THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 58, No. 8, October 1979
Printed in U.S.A.

A Vacuum-Assisted Plastic Repair Splice for Joining Optical Fiber Ribbons

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(Manuscript received May 11, 1979)

A vacuum-assisted, injection-molded, repair splice has been developed for joining linear arrays of optical fibers (fiber ribbons). We describe the assembly tool and procedure followed to fabricate an optical fiber ribbon repair splice. The use of vacuum assist in the connector itself during the assembly process allows one to easily hold the fibers in their grooves and greatly simplifies the assembly tools and procedures required to fabricate a splice. Numerous ribbon splices were made both in the laboratory and in a manhole test facility in an effort to evaluate the quality of the splices obtained using this splicing method. The average splice loss was 0.2 dB with 95 percent of the splice joints having losses less than 0.7 dB.

I. INTRODUCTION

A vacuum-assisted, injection-molded plastic splice has been developed for repairing optical fiber ribbons. In this paper, the molded plastic parts and the molding procedure used to fabricate them are described, the splice assembly process is discussed, and the loss characteristics of the completed splice are evaluated.

The problem of developing a field-adaptable repair splicing technique for joining groups of optical fibers in the form of linear arrays has been addressed by a number of different investigators.[1–5] The general approach followed by all these investigators has been similar and is described below.

To prepare a linear array of optical fibers (a ribbon) for repair splicing, the plastic material is removed from around the fibers and the ends prepared using a controlled fracturing technique.[6,2] The fibers are then inserted into a grooved substrate, which is used to align the fibers, to form a butt joint. The splice is completed by attaching a cover to the substrate and adding an index-matching material to the joint. Variations in the basic technique differ in the way the substrate is made, in the complexity of the assembly procedure followed, and in the tools used to fabricate the splice. For a repair-splicing technique to be field adaptable, the assembly procedure must be accomplished in a routine fashion by craftspeople of average skill level. The fabrication tools must be relatively simple and adaptable to a hostile field environment. In addition, the splice hardware must meet tight tolerances, be mass-producible, and be inexpensive. In the past, no splicing technique has met all the above requirements. Using injection-molded plastic parts,[2] splice hardware can be mass-produced inexpensively and meet the required tolerances. The problem to date has been to develop simple assembly tools and procedures to fabricate a splice. The vacuum-assisted plastic splice described in this paper was designed with this problem in mind. The use of vacuum assist in the connector itself allows one to easily hold the fibers in their respective grooves during the assembly process. This is an evolutionary improvement of past splicing techniques using injection-molded parts that greatly simplifies the assembly tools and procedures required to fabricate a splice.

II. DESCRIPTION OF VACUUM-ASSISTED SPLICE

The vacuum-assisted splice as shown in Fig. 1 and 2 consists of an injection-molded plastic (polycarbonate) coverplate and grooved substrate. Both the substrate and coverplate have six vacuum slots, transverse to the direction of the grooves, to facilitate assembly of a

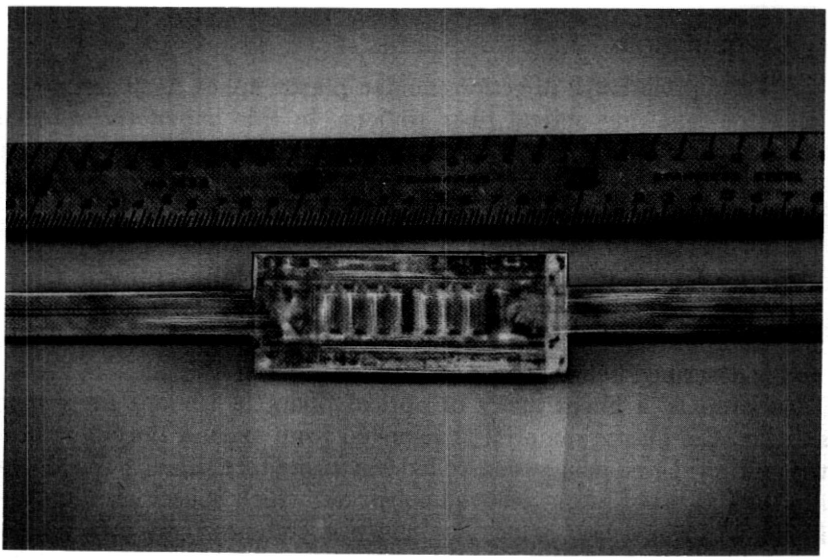


Fig. 1—Coverplate and substrate of injection molded splice.

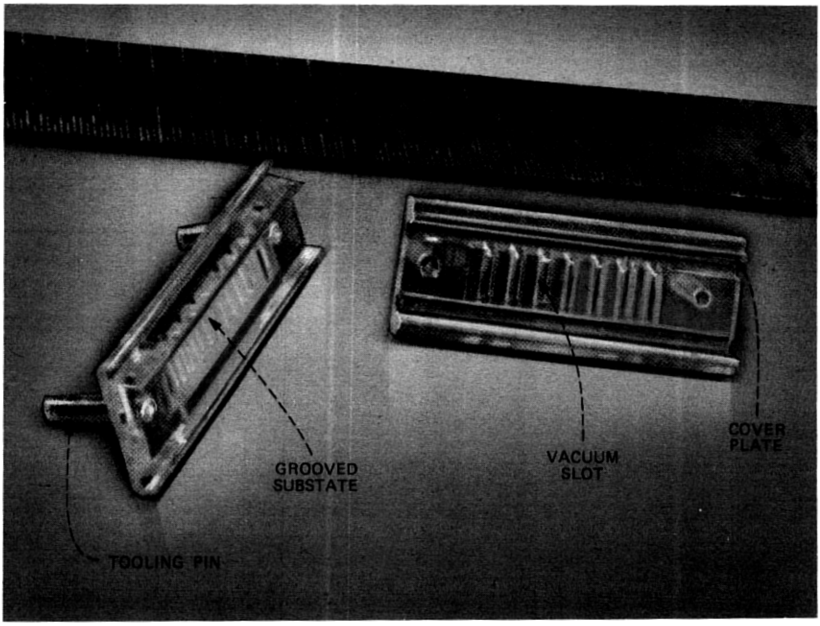


Fig. 2—Completed ribbon splice.

ribbon splice. A seventh slot is located in the center of the coverplate to allow injection of index-matching material into the completed splice. Tooling pins are molded onto both the coverplate and substrate to allow these parts to be easily mounted and aligned in the assembly tool. Injection-molded parts can be designed with a total assembly concept in mind. This allows a designer to build simplified assembly tools which take advantage of alignment features in the connector. After the ribbon splice has been assembled and removed from the assembly tool, the tooling pins are cut off to produce the completed splice shown in Fig. 1.

A cross section of the connector shown in Fig. 3 illustrates the grooves that house the fibers. The deviation of the critical width dimensions of the grooves in the plastic part compared to the master used in the mold was less than 1.0 μm.[2,3]

Figure 3 also shows the troughs which contain the adhesive needed to secure the coverplate to the substrate during the splice closure process.

III. MOLDING AND MATERIALS

The plastic parts were molded on an Arburg 200S Allrounder screw injection molding machine. The parts described in this paper have been molded from either polycarbonate (PC) or polymethylmethacry-

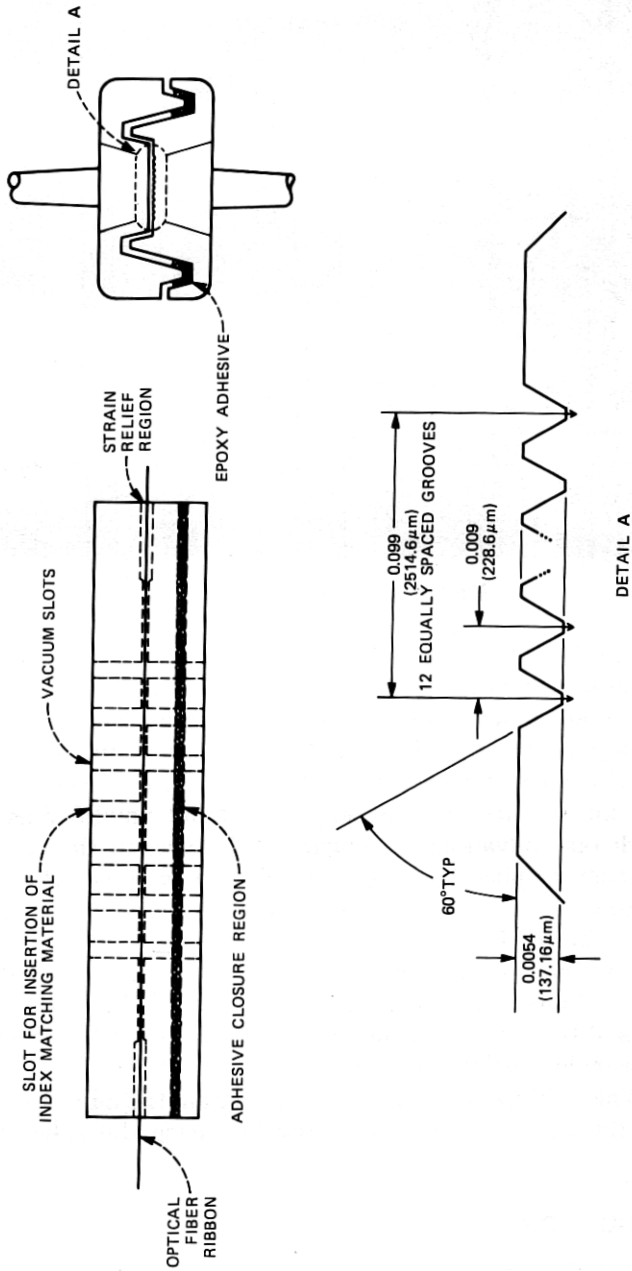


Fig. 3—Section through splice showing grooves and closure method.

late (PMMA). The reasons for these selections are discussed subsequently. Preliminary experiments with gate location indicated no significant differences in groove dimensions between the side and end gating. End gating, used in a feasibility plastic splice,[7] introduces the plastic into the mold cavity parallel to the grooves. In the vacuum-assisted repair splice geometries, this was not found to be necessary but may be required on more complex splice geometries.

It is important to remember that the plastic entering the mold cavity through the gate is *not* a simple liquid melt, but a rubbery solid exhibiting modulus values between 15 and 150 psi, depending upon the time scale of the deformation. If, for example, the gate cross-sectional area is not sufficiently large relative to that of the part to be molded, plastic will "jet" into the part producing undesirable features on the part surface. The gate for the plastic splice was designed to produce a uniform radial flow front.

Once the part has been filled, pressure must be maintained as the plastic is cooling to obtain precise reproduction of mold dimensions. This requires that the gate remain rubbery and thus capable of transmitting pressure until the part has cooled sufficiently to retain its dimensions. The 1-μm deviation out of the 228.6-μm groove width represents less than 0.5 percent shrinkage, well within the 1 percent claimed for amorphous plastics such as polycarbonate. It is instructive to calculate the maximum deviation to be expected from consideration of thermal expansion effects only. The plastic enters the mold at 300°C pushed by a pressure of 13,000 psi. The material is 150°C above the transition temperature, Tg, at which it will change to a glassy consistency common to many amorphous plastics, and it exhibits a modulus in the order of 200,000 psi. Above Tg, the linear thermal expansion coefficient is 1.35×10^{-4}°C^{-1}, approximately twice the value below Tg, 6.75×10^{-5}°C^{-1}. If the part were permitted to cool unconstrained by the pressure, a maximum deviation of 3 percent is calculated; that is, a 6-μm deviation for the groove width. Of course, in extreme cases where the pressure retention is not adequate to initially force the rubbery plastic into the mold details, greater deviations could be expected.[7]

In earlier designs, glass fibers were slid along the grooves during splice assembly. PMMA was selected because of its greater scratch resistance.[7] As information was obtained on environmental characteristics, it was determined that the Tg of PMMA at 115°C was too low. Distortion due to molded effects were observed at temperatures as low as 60°C. Since the vacuum-assist negated the need for scratch resistance, PC, with its Tg of 150°C, was selected. Higher temperature plastics such as polysulfone and polyphenylene sulfide are under study to further improve environment performance.

IV. A BRIEF DESCRIPTION OF THE ASSEMBLY PROCESS AND TOOLS

To prepare a linear array of optical fibers (a ribbon) for repair splicing, the plastic material is removed from around the fibers and the ends prepared using a controlled fracturing technique.[6] Figures 4a and 4b show the fracturing tool used to prepare the two ribbon ends. The resulting 12 uncoated fibers, on 9-mil centers, extend 0.40 inch beyond the plastic coated ribbon. After a substrate is placed into the assembly tool, the prepared fiber ends are inserted into the fiber-aligning grooves forming a butt joint in the substrate of the splice. Because of the vacuum-assist provided by the assembly tool (Fig. 5), the fibers are easily inserted into the aligning grooves and held in place during the remaining steps of the splice fabrication process. Adhesive (AP8004 epoxy, manufactured by Fenwal Inc.) is injected into the troughs of the substrate and, using the coverplate applique of the assembly tool, the coverplate is attached to the substrate. After the adhesive has cured (approximately 9 to 15 minutes), the coverplate applique is removed and index-matching gel is injected through the center slot of the coverplate. When the splice is removed from the assembly tool and the tooling pins cut off, the resulting completed splice is shown in Fig. 1.

The vacuum-assisted repair splice assembly procedure was analyzed to determine the amount of time required to assemble a ribbon splice. Table I provides a breakdown of the time needed for each of the assembly steps in the splicing process for two different epoxy curing times.

The manufacturer of the AP8004 epoxy claims a five-minute working time. To assure that the epoxy hardened properly, 15 minutes was allowed in this study. With insertion heaters in the assembly tool, this curing time could be easily reduced to 9 minutes. These realistic curing times result in a 19- to 25-minute assembly time for a one-ribbon splice. If 12 ribbons were spliced, the assembly time would be approximately 2¼ to 3¼ hours using current assembly tools and procedures.

V. LOSS CHARACTERISTICS OF SPLICE

Numerous ribbon splices were made both in the laboratory and in a manhole test facility (see Fig. 6 for an example of a manhole splicing environment), in an effort to evaluate the quality of the splices obtained using this splicing method. The 12 fiber ribbons that were used contained 110-μm O.D. graded-index fibers with 55-μm core diameters. To simulate the characteristics of a vacuum-assisted splice in a realistic communications system, the ribbon splices were used to join two 340-meter sections of optical fiber ribbon. The splices were measured in the configuration shown in Fig. 7. Insertion loss measurements were made using an optimized loose tube splice substitution technique.[8] To

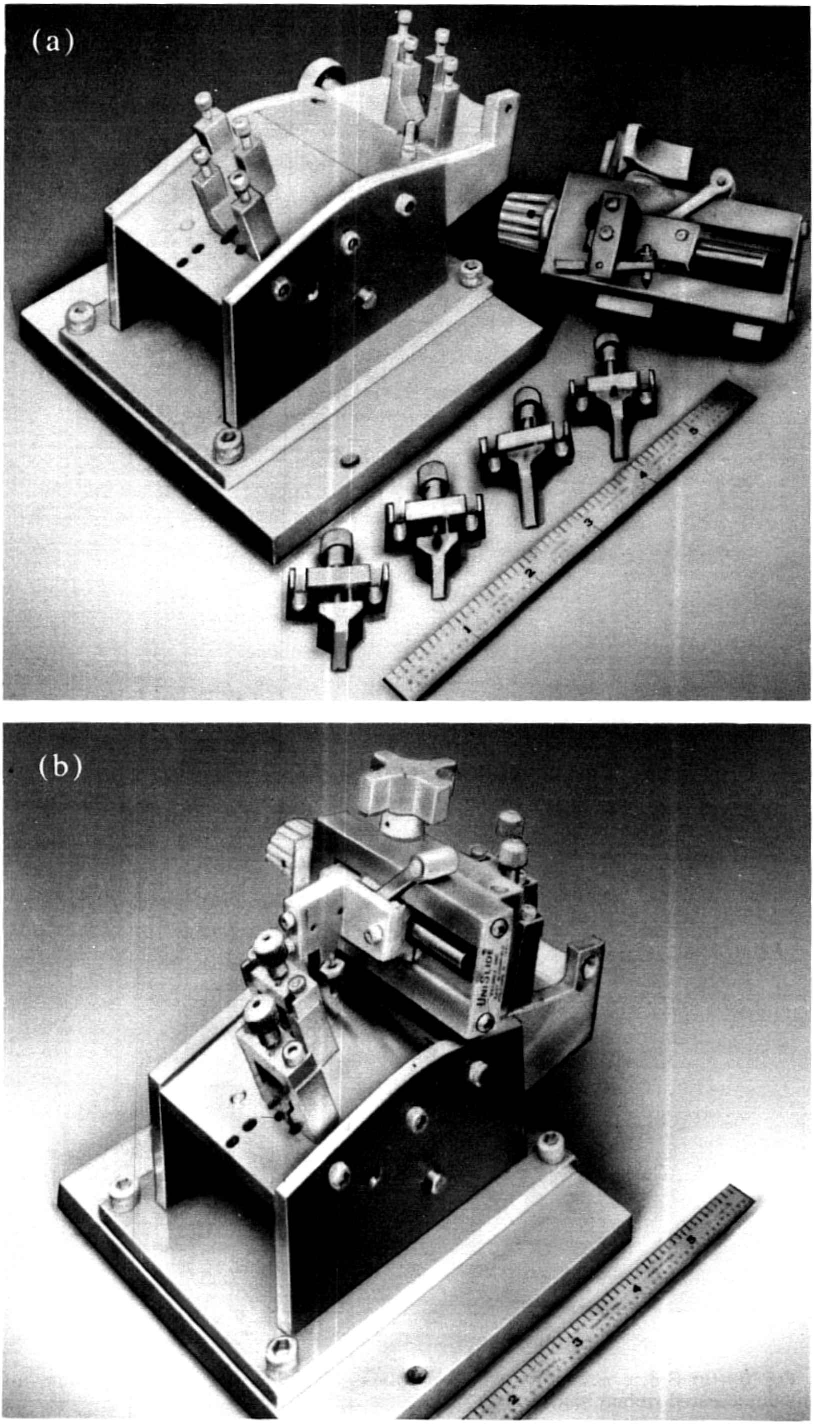
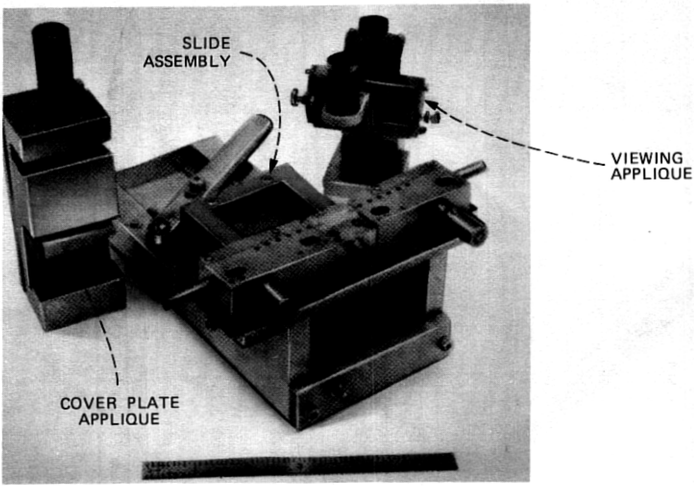
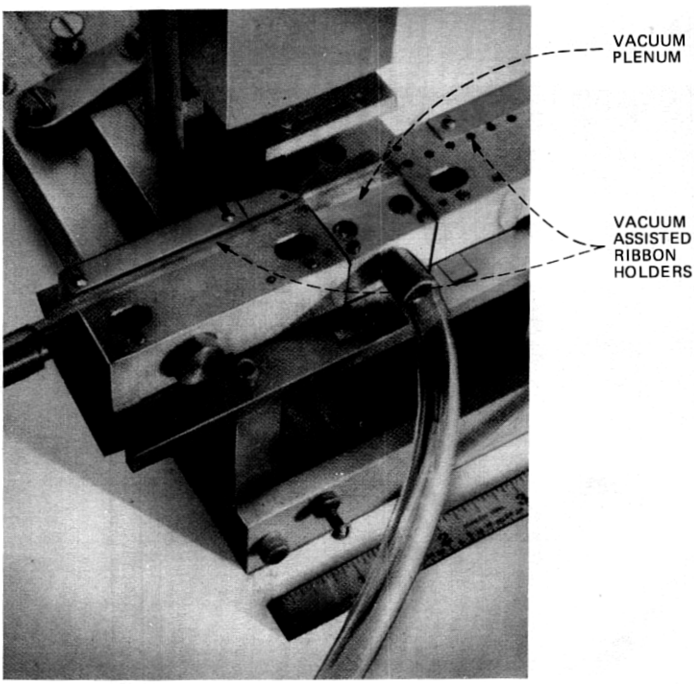


Fig. 4—(a) Component parts of fiber end preparation tool. (b) Assembled end preparation tool.



(a)



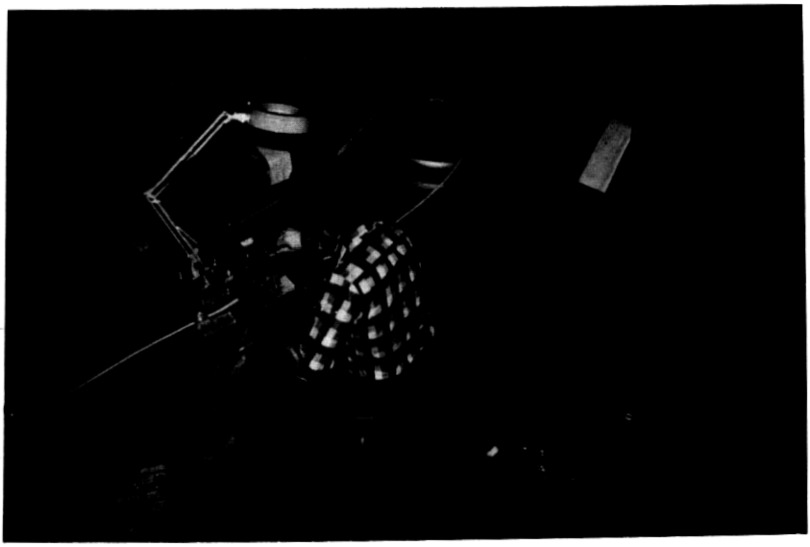
(b)

Fig. 5—(a) Splice assembly tool. (b) Splicing tool showing vacuum plenum and vacuum-assisted ribbon holders.

Table I

Procedure	Current Epoxy Cure Time	Accelerated Epoxy Cure Time
Ribbon stripping and end preparation	6 minutes	6 minutes
Splice fabrication	4 minutes	4 minutes
Epoxy cure	15 minutes	9 minutes
Assembly time for one ribbon splice	25 minutes	19 minutes
Assembly time for 12 ribbon splices	3.17 hours*	2.18 hours†

* Assembly procedure limited by epoxy cure time.
† Assembly time is operations limited.



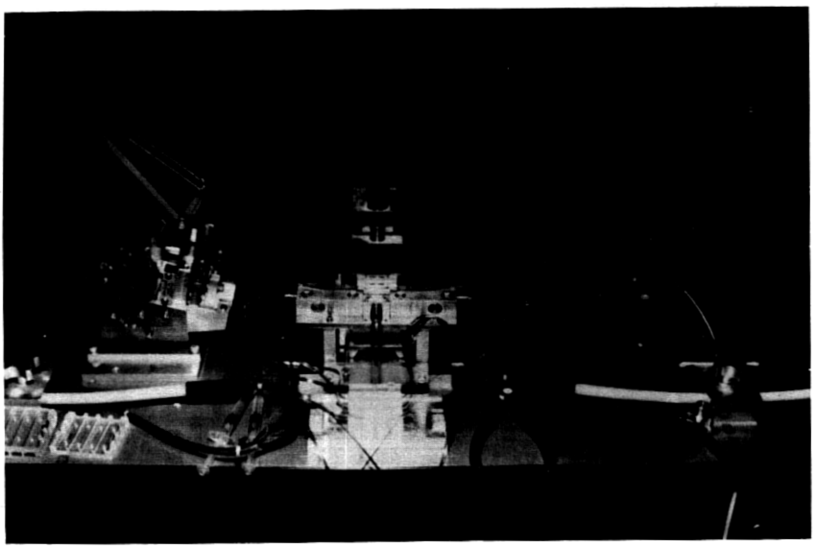


Fig. 6—Splice assembly tool in manhole environment.

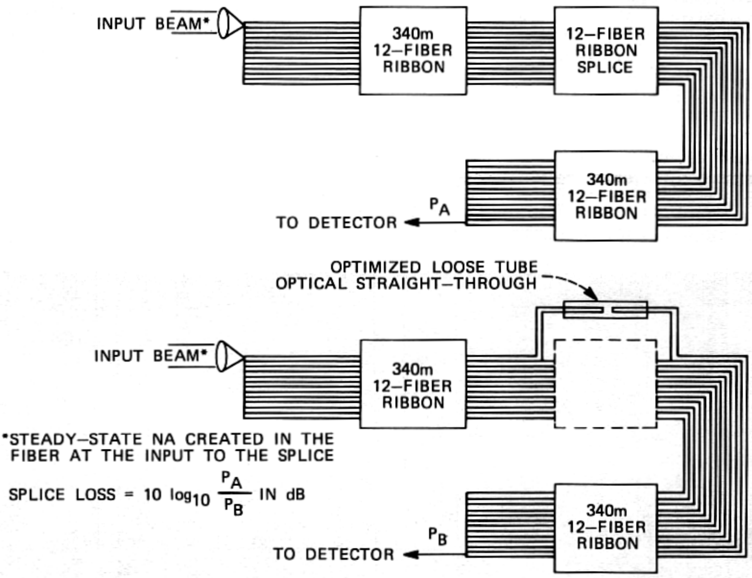


Fig. 7—Measurement procedure to obtain loss statistics of ribbon splice.

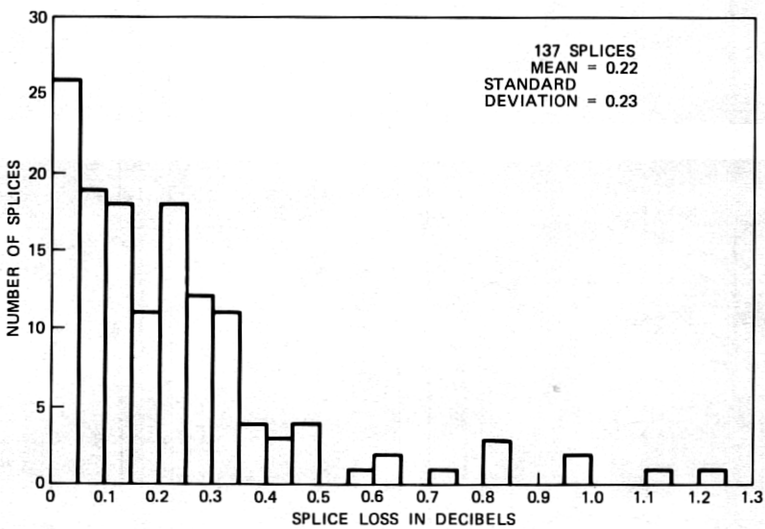


Fig. 8—Complete splice loss data.

understand this technique, consider fiber 1 in the 12-fiber-ribbon splice. To obtain splice loss, the system was tuned to obtain maximum output power P_A through the transmission path containing fiber 1. The splice containing fiber 1 was then cut out of the system and an optimized loose tube optical straight-through was substituted in its place. The system is then tuned to obtained maximum output power P_B. P_A and P_B are used to calculate the splice loss in decibels. The loss of the optimized loose tube straight-through was less than 0.03 dB.

The loss statistics for the vacuum-assisted repair splice, obtained

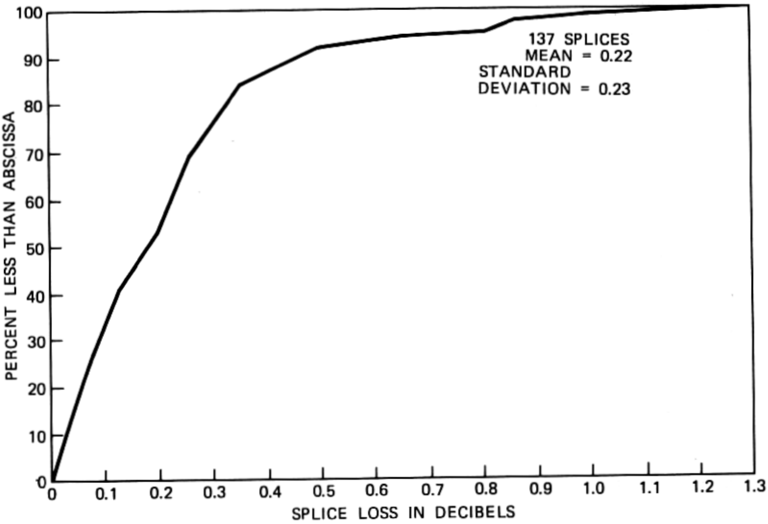


Fig. 9—Cumulative distribution function of complete splice loss data.

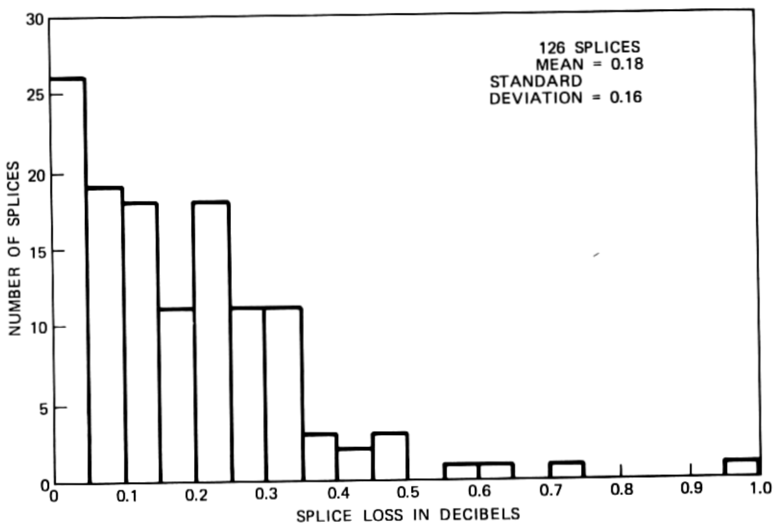


Fig. 10—Splice loss data.

from measuring 13 ribbon splices, are shown in Figs. 8 and 9. The average loss of the splices measured was 0.22 dB with a standard deviation of 0.23 dB. The data base for these statistics consisted of 137 splices. Only 11 fibers existed in a portion of the input ribbon preceding the splice. Therefore, one could only evaluate 11 of the 12 fiber splices in a ribbon splice. In addition, six fiber breaks occurred in the ribbon during the assembly and measurement processes. After the majority of the ribbon splices were made and measured analysis of the data showed that most of the outliers (splices with loss greater than 0.5 dB) occurred in one of the edge grooves of the ribbon splice. Modification of the coverplate applique reduced the number of subsequent outliers occurring in this groove. Elimination of this groove's loss data from the total data base results in the statistics shown in Figs. 10 and 11.

The average loss of the 126 remaining splices was 0.18 dB with a standard deviation of 0.16 dB. If one views the statistics shown in Fig. 10 as an optimistic assessment of the repair splice capability and those shown in Fig. 7 as a pessimistic assessment, bounds on the nature of the outliers produced by this splicing method can be obtained. A realistic appraisal of the loss statistics of the vacuum-assisted plastic repair splice would yield an average loss of 0.2 dB and outliers in the loss data that fall within the bounds shown in Fig. 12. It is of interest to note that no difference in the loss statistics was observed between splices made in the laboratory and those made in the manhole test facility.

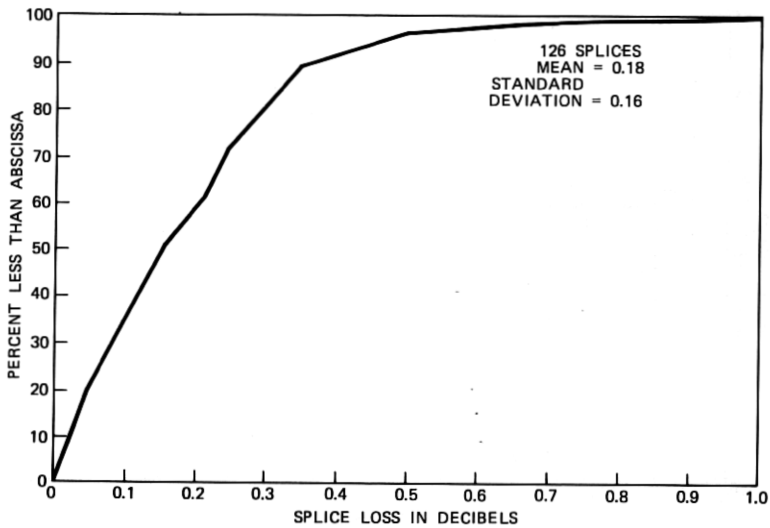


Fig. 11—Cumulative distribution function of splice loss data.

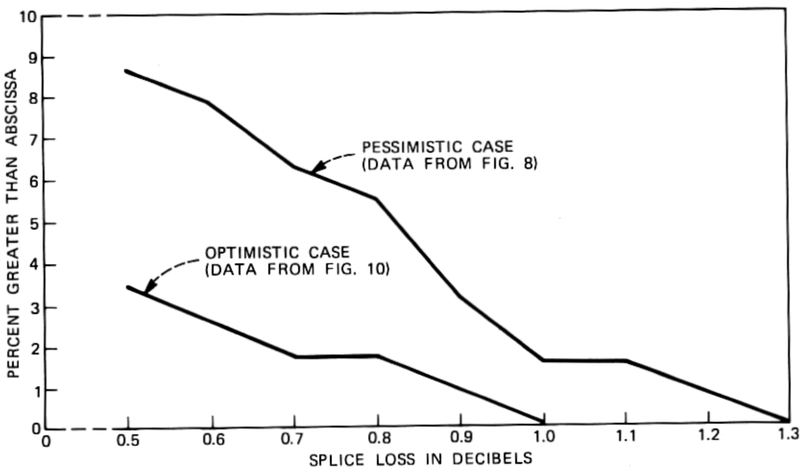


Fig. 12—Outlier cumulative distribution function bounds.

VI. FINAL COMMENTS

A field repair splicing method has been developed for joining 12-fiber optical fiber ribbons. This splicing method produces splices with an average loss of 0.2 dB in 20 to 25 minutes. The injection molded plastic hardware used is mass-producible and inexpensive. The use of vacuum assist during the assembly process allows one to easily hold the fibers in their aligning grooves and greatly simplifies the procedures required to fabricate a splice. The fabrication tools are relatively simple and, with proper redesign, adaptable to a field environment. Future work will be concentrated on determining the environmental characteristics of this splice. Preliminary data for polycarbonate plastic splices indicate that the temperature coefficient of the splice is approximately 0.007 dB/°C for the temperature range $-40°C \leq T \leq 5°C$, $35°C \leq T \leq 80°C$. This temperature coefficient can be decreased by proper materials considerations. Studies in this area are now in progress and will be reported in a future paper.[9]

VII. ACKNOWLEDGMENTS

The authors wish to thank D. M. Petrowski and A. Osborne for their assistance in the design and fabrication of the mold and assembly tool used in this work.

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