Reduced Diameter Optical Fiber and Cable

[1]Bob Overton, [2]Delya Gharbi, [2]Olivier Delwal, [3]Olivier Tatat, [4]Lionel Provost, [4]Louis-Anne de Montmorillon

[1]Draka Communications, 2512 Penny Rd, Claremont, NC.28616, USA
[2]Draka Communications, ZI Artois-Flandres, Billy Berclau, France
[3]Draka Communications, BP 194 62104 Calais Cedex, France
[4]Draka Communications, Site DATA4, Route de Nozay, 91460 Marcoussis, France

Abstract

The authors present the development of a new smaller diameter optical fiber targeting the applications and deployments where space is at a premium. The new optical fiber design provides for performance consistent with G.652.D standard singlemode fiber but in a package 200 microns in diameter, maintaining the standard 125 micron glass diameter. The reduced diameter, modified coating system in combination with G.657.A2/G.652.D-compliant glass gives microbending resistance equal to or better than standard G.652.D 250 micron fiber, thus enabling the use of tightly-packed cable designs 21% smaller in cross-sectional area than previously possible.

Keywords: Coatings; G.657.A2; reduced; diameter; microbending.

1. Introduction

A reduced diameter, dual coated optical fiber offers advantages in deployments where the cross-section of available installation space is limiting, as for example in pulling new high fiber count cable into existing duct already near-full to capacity[1]. A dual-coated fiber targeting smaller diameter must maintain a standard 125 micron glass diameter for backwards compatibility with standard plant, with the reduction in overall diameter coming from the coatings. Such a design faces challenges on several levels. A reduced coating diameter must maintain sufficient primary coating thickness to mitigate microbending while at the same time preserve an adequate secondary coating thickness for handling robustness. The coatings must maintain the necessary environmental protection to preserve a high strength in the fiber in the face of elevated temperatures and moisture content. In this work, a number of possible coating and glass combinations are evaluated, and the range of coating geometry is examined to balance the needs outlined. A new product is presented, combining all solid single-trench assisted fiber (STAF), a G.657.A2 bend insensitive glass design[2][3], with a thin-layer, low modulus primary coating[4] and a tough, brightly-pigmented secondary coating that needs no additional ink processing.

2. Fiber Design Considerations

The target is an optical fiber with reduced diameter, 200 microns OD being the desired level. Both dual coating structures and single coatings were examined, the former judged to provide the better microbending resistance and the latter better handling characteristics. In order to preserve protection against microbending it would be necessary to maintain a significant buffer layer of soft primary coating, but as a result the thinner secondary coating might not offer enough toughness to make the fiber handle-able. If a compromise of reduced thickness, dual coating dimensions could not be obtained, a single coating of lower modulus than a secondary coating would be the answer.

In addition to the physical attributes that impact microbending and handling, the coating/fiber combination must meet the industry requirements for tensile strength, fatigue properties, sensitivity to temperature excursions, effects of harsh environments, etc.

A summary of the coating materials comprising the candidates for the new design is shown in Table I.

Table 1. Coating candidates

Primary Coating	Characteristics
A	low modulus, low Tg
B	low modulus, low Tg
C	medium modulus, low Tg
D	higher modulus, high Tg, high adhesion
E	higher modulus, low Tg
F	single coating
Secondary Coating	**Characteristics**
1	colored secondary
2	clear secondary
3	clear secondary

G.657.A1 and G.652.D glass designs were included along with G.657.A2 glass in order to judge the need for the trench-assisted BIF and the benefits derived.

3. Experimental

3.1 Coating Robustness

With reduced diameter, the robustness of the coatings for handling and post-processing can be a concern. Taking as much of the diameter reduction as possible from the secondary coating of a dual coated structure is a natural direction in order to preserve the protection against lateral stresses given by the primary coating.

A simple robustness test was devised based on the conditions of handling and in the cabling processes known to be more aggressive in effects on coating integrity. Dragging an optical fiber around a pin or through an eyelet with back tension induces the highest degree of lateral stress on the coating. The simple test consists of drawing the specimen optical fiber over 90° of the surface of a 3mm diameter steel pin, using fixed back tension on the fiber to generate stress in the coating in contact with the pin. The fiber specimen is examined under an optical microscope to evaluate the results.

A complex system of categorizing the results was used, summarized in Table 2 where the fiber tension resulting in various degrees of delamination is given. Note that the table contains a sampling illustrating the test results.

Table 2. Sample of robustness test observations, tension resulting in delamination on the 3mm mandrel.

primary	sec	1° diam	2° diam	delamination
A	1	170	200	150 grams
A	1	160	190	150 grams
B	1	160	200	200 grams
B	1	150	200	350 grams
B	1	155	200	300 grams
B	2	145	200	250 grams
B	2	145	200	350 grams
B	2	150	200	350 grams
C	1	160	200	400 grams
C	1	150	200	450 grams
D	1	150	200	>500 grams
D	1	145	200	>500 grams
D	3	150	200	>500 grams
E	2	160	200	300 grams

Overall, Primary A showed the least resistance to delamination in the test. In addition, the robustness results indicated a maximum primary diameter of 160 microns for a 200 micron fiber diameter when the low modulus primary coating is used. The higher modulus and high adhesion primary D resisted delamination better than all the other combinations. Coating E/Secondary 2 represents a standard coating system in the industry. In a typical 250 micron coating geometry, this system exhibits delamination at 400 to 500 grams tension in this test.

Robustness was evaluated further by direct experiments with removing the fibers from small diameter 12-fiber buffer tubes, or "micro-module" buffer tubes. The micro-modules are designed to be opened by pinching the tube material with the fingers and pulling the tube end off of the fibers, a convenient feature. This places a significant shear stress on the fibers, something the smaller diameter coating must resist as well as standard singlemode fiber coatings do. While it is not unknown for a fiber to break on accessing a tube in this way, the incidence of such breakage must be minimized for the design to remain practical.

The experimental 200 micron fibers were processed into the micro-modules. Then experienced technicians accessed the fibers as described above. The fibers were cleaned with alcohol and wiping tissues, and each technician used an aggressive level of gripping and wiping to accomplish the task. Any fiber breaks were noted as well as any damage to the coatings. Normally if the coatings were removed by any of the steps, the fiber would break. The results are summarized in Figure 1.

The handling tests generally agreed with processing robustness tests using the 3mm mandrel. The handling exposed weaknesses in having the thicker primary coating layer as seen in the data for Primary A. It was learned that high adhesion to glass did not preserve the fiber in the thin coating geometry, witness the results with the high adhesion, higher modulus Primary D.

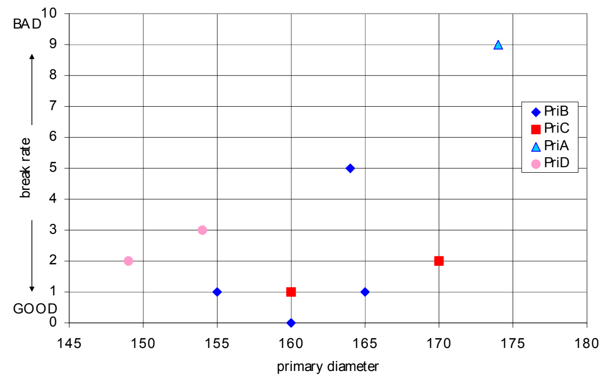


Figure 1. Handling evaluation – removing fibers from buffer tubes and manually cleaning

In additional blind tests, the technician evaluations supported the best combinations for handling robustness were found in Primary B and Primary C with Secondary 1 and Secondary 2.

Stripping the fiber was part of the additional evaluation. It was found that tools designed to strip the coatings using paired blades that close around and precisely cut the coatings are not effective in removing the coatings due to the small diameter of the coating systems. Considerable residue was left behind on the glass, especially with the high adhering Primary D. However, tools that utilize scissor-like action to close a set of V-grooves around the coating (e.g., the Miller Tool™) work perfectly well in removing the coatings of the 200 micron fibers.

Overall, the critical coating robustness tests and the handling exercises narrowed the choices for coating down to the low modulus Primary B and Primary C, along with the tough and resilient single coating F.

3.2 Microbending Resistance

The microbending resistance was evaluated using IEC TR62221, Method B, fixed diameter sandpaper drum test. In this procedure, the candidate fiber specimen is wound with a fixed back tension onto a drum carefully covered with 320 grit sandpaper, and the attenuation change is determined relative to the fiber on a shipping spool.

Microbending sensitivity tests were performed on a range of the candidates where the combination of primary and secondary coatings as well as the primary diameter were variables, always keeping the overall fiber OD near 200 microns. The sandpaper-covered drums used in the experiment are made of quartz, so the fibers on the drums could be temperature cycled without incurring significant dimensional change in the drum. In addition to room temperature measurements made within 10 minutes of completing the windings, the fibers were cycled to -40°C and to -60°C where attenuation was measured after 2 hours at temperature. A sampling of the results are shown in Figure 2 to illustrate the outcome.

Primary coating A was a part of the testing shown in Figure 2, but the results of the robustness tests eliminated this coating as a candidate for the 200 micron fiber. In mechanical properties, Primary A and Primary B are nearly identical, but Primary B was formulated for improved adhesion to glass and for enhanced mechanical integrity under stress.

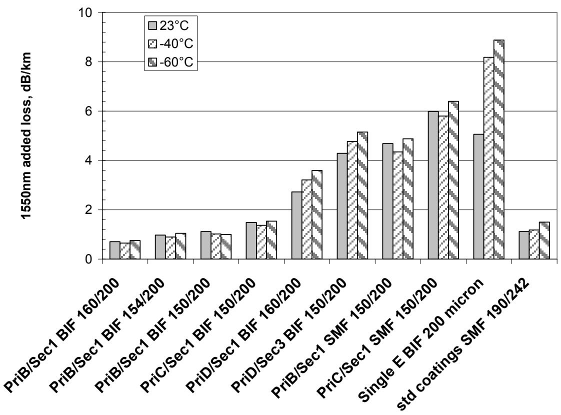


Figure 2. 1550 nm added loss due to microbending in TR62221, fixed diameter sandpaper drum test.

The best performance in resisting microbending in the 200 micron geometry is Primary B on G.657.A2 fiber whether in combination with the colored Secondary 1 or with non-colored Secondary 2. Primary C shows somewhat higher added loss due to a moderately higher primary coating modulus. Primary D exhibits much higher microbending sensitivity because of 1) a modulus near 140 psi and 2) a high glass transition temperature that gives a strong temperature dependence to the loss. The single coating lacks the cushion of the primary coating and is the most microbend sensitive even with the STAF G.657.A2 glass design.

The standard coating singlemode G.652.D fiber with the 190 micron/242 micron coating geometry represents coating properties typical of the SMF market at this time, a primary coating with a low Tg but a modulus on fiber in the 100 psi range. The results shown for this fiber also represent one of the lowest microbending responses observed in this type of glass/coatings combination. The Primary B/Secondary 1, 200 micron fiber with STAF G.657.A2 glass is at or below the microbend response of the standard SMF fiber available at this writing.

A critical feature observed in the test results is the necessity of pairing the soft primary coating with the trench-assisted, bend-insensitive fiber type compliant with G.657.A2. The soft primary candidates with G.652.D glass design give microbending performance no better than the high modulus primary coating on the BIF design. The synergy of the soft primary coating and the G.657.A2 STAF is key to minimizing microbending in the 200 micron diameter fiber.

3.3 Initial Cable Trial

A 720 fiber micro-module cable was made with the candidate fiber/coating combinations for testing. The candidate coating systems were represented in this cable in varying primary diameters between about 145 microns and 170 microns, with all the fibers targeting 200 microns for OD. The diameter of the cable, shown in schematic in Figure 3, is 16.0mm, translating to about 30% smaller cross-sectional area than the same 720 fiber cable design made using fibers with standard coating dimensions.

The micro-modules were accessed similarly to the work done to obtain the observations described in Section 3.1. The results confirmed the relative behaviors of the different coating types and dimensions seen in the first exercise of fiber handling with the different coatings and dimensions. Again the fibers with primary coating diameters >160 microns showed excessive problems with coating robustness and fiber breaking in accessing the buffer tubes.

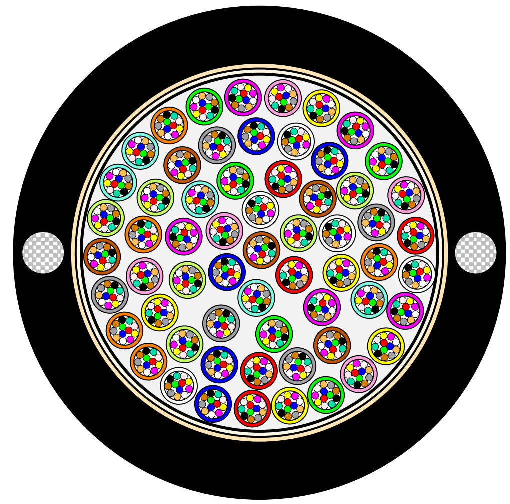


Figure 3. Schematic of 720 fiber micro-module cable made with 200 micron fibers

The cable was placed into a thermal cycling chamber, spliced to the loss monitors, and cycled from room temperature to -20°C, -30°C, +70°C and -20°C again, a standard internal temperature cycling test. The results are in Figure 4, showing added loss at 1625nm due to the thermal cycling. The data represent the mean added loss at temperature of several individual fibers of each type and geometry.

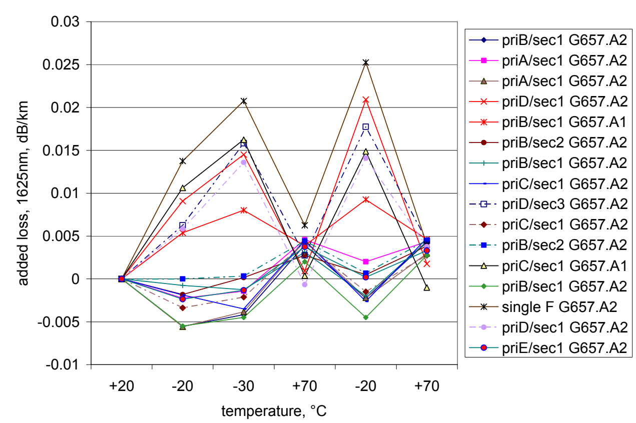


Figure 4. Added loss at 1625nm during thermal cycling of a 720 fiber micro-module cable made with 200 micron optical fibers

Figure 4 is a busy chart, but it can be simplified by noting that all the data that increase at low temperature are from the fibers made with the higher modulus, high Tg primary coating, the single coating, or with G657.A1 bend tolerant glass. Again the synergy of the soft, low Tg primary coatings and the G.657.A2 STAF bend insensitive fiber type is observed in the response to microbending induced by thermal cycling.

A final experiment with varying primary diameter, all with 200 micron coating OD, was carried out to determine the target range for the primary coating. At this stage the choice was clear for Primary B with Secondary 1, based on the initial microbending tests and handling results.

Primary B was applied on G.657.A2 single-trench assisted, bend insensitive fiber in diameters ranging from about 145 microns to 160 microns, with Secondary 1 taking the OD to 200 microns. The

TR62221.B sandpaper drum test was used to evaluate the microbending sensitivity through added loss at 1550nm as a function of the coating geometry, thermally cycling to -40°C and -60°C in addition to the initial room temperature measurements. Figure 5 gives the results.

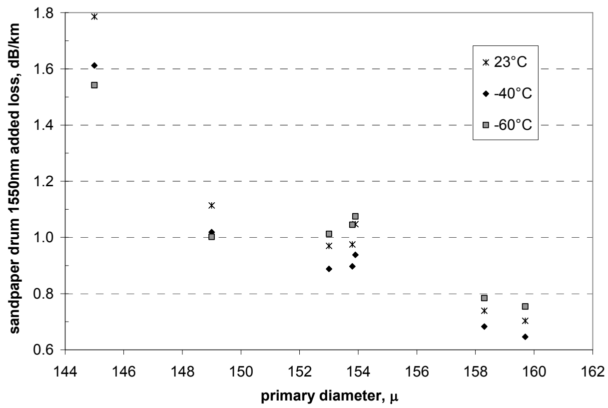


Figure 5. Added loss at 1550nm in the TR62221.B sandpaper drum test for microbending sensitivity.

The results of the experiment confirm those of the earlier work, Figure 2, and indicate a practical range for primary diameter of 150 to 160 microns. This range remains below the primary diameter at which handling issues might be found while maintaining a good protection against microbending induced by lateral stresses.

Tuning in the process, it is clear that the primary diameter can be well-controlled in this range based on the first 30,000 fiber kilometers produced commercially, Figure 6. Further improvement in controlling the range comes with experience.

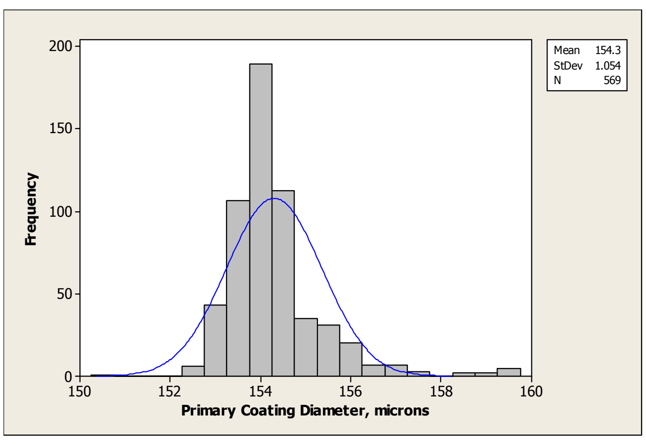


Figure 6. Distribution of primary diameter in an industrialized process for 200 micron fiber.

3.4 Field Handling

The smaller diameter coated fibers must adapt well to standard field equipment and installation procedures without special needs for handling, stripping the coating or splicing.

Stripping the coatings from the 200 micron fibers was evaluated using four different common field tools:

- Miller FO-103S
- Clauss CFS-2
- No-Nik
- Fujikura PS-02

The number of passes was limited to one or two to avoid inducing weak flaws in the glass, and the results were evaluated by the amount of coating material remaining on the fibers after the passes. Experienced technicians performed the exercises, and the consensus was clear that there is no difference in the quality of stripping with the above tools between the 200 micron fibers and fibers with the standard coating dimensions.

Cleaving the glass after stripping was tested with 7 field cleaving tools. No statistical difference was found in cleave quality comparing the 200 micron coated fibers and fibers with standard coating dimensions. There is no reason why cleaving should be affected, however, as the stripped fibers are the same.

Splicing tests were conducted to ensure no problems exist in splicing 200 micron coated STAF G.657.A2 BIF to other 200 micron fibers and that the 200 micron coated fibers are backwards compatible with 250 micron coated fiber in fusion splicing. More than 900 splices were made with 6 splicing instruments, after which bi-directional OTDR measurements were made to evaluate the quality of the splices. Figure 7 compares the splice loss distributions for 200 micron/200 micron splices and 200 micron/250 micron splices.

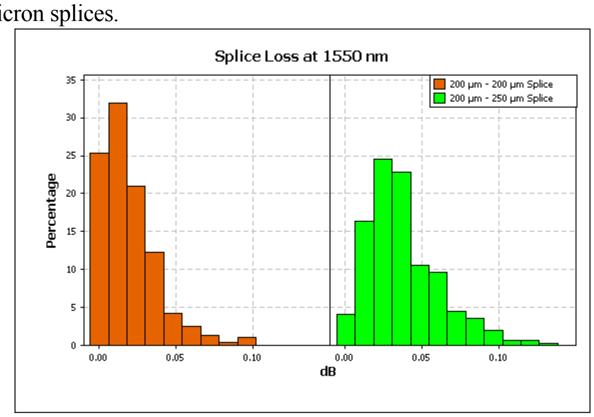


Figure 7. Splice loss measurements for 200/200 micron OD splicing and 200/250 micron OD splicing.

Mean splice loss for the 200 micron/200 micron fiber splicing was 0.02 dB/km at 1550nm, and 0.04 dB/km at 1550nm for the 200micron/250 micron fiber splices.

No special measures are required for field handling and installation practices with the 200 micron coated fiber. The usual care should be taken to maintain instruments and tools in proper condition.

3.5 Mechanical Properties

Although developed to match the resistance to microbending and the processability/handling of standard dimensioned coated fibers, the 200 micron coated fiber must meet the other requirements for optical fiber to be accepted in the marketplace (e.g., GR-20, IEC 86A.60793-2-50). To this end, all of the tests required by the standard specifications have been performed on the 200 micron coated optical fiber product, and the 200 micron fiber meets all the requirements, with the exceptions of the coating geometry specifications (which target the standard dimensions) and the strip force requirement, described below. Details of the test results are available elsewhere.

An example of the tensile strength Weibull distribution is shown in Figure 8, where the 50 percentile strength is 5.00 GPa and the 15 percentile strength is 4.94 GPa. All specimens tested exceed the minimum values for 50 percentile and 15 percentile strength by large margins before and after the aging treatments.

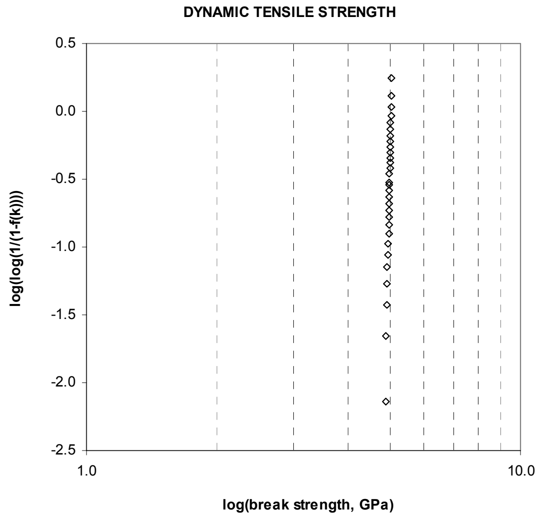


Figure 8. Typical Weibull plot of the 0.5 meter tensile strength distribution of the 200 micron coated G.657.A2 fiber

The dynamic fatigue stress corrosion test is shown in Figure 9, where the calculated n-value is 21.5. The range exemplifying all 12 colors of the fibers is 21 to 23 for n-value. After damp heat aging, the range of n-values is 24 to 26.

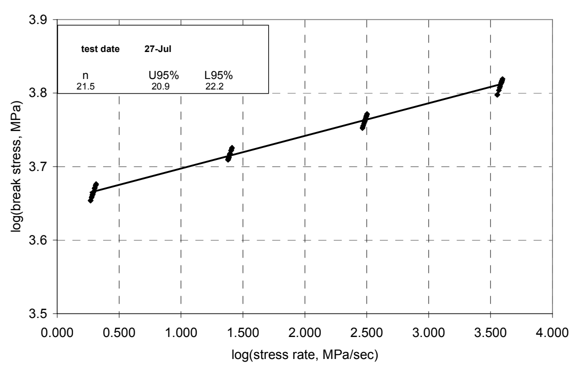


Figure 9. Typical dynamic fatigue plot for the 200 micron coated fiber.

The strip force test is problematic because of the particular design of tool required to perform the test. This type of tool utilizes paired blades with a circular hole formed when the blades close together. The size of the hole is made to accommodate the standard coating dimensions of 235 to 250 microns, and the blades do not bite through the secondary coating of the 200 micron coated fiber. Nevertheless, as demonstrated by the results reported in Section 3.5, there is no difficulty in cleanly stripping the 200 micron coatings using the tools commonly found in the field.

3.6 Cable Qualification

The 720 fiber micro-module cable design has been fully qualified through all the industry test requirements. No issues were identified in any of the test results. The critical thermal cycling tests show the combination of the G657.A2 STAF/BIF and the 200 micron dual coating system featuring a low modulus primary coating gives performance exceeding expectations, Figure 10. Even at 1625nm, the added loss on cycling is far below the 0.05dB/km target for maximum change.

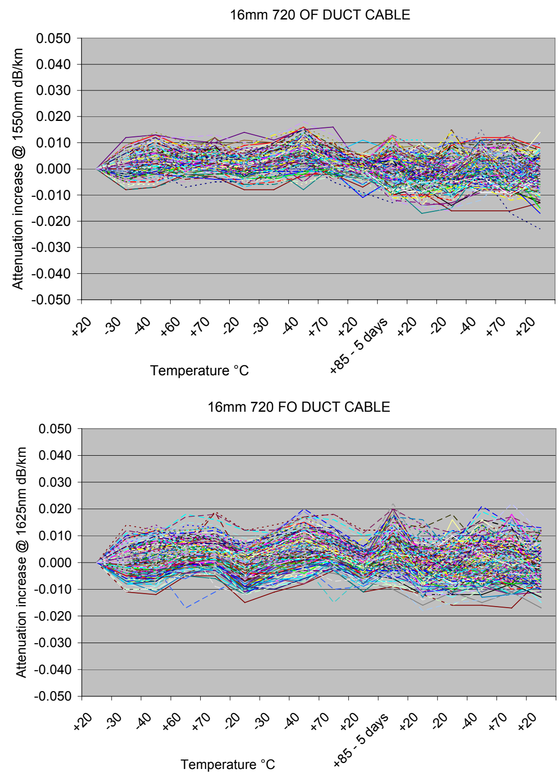


Figure 10. Thermal cycling results on a 720 fiber micro-module cable, 1550nm and 1625nm, 180 fibers monitored in the cable.

4. Conclusions

A new dual coated 200 micron diameter optical fiber product has been developed for applications where reduced fiber diameter is a benefit, e.g., limited or expensive duct space. This has for example made possible a 21 percent reduction in cross-sectional area for a 720 fiber micro-module cable, where the 12-fiber micro-buffer tube diameter is reduced and the finished cable diameter taken from 18mm to 16mm. The performance attributes of the fiber product are equal to or better than those of standard 250 micron singlemode fibers, made possible by the combination of a G657.A2 trench-assisted, bend insensitive fiber core design with a low modulus primary coating system. The range of primary coating diameter has been optimized around 155 microns ± 5 microns for balanced handling characteristics and maximum microbending protection.

5. References

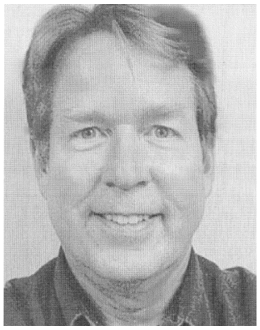
[1] D. Boivin, et al, "Design and Performances of Trench-Assisted G.657.A&B Fiber Optimized Towards Moe Space Savings and Miniaturization of Components", *Proceedings SPIE 7212* (2009)

[2] L.A. de Montmorillon, et al, "Bend-Optimized G.652.D Compatible Trench-Assisted Single Mode Fibers", *Proceedings of the 55th IWCS Conference*, pp 342-347, (November 2006).

[3] L. Provost, et al, "Cabling and Installation Aspects of Full-Silica Bend Insensitive Single Mode Fibers", Optical Cabling and Infrastructure Conference, (July 2008).

[4] B. J. Overton, et al, "Microbending-Resistant Fiber", *Proceedings of the 57th IWCS Conference*, pp 279 – 283 (November 2008).

6. Authors



Bob Overton is a Senior Principal Scientist with Draka Communications. He holds a BS in Chemistry from Mercer University and a MS in Chemical Engineering from the Georgia Institute of Technology. He worked with AT&T Bell Laboratories from 1980 to 1991 in optical fiber coatings and cable materials. From 1991 to the present he has managed the Coatings Technology Group with Alcatel and Draka Communications, and the Cable Materials Technology Group from 2002 to 2008. He has received 40 patents in the fields of optical fiber coatings, cable materials, and processes. Email bob.overton@draka.com

Delya Gharbi received her degree in Engineering in Physics from the National Institute of Applied Science and the Masters Degree in Photonics from the University of Essex in 2007. She joined Draka in 2008, now working in the Fiber Process Research and Development Group in Douvrin, France. Since then, she has received a patent in fiber process technology. Email delya.gharbi@draka.com

Olivier Tatat received his Engineering degree with a specialty in Materials in 1982, from the Institut des Sciences de l'Ingenieur in Montpellier (France). In 1985, he joined Alcatel Cable France, working as a Material Engineer. From 1993 to 1998 he was the Material Technology Group leader in the Alcatel Optical Fiber Cable Competence Center (OFCCC) in Claremont, NC (USA). In 1998 he joined the Optical Aerial Cables Engineering Group of Alcatel Cable in Monchengladbach (Germany). Since 2001, he is leading the Engineering and Development Group of Draka Comteq France in Calais. He holds 8 patents in the field of cable materials and design. Email Olivier.tatat@draka.com

Olivier Delwal received his Engineering degree from Ecole Supérieure d'Optique in 1997 and a Masters degree in Optics & Photonics at Université Paris-Sud 11 the same year.. He joined Alcatel, later Draka, in 1997 working in the Fiber R&D group as a draw process engineer. From 2003 to 2007 he was the manager of the Draw and Measurement Process R&D Group in Douvrin, France, and from 2007 to the present he has held the position of Manager of Fiber Process Research & Development for Draka Communications. Email Olivier.delwal@draka.com

Lionel Provost graduated in optics engineering from the Institut National des Télécommunications (Evry) in 2000. That year he joined Alcatel CIT and began working on fiber-based components. In 2005 he stayed at the Optoelectronics Research Centre (Southamption). Then in 2008 he joined Draka Communications and is currently working in fiber optic applications engineering. He has 11 patents in the field of optical fiber design. Email lionel.provost@draka.com

L.A. de Montmorillon graduated in optics engineering from Ecole Supérieure d'Optique (Orsay) in 1993. He received the PhD from the Université Paris-Sud 11 in 1997 for work devoted to photorefractive ultrasonic detection. He joined Alcatel working in the Fiber Ooptic R&D area, and since 2004 has been working in Draka Communications on new telecommunication fiber design. He holds 38 patents in the field of optical fiber design. Email louis_anne.de_montmorillon@draka.com