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Laminated Fiber Ribbon for Optical Communication Cables

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Laminated fiber ribbon (LAMFIR) exhibits mechanical properties of a composite structure and is strong enough to withstand the stresses of cable fabrication. Laminating parameters have been adjusted to make the LAMFIR relatively easy to separate for accessing the fibers. Optical properties of LAMFIR have been characterized, so that trade-offs between numerical apertures (NA), cladding thickness/core diameter (t/d), and additional loss are given for uncoated, step-profile fibers and one set of laminating conditions. Larger values of t/d than originally expected are desirable due to the bends in the fiber axes.

I. INTRODUCTION

The minimum loss obtainable in high-quality optical fibers has been steadily decreasing over the years with losses of less than 2 dB/km at 1.06 μm now being reported.[1] These advances along with those in the area of sources and detectors indicate that the basic components needed to build digital fiber links capable of operation in the tens or perhaps even hundreds of Mb/s range are becoming available. Combining a plurality of fragile optical fibers with adequate packaging to form a rugged communications cable is needed before fiber systems become practical.

The ribbon structure (linear array) for packaging optical fibers was suggested by Standley[2] and others of Bell Laboratories. This linear array structure is attractive from the splicing standpoint since groups of fibers can be handled at once. The "essentially two-dimensional" nature of fiber ribbons relaxes the alignment requirements needed to accomplish mass field splicing of optical cables. This is advantageous for multifiber splicing. In addition, the ribbon provides mechanical support and increased bulk, thereby greatly improving the "handling qualities" of individual fibers.

Other fundamental requirements of any ribbon structure are as follows:

(*i*) The ribbon structure must protect the fibers against breakage due to handling and must have an adequate service life. The mechanical strength and abrasion resistance must be sufficient to withstand forces generated in the cabling operation as well as the cable handling required to emplace these cables.

(*ii*) The optical properties of the fibers must not be significantly degraded by the ribbon structure or the subsequent cabling operation.

(*iii*) The ribbon structure must be strippable in order to expose the fibers for splicing or terminating to sources or detectors. Alignment accuracy of fibers within the ribbon and relative to the edge of the ribbon will probably be dictated by splicing requirements.

(*iv*) The ribbon structure must be economically manufacturable.

This paper reports on a laminated fiber ribbon (LAMFIR) which has strong bonding between the fibers and the ribbon structure. As shown in Fig. 1, a composite polyester-polyethylene tape forms each side of the structure with the fibers between them. At the polyester-polyethylene interface, the ribbon must be peelable in order to gain access to the fibers.

II. FABRICATION OF LAMFIR

A commercially available roll laminator, designed to plastic-encapsulate identification cards, was modified to fabricate LAMFIR. The additions to the original machine include (*i*) a fiber guide to provide uniform fiber separation, (*ii*) a cutter to trim away excess tape material, (*iii*) a more accurate temperature controller, and (*iv*) modified gearing to increase the laminating speed. As shown in Fig. 2, two supply reels feed the composite polyester-polyethylene material over heated rollers which soften the polyethylene. The two heated tapes are brought into contact under pressure and the fibers are sandwiched in polyethylene which serves as the adhesive. Forced-air cooling is applied after the pressure rollers. Power rollers pull the laminated

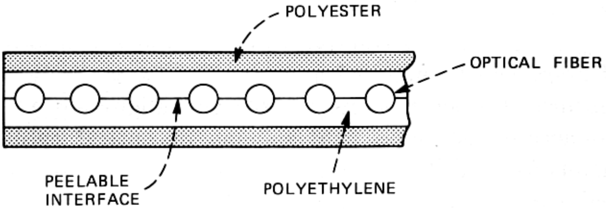

Fig. 1—Cross section of a laminated fiber ribbon.

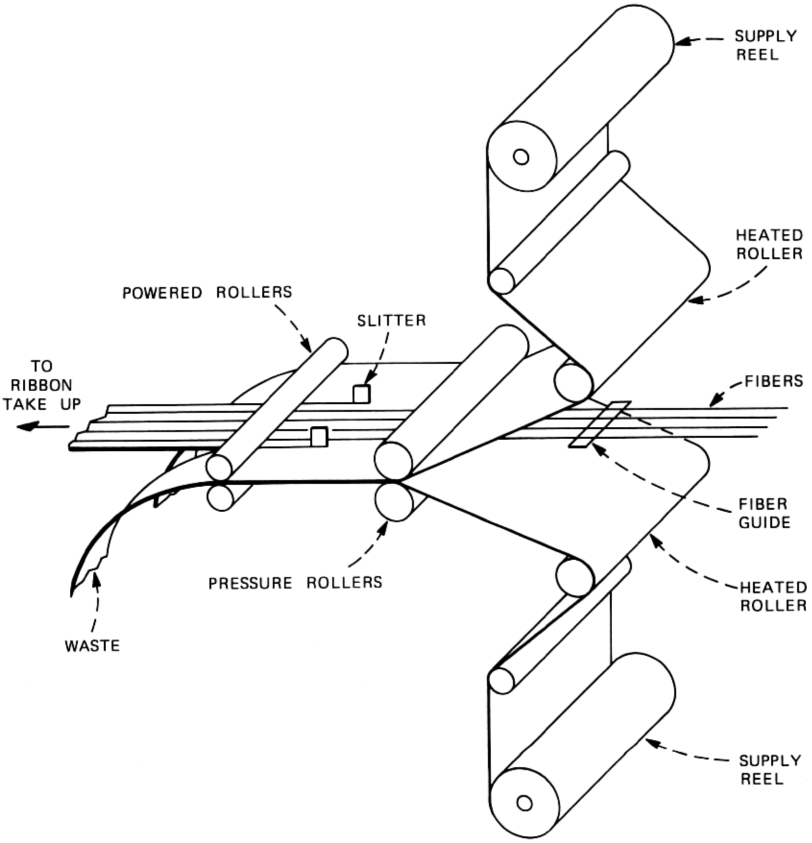

Fig. 2—Laminated fiber ribbon fabrication.

material through the slitting station, with tension provided by the supply reels.

The polyester maintains dimensional stability (higher melting temperature than polyethylene), while the polyethylene is softened by application of heat. At the proper temperature and pressure the polyethylene flows sufficiently around each fiber to form the cross section shown in Fig. 1.

III. MECHANICAL PROPERTIES

Mechanical strength tests have been performed on the LAMFIR structure.[3] The purpose of these tests was to determine how the structure modifies the mechanical properties of individual fibers. Tensile tests were made on two-foot samples with individual fiber breaks being detected *in situ* by an optical technique. The results of these tests[3] on the LAMFIRs containing different numbers of fibers are shown in Fig. 3. The output of an optical sensor indicates that the first break in the straight portion of the curve corresponds to the load at which all the fibers have broken. It is seen that the load-bearing capacity of the fibers, as well as the slope, increases with the number of fibers. A comparison of the curves for the LAMFIR

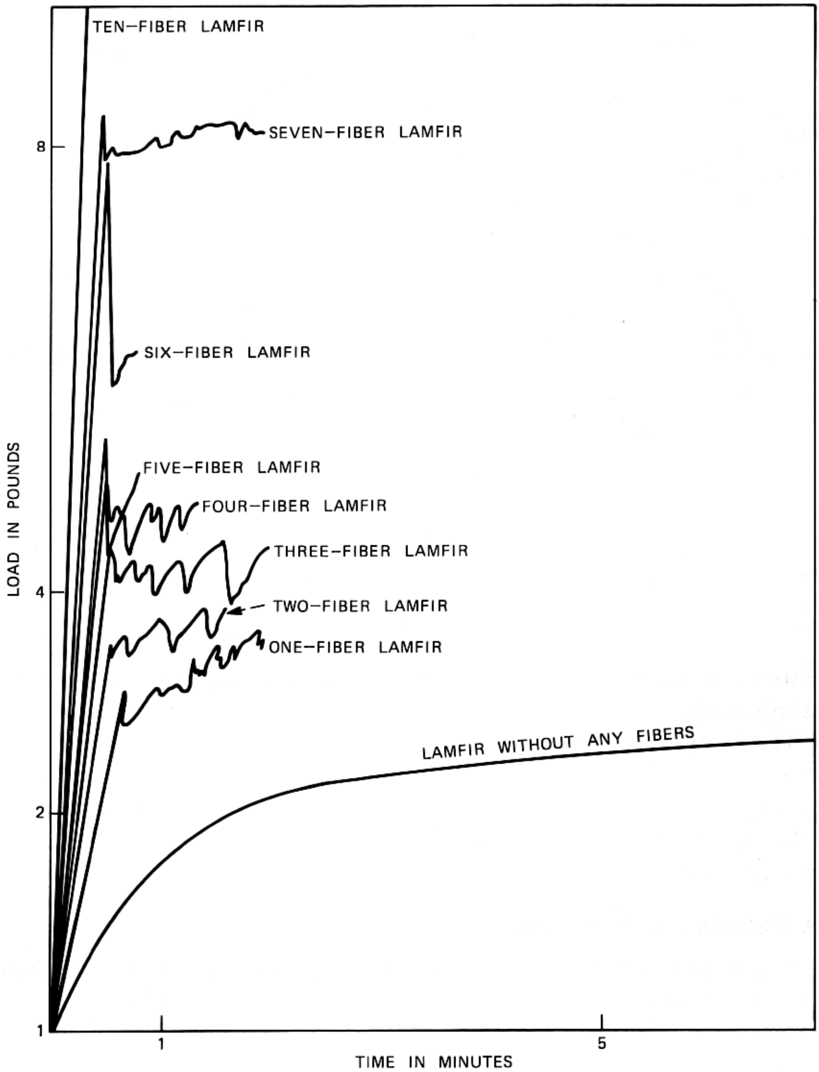

Fig. 3—Strength of a LAMFIR.

composites with the curve for LAMFIR containing no fibers shows that the fibers indeed carry the major portion of the load. After all of the fibers had fractured, the load did not decrease to the load-bearing capacity of the plastic alone. The fibers broke at different locations with respect to the tape, and the ribbon now behaves like a mechanical composite containing discontinuous fibers. Well-bonded discontinuous fiber composites react to applied loads by locally transferring stress through the matrix across the fiber discontinuities.[3]

From a mechanical standpoint the LAMFIR structure performs well. Rudimentary cables fabricated with LAMFIRs preserve the composite character of the ribbons. Tensile loads comparable to those anticipated in pulling long cables into ducts can be withstood without fiber breakage. Should additional strength be required, load-bearing fibers of graphite, Kevlar 49,* or glass could perhaps be guided into place during lamination to increase the strength of the ribbons. Load-bearing elements might also be embedded in the cable sheath[4] or elsewhere if additional strength is needed for pulling cables into rough or tight (high coefficient of friction) ducts.

IV. OPTICAL PROPERTIES

Initial LAMFIRs exhibited exceedingly high losses (hundreds of dB/km). It was found that random bending of the fiber axis caused this increased loss. The random bending was caused by shrinkage in the polyester component of the composite film after lamination during cooling of the polyethylene. A thicker polyester component which was oriented longitudinally to reduce shrinkage greatly reduced the additional loss.

The fiber cladding thickness is another factor that greatly affects the loss due to bending in the presence of a lossy jacket. The cladding optically isolates the fiber core by providing a low-loss medium for the exponentially decaying evanescent field. If the cladding is too thin, this evanescent field has appreciable intensity at the boundary between the cladding and, in the case of LAMFIR, the polyethylene which is lossy at optical frequencies. When bending of an optical fiber occurs, the transverse field extends even further into the cladding on the outside of the bend.[5]

Increased mode coupling due to random bending may also be contributing to the added loss.[6] This mechanism may result in a continuous transfer of energy to the lossier high-order propagating modes and to radiating modes. Either effect, inadequate cladding thickness or increased mode coupling, can significantly increase the loss of fibers.

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* Trademark of E. I. duPont de Nemours and Company, Inc.

A set of 12 ribbons was fabricated with the emphasis on uniformity of ribbon geometry and repeatability of laminating conditions. All conditions during ribbon fabrication were held as constant as possible at a set laminating temperature and a constant laminating pressure supplied by pressure rollers. Additional loss vs cladding thickness/core diameter (t/d) for various fiber numerical apertures (NA) are shown in Fig. 4. All data points follow the dashed curves which indicate the trends in the data. Conclusions based on these particular laminating conditions (not necessarily optimum) are as follows:

(*i*) Additional loss decreases with increasing t/d and increasing NA as expected.

(*ii*) Three-mil OD fibers consistently exhibit higher additional losses than 5-mil OD fibers with the same t/d and NA. The amplitude and spatial frequency spectrum of the bends depend

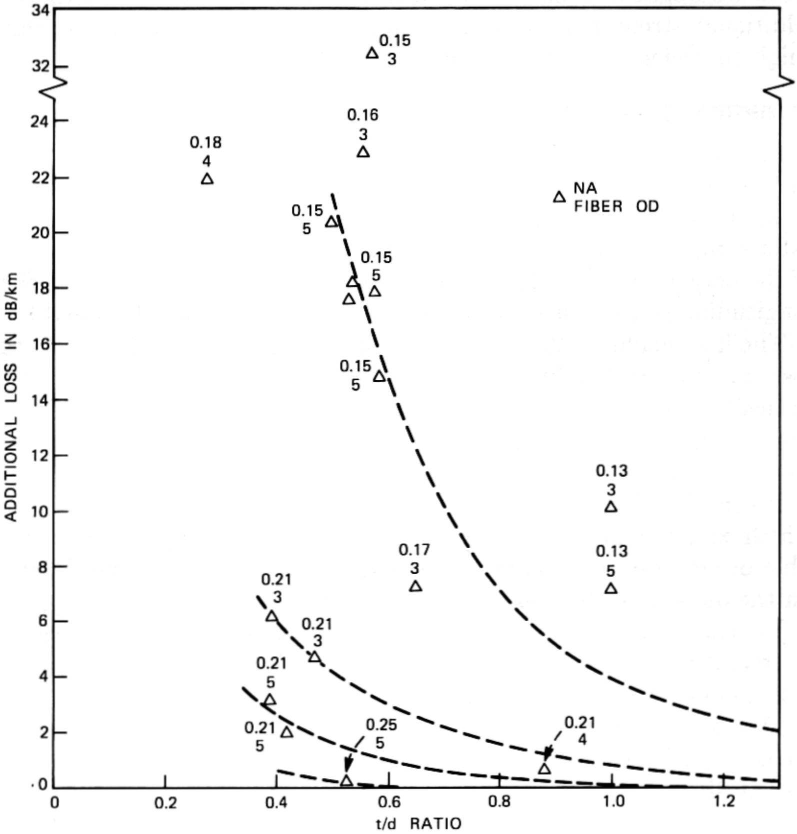

Fig. 4—Additional loss in a LAMFIR structure.

on the fiber stiffness. Five-mil fibers are much stiffer and probably assume bends with smaller amplitudes or longer periods (or both) as compared with 3-mil fibers.

(*iii*) A relatively high t/d value is needed for the LAMFIR structure. A t/d ratio approximately equal to 0.5 is required for 5-mil fibers at NA = 0.21 and probably $t/d \approx 1.3$ for 5-mil fibers with NA = 0.15 for less than 2 dB/km added loss. The t/d parameter was selected because added loss increases with d and decreases with t. Since the powers of these two dependences may differ, loss may not be a single-valued function of t/d for a wide range of t and d. It is unclear which loss mechanism is responsible for the added loss, and indeed, inadequate cladding thickness may be important at small values of t/d while mode-coupling effects should dominate at large values of t/d.

(*iv*) Excellent repeatability of the data is indicated by the cluster of points with NA = 0.15 in the interval $0.5 < t/d < 0.6$. These fibers were all in different ribbons.

V. ACKNOWLEDGMENTS

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