Optical Fiber Reliability

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In a relatively short time, fiber optic technology has made rapid strides from a laboratory curiosity to a multitude of technically and economically successful commercial systems. These extend to all major areas of communications, sensors, and signal processing applications, and the technology has reached the threshold of even larger scale commercial exploitation. With a bandwidth or information capacity thousands of times greater than that of copper circuits, fiber optics may soon provide us with all the communication paths we could ever want, at a price we can afford. To date, fiber optics has found its greatest application for voice traffic in the telephone industry, but its capabilities for transmitting data and video are increasingly important in other areas, such as computers, cable television, and industrial instrumentation. Still other uses are expected to be found as the price of fiber optic systems drops and components are perfected. But the very high transmission capacity of fiber optic systems carries with it a requirement for high reliability, because a sudden failure can disrupt so many communications channels.

Today, more than nine million kilometers of fiber have already been installed in the United States. Ninety-five percent of that cable connects central offices through underground ducts, which afford a relatively high degree of protection. But as fiber optic networks continue to expand, fibers will be exposed to much harsher environments, as is the case with fiber in the loop (FITL) leading directly to businesses and residences. The stresses specific to these new environments must be carefully analyzed to anticipate problems and help prevent failures. FITL applications also mean increased fiber handling, which leads to a higher risk of error, such as damaging the surface of glass. In addition, remote terminals and pedestals present new challenges for fiber, such as exposure to higher temperatures and severe chemicals. The fiber must retain its mechanical integrity after exposure to these tougher environmental elements to allow for rearrangements and maintenance. To address increased requirements of mechanical reliability, more fundamental research in this field is required.

In the literature that first addressed glass optical fiber strength, there were always discussions of brittleness, crack formation and growth, lack of plastic flow, etc. Perhaps a sign of our "advanced" understanding is that we no longer feel the need to discuss these "simple" issues. However, the replacement of a ductile material (copper) with a brittle one (glass) is still at the heart of our problem of reliability. Fiber strength is controlled by the presence of small surface flaws that can be introduced during fabrication by even minor contact of the fiber surface with a solid object or by incorporation of inclusions from the manufacturing environment into the fiber. Current commercial fibers have strengths in excess of 5.5 GPa (800 ksi) when tested in short lengths (about 1 m). These strengths have been achieved by carefully avoiding surface damage and inclusions during fiber drawing and by protecting the fiber surface with a polymer coating. However, like any communication cable, fiber cable must be spliced and connectorized. In the process of splicing fibers or installing connectors the coating must be removed, thus exposing the glass surface to damage and to degrading environments. Installation of either mechanical or fusion splices or various types of connectors involves several steps that may induce surface flaws. These include removing the cable structure (sheath, jacketing, and buffer tubes), stripping the coating, cleaning the stripped fiber end, cleaving the fiber end, installing the splice or connector, and recoating the fiber or installing the splice supporting structure. Thus, while studying the detailed mechanics as described in this issue, we should not lose sight of the fact that the training of any person handling lightguide fibers at any stage is extremely important. Also, a better understanding of these issues will make the teaching process more effective.

The intent of this special section is to address the reliability of fiber optics and fiber optics systems in benign and adverse environments. The authors are researchers in industry, universities, and government laboratories who are striving to perfect this discipline.

The first part of this special section includes papers on reliability and lifetime considerations for fiber optics. The first paper (Kurkjian and Inniss) gives an overview of the mechanical reliability of optical fibers. This paper clearly shows that substantial effort is ongoing in the study of strength and fatigue of optical fibers, though not enough fundamental work. It is important that the latter be maintained, since such work in the general area of the strength of glass seems to be declining. Although no papers from outside the United States (except for the USSR) are contained in this issue, partly because of time constraints, apparently work in this area outside the United States is also declining. As seen by the paper by Bogatyrjov et al. and others in this special section, considerable interest and work in the area of prooftesting still exist. This is of course natural since this is the on-line test affecting fiber manufacturing yield. Lifetime predictions are made using a power function model, and considerable insight is gained using this tractable mathematical format. Too often no effort is made to estimate the differences between one model and others that have been proposed. This issue not only gives the possible theoretical preference of the exponential model, but also illustrates the differences in time to failure using different models.

While there appears to be somewhat of a resurgence in the amount of development work on polymer coating, again, little fundamental work is being reported. Thus, the paper by Gebizlioglu and Plitz is a welcome addition to this special section. Understanding of adhesion and its effect on initial strength, fatigue, and aging has yet to be achieved. Although a fair amount of polymer chemistry is being done to produce good polymers, the composite coated fiber is seldom studied in the same detail. The paper by Inniss and Krause presents a very practical technique to overcoat spliced hermetic carbon-coated silica fibers.

The third portion of this special section includes papers on long-term hydrogen- and radiation-induced losses. A comprehensive overview of the reliability of optical fibers exposed to hydrogen is given by Lemaire. The work by Schick et al. shows that corroding galvanized steel and hydrogen-producing bacteria can generate enough hydrogen to cause appreciable signal attenuation in optical fibers.

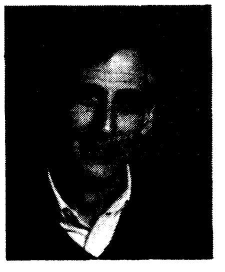
The paper by Unger and Spencer explores several aspects of FITL equipment reliability and availability. Connectors are another area in which empirical work is being done because of the complexity of the problem. The paper by Young highlights some of the important reliability-related problems in butt-joint type connectors.

We hope that the papers presented in this special section contribute to a better understanding of the current research in the area of optical fiber reliability and stimulate further development of this very important field.

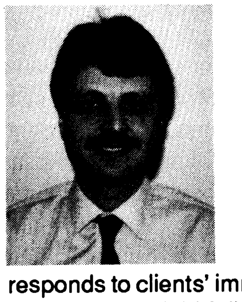
Our strong recommendations for work in the field of fiber optics are:

- Continue and expand fundamental studies of fracture and fatigue.
- Continue and expand modeling of fiber reliability.
- Develop more sophisticated studies of polymer/glass composite.
- Develop more radical systems, e.g., composite glass or polymer overclad fiber and hermetic coatings.

The papers gathered for this special section are intended to represent current research in fiber reliability. We would like to thank the individual authors for their cooperation and the institutions that support their efforts. We also would like to thank Dr. Jack Gaskill, former editor of *Optical Engineering*, for his support and patience during the preparation of this issue and the reviewers for their prompt and professional help that goes unreferenced.



Charles R. Kurkjian received the B.Sc. degree in ceramics from Rutgers University in 1952 and the Sc.D. degree in ceramics from MIT in 1955. After postdoctoral appointments at MIT and The University of Sheffield, England, he joined Bell Laboratories in 1959. He has worked in various areas of glass science, most recently with fracture and fatigue of silica fibers.



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