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Microstructure and Fatigue of Textile and Industrial Fibers

Project Number: S94-2

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Goal

The goal of this project is to develop methods for managing, i.e. either increasing or decreasing, damage accumulation in torsion and flex fatigue of fibers by controlling their structure, and to uncover the nature of the asymmetrical response of fiber microstructure to stress which makes damage accumulation and fatigue occur.

Abstract

This new project is off to a good start. Graduate students are in place and working both at Clemson and NCSU. Partnerships have been organized with two fiber producers who are providing the project with dried, clear PET flake, polymer and other characterizations which neither Clemson nor NCSU can do, and with a desirable information exchange/ sounding board relationship. Equipment fabrication is 80% complete, and software will be operational by October. Planned optimizations of the NCSU interference microscopy capability are complete, although we intend to continue improvements as needs become apparent.

Background

Long term competitiveness of the USA textile industry depends on its ability to produce products which meet customer expectations at lowest cost. Customer expectations derive from the entire range of products available from worldwide sources. While synthetic fiber properties are on average extremely good, there are areas where they could fit end uses better, thus offering competitive advantage to the owner of the improving technology. An important fiber property, which is poorly understood in a fundamental sense and which could offer both cost and performance competitive advantage, is fatigue behavior. Fiber fatigue is important in all three market segments--apparel, carpet and industrial, although the exact details vary. Apparel fibers can be both too resistant and inadequately resistant to fatigue. Industrial and carpet fibers would benefit from longer fatigue life.

Fibers are susceptible to fatigue of two main types. One of these, cyclic tension fatigue, involves only tensile stresses along the axial (chain) direction. The other, which involves forces normal to the chains and/or compression along the chain direction, is more destructive to fibers than tension. Fatigue failure is an asymmetric response of the fiber microstructure to stress. This means that the result of a tensile deformation is not opposite to the result of a parallel compressive deformation. This asymmetry causes accumulation of damage with time at low stress amplitudes, and this damage weakens the fiber. A useful understanding of fatigue must include detailed knowledge of this asymmetry, because intervention is required at this point to get the best fatigue performance.

~~Cyclic tension fatigue is the same as static tension fatigue and is not a severe problem in~~ fibers. The fundamental asymmetry involved is intrinsic to fiber structure. When the stress is high there is tension on the load bearing molecules which causes them to fail due to stress biased thermal activation with a probability P^+. The probability for the reverse process P^- is lower than P^+ because a natural tendency of the free ends of a broken molecule is to diffuse apart. Consequently broken chains do not recombine when the stress is relaxed. When fibers are made stronger, by effectively increasing the concentration of load bearing chain segments, tensile fatigue life also increases. In general the fatigue life of fibers is lower under torsion and bending than in tension. In addition compressive fatigue life usually decreases as fibers are made stronger in tension. The nature of the asymmetry is not known in this case, and strategies for dealing optimally with the fatigue problem are not clear. This project aims to 1) develop methods for managing damage accumulation in torsion and flexure, which are independent of understanding the asymmetry and 2) discover the nature of the asymmetry in cyclic fatigue so that maximum fatigue resistant fibers can be made.

We have past experience which suggests that fatigue performance of fibers can be varied by changing the surface-to-center birefringence (i.e. orientation and crystallinity) profile, but these effects have never been confirmed or thoroughly quantified. In addition previous work also indicates that fatigue damage accumulation is accompanied by crazing and "delustering", which can be studied by transmission electron microscopy and which might reveal the fundamental response asymmetry mentioned above.

Specific Objectives

The specific objectives for the first year of this project, which at the time of this Annual Report is 50% over, are:

1. Develop methods to produce fibers having substantially different radial microstructure profiles with deniers, physical properties and luster which are 1) close to those of commercially available fibers and 2)optimally suited for microstructure analysis and fatigue testing.
2. Fabricate a 12 station torsional fatigue tester-complete with strain gauges and special clamps for holding fibers.
3. Complete implementation of computer controlled, 5 position bending fatigue tester.
4. Refine analysis methods and models used for determination of radial structure profiles in fibers to make them optimally applicable to fibers produced in this project.

Status

Three graduate students have currently been working on this project since last March. Sridhar Siripathy is seeking a MS degree at NCSU; Rajiv Jain and Ajay Padsalgikar are seeking Ph.D. degrees at Clemson. Their work continues.

Flex Fatigue

A 5 station (expandable to 16) computer controlled, bending fatigue apparatus, designed as

~~part of a previous NCSU project, is nearly complete. Mainly we have only to work out the~~ bugs and to write the software. Recently, however, it was discovered that 4 of the 5 load cells were non-functioning. While these are being repaired, software development will continue. At present the equipment is functioning, and the preliminary software has been implemented. Software, capable of running a fatigue test, is expected by October.

The design of the pin flex fatigue device at Clemson is currently being changed. The new design will use hardware similar to that of the torsion fatigue apparatus already in use, which is discussed below.

Torsional Fatigue

A torsional fatigue tester, which was built as part of a previous project [1], has been improved and recommissioned for this project. A sketch of the essential components of the improved tester is shown as Figure 1. There were two significant modifications. Spacers were installed to raise the motor and other moving parts by 5 cm. This change allows the testing of longer fibers than the previous design. The method for attaching fibers to the fatigue device was improved based on a design due to Kawabata [2]. In the new method the fiber to be tested is attached to two tabs, which mate with hooks as shown in Figure 1. This improvement makes it easier to install fibers in the device, and consequently prevents possible damage. Previously the ends of the test fibers had to be glued to two steel pins. The top end of the fiber specimen was held by gripping one pin in a chuck. The bottom end hung freely but was restricted from rotating by a tab attached to the bottom pin. We made the modifications described above only after considerable experience with this method.

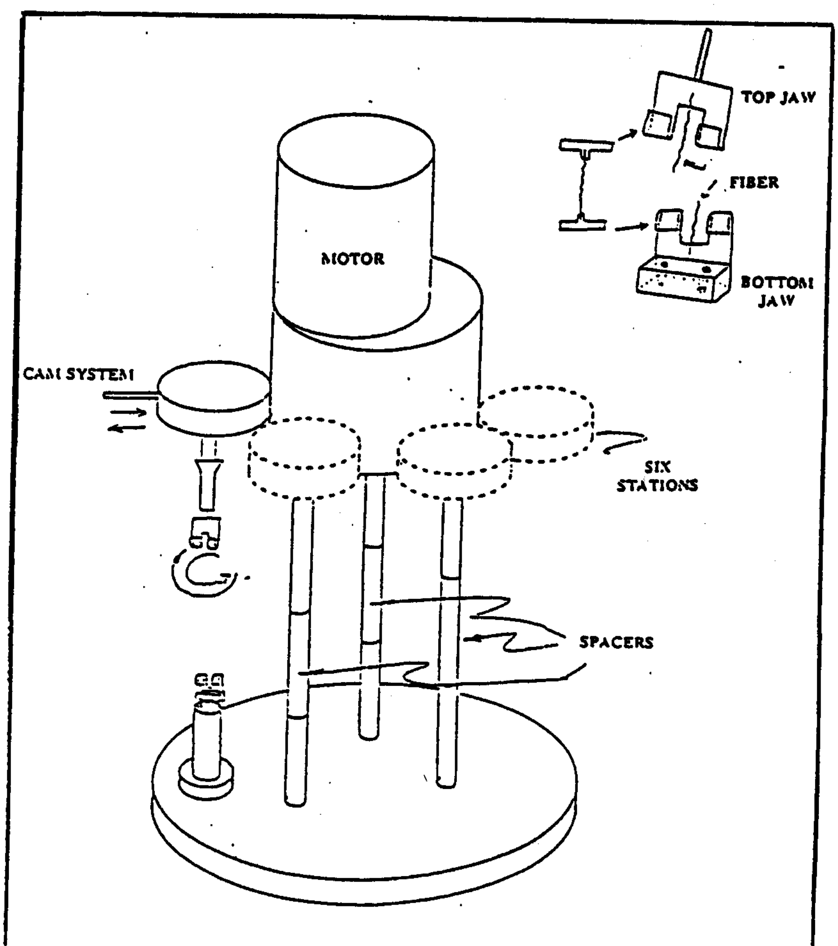

Figure 1 Schematic of Clemson's Torsional Fatigue Apparatus

Testing of control fibers with this device is already underway.

Interference Microscopy

A critical part of this project has been to make the NCSU system for measuring radial refractive index profiles of fibers conveniently useable. To do this required 1)modification to existing software, 2)development of new software and 3) equipment changes. All of this is complete. The revised system was tested on polypropylene fibers used in torsional properties tests at Clemson, and found to show differences in radial structure which corresponded with torsional properties. In this case the mathematical model used in the software was found to be adequate. It is possible that this model will need to be changed for fibers produced as part of this fatigue project, but this will not be known until the fibers are made.

Strategic Activity

An important part of the initial phase of this project has been to decide exactly what kinds of fibers to work on. A number of options were considered. At present we have concluded that during the first two project years work should be done mainly on 12-25 dpf PET fibers made from clear polymer of 0.65 and 0.95 intrinsic viscosity. We are aware of a commercially significant fatigue problem in high strength nylon fibers and expect to extend the work to these fibers in the third project year.

Two industrial partnerships have been negotiated for this project. The industrial partners, both of which are fiber producers, will provide the project with PET flake and will also do viscosity and other fiber property tests which are not available internally. We believe these partnerships will be mutually beneficial.

Program Highlights

o	Complete NCSU flex fatigue equipment	9/94
o	Software for NCSU flex fatigue equipment functional	10/94
o	Spin and characterize first fibers at Clemson	11/94
o	Spin different skin/core fibers with goal polymer properties at Clemson	2/95
o	Characterize and fatigue test 2/95 fibers	4/95
o	Begin transmission electron microscope characterization of fatigued fibers	6/95
o	Develop first generation model of asymmetry	Continuing

Personnel Issues

Effective July 31, Prof. Sol Hersh retired from his position as Charles A. Cannon Professor of Textile Engineering, Chemistry and Science. At this point project leadership was assumed by Prof. Subhash K. Batra. We hope that Prof. Hersh will continue to work with this project in a consulting relationship, at least for the next year. The project is grateful for Prof. Hersh's leadership during its first year. In addition Dr. M.G. McCord, who recently joined NCSU as Assistant Professor in the Fibers Materials Science program, will become a co-PI for this project. Dr. McCord has special expertise in the torsional behavior of fibers, and we believe she will be a strong contributor to the understanding of fatigue failure.

Citations

1. Duckett, K.E. and B.C. Goswami, *Text. Res. J.* 1984, 54, 43

2. Kawabata, S., personal communication