of rotation. The diamagnetic susceptibility of the carbonaceous mesophase has also been measured.⁴

Experimental Procedure

The pyrolysis of carbon composites with petroleum-pitch precursor was conducted with the use of radiant lamps and in the presence of a magnetic field. Glass test tubes of inside diameter of 10 mm were placed vertically between opposing radiant lamps. At 90° to the lamps were the poles of the permanent C magnet of 5500 gauss. The radiant lamps

were used, rather than a resistively heated furnace, to eliminate any interference with the magnetic field. A chromel-alumel thermocouple was placed in a graphite sleeve and inserted in the pitch.

Ashland A240 petroleum pitch was used, as it is relatively free of inert quinoline insolubles which could interfere with the development of the mesophase structure. A graphite-fiber fabric with T300 PAN fibers in an 8-harness satin weave was wrapped circumferentially inside the glass tubes. The pyrolysis heating rate was 100°C/hr from room temperature to 380°C and 20°C/hr from 380°C to 460°C. The pyrolysis in the test tubes was conducted in a nitrogen atmosphere to prevent oxidation. In some cases, the test tube was rotated about its axis (vertical) at 10 to 15 rpm with the use of an electric motor and belt system. A circular, sliding-contact mechanism was used at the top of the tube for the thermocouple wires.

Bubble percolation of escaping volatile gases tended to disrupt any alignment introduced by the magnetic field. Thus, the fiber-pitch samples were slow cooled from the maximum pyrolysis temperature to allow alignment by the magnetic field without interference from bubble percolation.

Alignment in a Fiber Composite

One of the primary failure modes of a bidirectional carbon-carbon composite is interlaminar shear. This shear fracturing in the matrix occurs on planes parallel to the fabric laminate plies, as the easy cleavage direction (parallel to the graphitic layers) tends to be parallel to the plies. If the matrix layers were perpendicular to the plies, such fracturing may be more difficult. Bulk mesophase, which is characteristic of the matrix between fiber bundles in the carbon-carbon composite, has been shown in this study to be aligned by a magnetic field. The resulting structure is the fibrous structure characteristic of needle coke. The tough fracture direction for this fibrous structure is perpendicular to its axis. Thus, if the composite matrix could be aligned with this fibrous structure perpendicular to the shear fracture plane, the composite may have improved shear properties. The magnetic field would be perpendicular to the fabric plies.

Optical micrographs of a bidirectional composite carbonized in this magnetic field are shown in Figure 1. The plane of section for these micrographs is perpendicular to the fabric plies and

parallel to the magnetic field. In the top figure, the matrix between the fiber bundles is dark (in extinction), implying that the molecular layers are aligned and are perpendicular to the vertical polarizing direction. At the 45° rotation of the polarizers, this same aligned matrix is light, indicating it is now not perpendicular to the polarizers. The matrix within the tightly packed fiber bundles is not so aligned. These micrographs

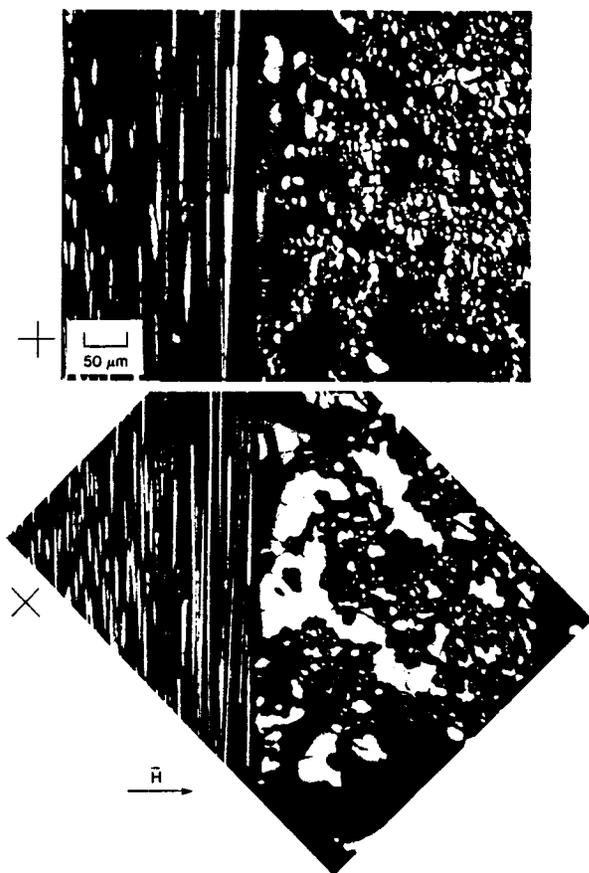


Figure 1. Micrographs of bidirectional composite perpendicular to magnetic field



Figure 2. Micrograph of fiber bundle rotated in magnetic field perpendicular to bundle axis

show that the magnetic field aligned the mesophase matrix between the fiber bundles perpendicular to the laminate fiber directions. The wedge disclinations in the fibrous microstructure of the matrix are thus aligned perpendicular to the fabric plies. This perpendicular alignment of the matrix should provide increased resistance to interlaminar shear fracture in this bidirectional composite.

Bend Elastic Constant

In an individual bundle of graphite filaments, there is a competition between the alignment of the disklike molecules by the filament surfaces⁵ and the alignment by an external magnetic field. For a fiber bundle rotated in the magnetic field with its axis parallel to the field, all the molecules should lie perpendicular to the filaments. This is the case in Figure 2 for the bulk mesophase surrounding the tightly packed filaments. But within the fiber bundle itself, the alignment by the fiber surface dominates. The dark areas do not change with rotation of the crossed polarizers. The white ring about isolated filaments denotes a region of layer orientation parallel to the filament surface.

For the competing effects of strong anchoring at the filament surface and the alignment by the magnetic field, the molecular orientation changes from parallel at the surface to perpendicular in the bulk matrix. This curvature is bend and is one of three curvatures possible for a liquid crystal. (The other two are splay and twist.) The surface exerts a torque on the material away from the wall; this torque is related to the elastic constant K_3 for bend. This elastic constant is a measure of the resistance of the liquid crystal to bend as a result of some external force. The magnetic field also exerts a torque on the bulk liquid crystal, which is related to the difference in the parallel and perpendicular diamagnetic susceptibilities and the magnetic field strength. A length can be defined over which these two torques balance. This length is called the magnetic coherence length and is the thickness of the white ring about the filaments in Figure 2. Since both the diamagnetic anisotropy of the carbonaceous mesophase and the magnetic field strength are known, the elastic constant for bend for the carbonaceous mesophase can be determined. For a magnetic coherence length of about $7 \mu\text{m}$ (Figure 2), the bend elastic constant is $K_3 = 10^{-5}$ dynes. This elastic constant for bend for the mesophase, a discotic nematic liquid crystal, is about 10 times larger than the bend constant for rodlike nematic liquid crystals. This difference may be related to the higher molecular weight and the disklike shape of the aromatic molecules. This is the first determination of one of the three elastic constants for bend, twist, and splay for the carbonaceous mesophase.

References

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