160-μm Coating Optical Fiber for 1728-Fiber Cable

Hironori Sato,[1] Yusuke Tsujimoto,[1] Noriaki Yamashita,[1] Akira Murata,[1] Ken Osato,[1]
Kenji Yamashiro,[2] Shoichiro Matsuo[2]

Along with the explosive growth in broadband services and data center market, optical cables with high fiber density and reduced diameter will be more demanded. A thin coating fiber is an attractive solution for realizing a high density and reduced diameter cable. In this study, we fabricated a 1728-fiber cable using 160-μm coating fiber with 80-μm cladding. This cable realizes 26% reduction in cable diameter and 42% lighter in weight while comparing with a cable with 250-μm coating fibers and shows good attenuation characteristics over wide range of temperature and satisfies general requirement for optical fiber cables.

1. Introduction

The explosive growth in broadband services and data center market has started demanding deployment of high fiber count, reduced diameter cables in new or existing duct networks economically and effectively. In order to minimize the construction time and cost, it is necessary to reduce the diameter and weight of the cable. Decreasing the cable diameter and weight allows effective utilization of existing facilities such as underground ducts. In order to address these demands, we had launched an intermittently connected ribbon (Spider Web Ribbon™ : SWR™) and a cable in which SWRs are wrapped with a water-blocking tape, which is then jacketed along with embedded strength members (Wrapping Tube Cable™ : WTC™). We had succeeded in designing 200-μm coated fibers, maintaining the standard 125-μm cladding diameter, which enabled us to make high-density cables, smaller than that we used to make with 250-μm coated fibers. Now we tried to reduce cladding diameter of fiber to achieve further reduced cable diameter.

In this paper, we demonstrate the possibility of a 160-μm fiber with an 80-μm cladding to achieve an ultra-high-density cable1). We fabricated two types of 160-μm fibers with an 80-μm cladding. An 80-μm cladding design has been a popular design for fibers used in optical devices but has not been applied for a high density cable. This 80-μm cladding enabled us to further reduce fiber diameter and realize ultra-high-density cables.

2. Fiber Design

2-1. Design guidelines from the viewpoint of micro-bending characteristic

Figure 1 shows a cross sectional view of an optical fiber and the definition of structural parameters used in the paper.

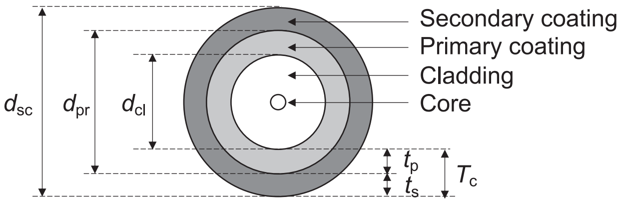

Fig. 1. Cross sectional view of an optical fiber and definition of structural parameters.

When fibers are used in a high-density cable, lateral forces and tension are added to the fibers. These lateral forces and tension generate tiny bend of fibers called micro-bending which causes attenuation increase. Micro-bending is inevitable when the density of a cable increases, so it is important to reduce micro-bending sensitivity of the fiber.

Micro-bending Sensitivity is expressed as

$$\alpha_{\mathrm{mic}} \propto K_{\mathrm{coat}} = \frac{\left(E_{\mathrm{p}}\dfrac{d_{\mathrm{cl}}}{t_{\mathrm{p}}}\right)^{2}}{{H_{\mathrm{f}}}^{2}{H_{0}}^{0.25\mu-0.125}\left(E_{\mathrm{p}}+\dfrac{{t_{\mathrm{s}}}^{3}}{{R_{\mathrm{s}}}^{3}}E_{\mathrm{s}}\right)^{1.125-0.25\mu}}$$

where, K_{coat} is the micro-bending sensitivity by design of fiber coating, H_f is the stiffness of the glass portion, H_0 is the stiffness of the secondary coating, E_p and E_s are Young's moduli of the primary coating and secondary coating, t_p and t_s are thicknesses of the primary coating and secondary coating, R_s is outer radius of secondary coating, dcl is outer diameter of glass, and μ is a parameter related to the surface deformation spectrum. In this paper, we used $\mu = 3$ 2).

This formula indicates that there are several ways to improve micro-bending sensitivity, except for changing the profile of glass core. In this paper, aiming to get 160-μm fiber with an 80-μm cladding, it is one of the best ways to improve micro-bending sensitivity from the viewpoint of Young's modulus of coatings. K_{coat} becomes smaller when we lower Young's modulus of the primary coating or higher Young's modulus of the secondary coating.

---

[1] Optical Cable Research and Development Department, Optical Cable Systems Division, Fujikura Ltd.

[2] Optical Fiber Development Department, Fujikura Ltd.

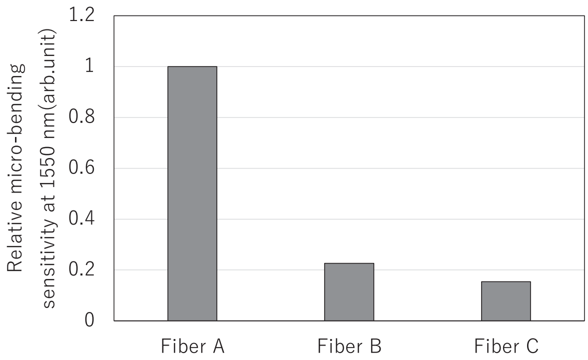

Fig. 2. Measured micro-bending loss.

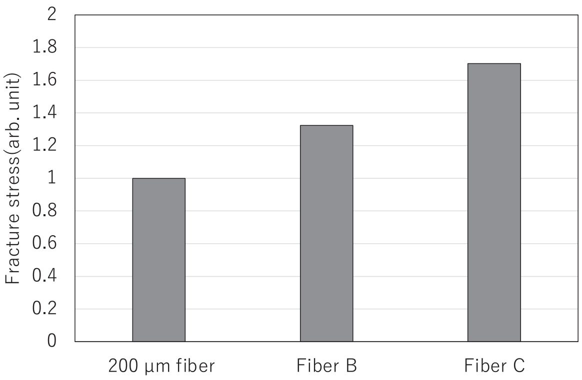

Fig. 3. Fracture stress of the sandpaper tensile test.

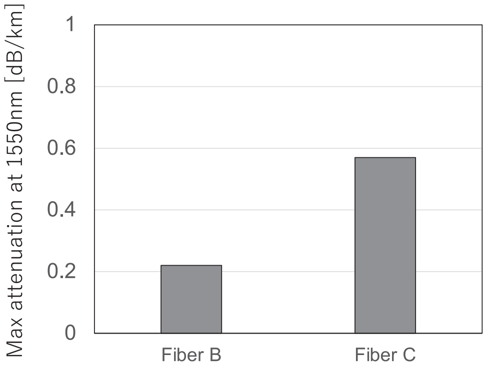

Fig. 4. Water immersion test.

2.2 Measurement of Micro-bending Sensitivity

Figure 2 shows measured micro-bending loss. The micro-bending sensitivity was measured according to method B in IEC TR62221 3). Fiber A is 160-μm fiber with primary coating and secondary coating conventionally used in 200-μm fiber. Fiber B is 160-μm fiber with newly developed primary coating and conventional secondary coating. The Young's modulus of the primary coating is lower than that of the conventional 200-μm coating fiber. Fiber C is 160-μm fiber with new primary coating and secondary coating. The Young's modulus of the secondary coating is higher than that of the conventional 200-μm coating fiber. As shown in Figure 2, micro-bending sensitivity is lowered to less than one third of that of a fiber with conventional coatings by using new primary coating and further reduced by using new secondary coating.

2.3 The design of fiber coating

We also tested the tolerance ability of protective coatings to resist damage to the underlying glass. Fracture of the fibers due to the damage to the glass through the coatings easily happens when the devices that come in contact the fibers are not kept clean enough 4). To evaluate the tolerance ability, we pulled fibers pressing against abrasive surface of sandpaper and measured fracture stress (sandpaper test). The result is shown in Figure 3. Fiber B is 160-μm fiber with new primary coating and conventional secondary coating and Fiber C is 160-μm fiber with new primary coating and new secondary coating. The fracture stress of a conventional 200-μm coating fiber is used as the reference, and the values of fibers B and C are shown relative to the reference. Thickness of the coating which is equal to half of the outer diameter minus the cladding diameter is 37.5 μm, and 40 μm, for 200-μm fiber, and 160-μm fiber, respectively. 160-μm fiber which has a little bigger thickness than that of 200-μm fiber is better than 200-μm fiber in terms of tolerance ability. As shown in Figure 3, Fiber B has sufficient performance of tolerance. High Young's modulus of secondary coating further improves protective performance and Fiber C showed better performance compared to Fiber B.

These results seem to indicate that lower Young's modulus of primary coating and higher Young's modulus of secondary coating, contributes to the better performance. However, we have to improve not only micro-bending sensitivity but also other performances of the fiber.

Finally, as a reliability test of optical fibers, the attenuation loss during immersion in water as defined in IEC 60793-2-50 was confirmed for fibers B and C. Figure 4 shows the test result. As a result, Fiber B, 160-μm fiber with new primary coating and conventional secondary coating, showed good performance compared to Fiber C, 160-μm fiber with new primary coating and new secondary coating. Therefore we selected the combination of newly developed primary coating and conventional secondary coating.

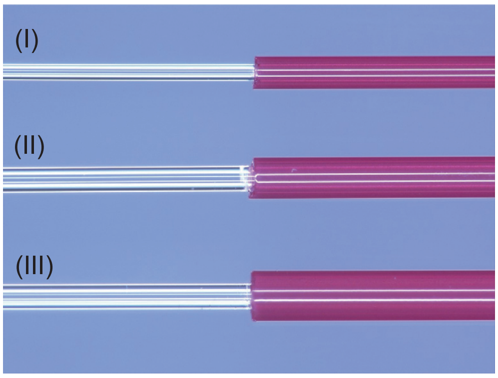

Fig. 5. Side view of fabricated fibers. (I) 160-µm fiber with 80-µm cladding. (II) 200-µm fiber with 125-µm cladding. (III) 250-µm fiber with 125-µm cladding.

2.4 Characteristics of fabricated fibers

Figure 5 shows a side view of a fabricated 160-μm fiber. Side views of 200-μm and 250-μm fiber with conventional 125-μm cladding are presented for comparison. Table 1 shows the typical characteristics of the fabricated 160-μm fibers. Fibers D and E shown here adopt the coating material of Fiber B described above, and the optical characteristics of the fibers were compliant with ITU-T G.657.A1 and A2 except cladding diameters [5]. The refractive index profiles of Fibers D and E were almost the same as that of a 125-μm cladding fiber with the same specifications. The attenuation of the fibers was at the same level as that of the 125-μm cladding fibers. Also the tensile strength [6] is almost the same level as that of the 125-μm cladding fibers. Even when it becomes thinner, the tensile strength dose not decrease in terms of cross sectional area of the glass.

Table 1. Characteristics of fabricated fibers.

Item	Fiber D	Fiber E
Optical characteristics	G.657.A1	G.657.A2
Cladding diameter	80 µm	80 µm
Coating diameter	160 µm	160 µm
Attenuation at 1550 nm	0.197 dB/km	0.209 dB/km
Cable Cutoff Wavelength	1,181 nm	1,204 nm
MFD at 1310 nm	8.4 µm	8.6 µm
Macro-bending loss		
1,625 nm, R =10 mm	0.11 dB/turn	0.05 dB/turn
1,625 nm, R=7.5 mm	2.3 dB/turn	0.11 dB/turn
Fiber strength	5.0 GPa	5.0 GPa

3. Design of WTC with SWR

3.1 The design of SWR and performance of the fabricated SWR

Figure 6 illustrates a schematic of a ribbon that are used in this trial. We developed an intermittently bonded ribbon (Spider Web Ribbon, SWR) [7] arranging twelve 160-μm fibers in a ribbon shape and intermittently bonded in the length and width directions. The flexible structure of SWRs enables them to be bundled easily and to resemble a single fiber in a cable in terms of behavior, thereby allowing them to be packed at a higher density.

Fabricated SWR with 160-μm fibers reduced the thickness by more than 20% and the width by more than 20% compared to that with 200 μm fibers. This result leads to more than 40% reduction of the volume compared to conventional 200-μm fiber SWR and enabling them to be packed at even higher density in the cable.

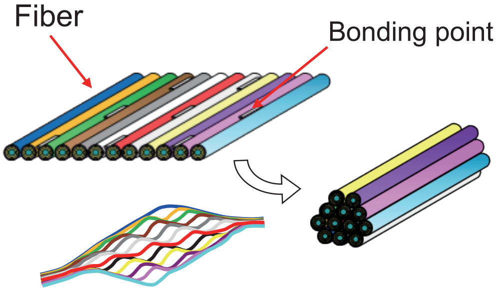

Fig. 6. Schematics of SWR.

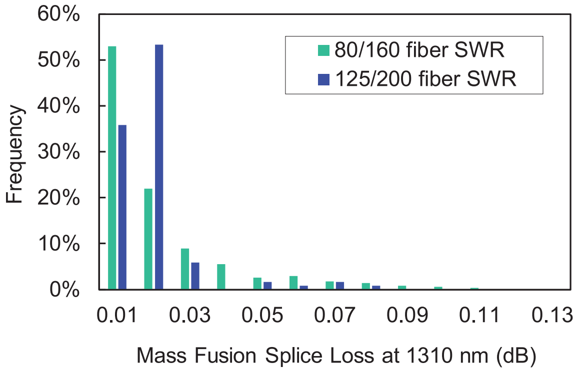

Fig. 7. Measured mass fusion splice loss of SWR comprising 200-µm fibers and 160-µm fibers.

Table 2. Dimension of fabricated 1728-fiber WTC.

		250-µm fiber	200-µm fiber	160-µm fiber
Outer diameter	(mm)	23.0	22.0	17.0
Weight	(kg/km)	360	300	210
Core density per a cable cross section	(cores/mm^2)	4.16	4.55	7.61

Figure 7 shows mass fusion splice loss of conventional 200-μm fibers and 160-μm fibers. Splice loss when a 200-μm fiber and a 200-μm fiber are spliced and a 160-μm fiber and a 160-μm fiber are spliced is measured. It was confirmed that fusion splice performance of 160 -μm fibers with fibers of the same diameter is not inferior to that of conventional 200-μm fibers and that fusion connection between 160-μm fibers is satisfactorily possible.

3.2 The design of WTC with SWR

We fabricated a 1728-fiber cable comprising SWRs with 160-μm fibers. The cable consists of two types of fibers, Fiber Ds and Fiber Es. The cable has a simple structure, in which the SWRs are wrapped with a water-blocking tape and jacketed with strength members (Wrapping Tube Cable, WTC) [8]. This feature enabled a high-density optical fiber cable with a small diameter with stable attenuation characteristics to be realized.

The dimensions of the cables are shown in Table 2. For comparison, dimensions of a 1728-fiber cable with 250-μm and 200-μm fibers are shown. The 160-μm fiber WTC is 26% smaller in diameter and 42% lighter in weight than the conventional 250-μm fiber WTC.

4. Cable Performance of 1728-fiber WTC

4.1 Attenuation characteristics under temperature cycling

The results of the attenuation characteristics over a heat cycle test are shown in Figure 8. It was confirmed that the cable exhibited stable and favorable attenuation characteristics after cabling as well as at a wide temperature range of -50 °C to +70 °C for both the fabricated 160-μm fibers, Fiber Ds and Es.

4.2 Mechanical characteristics

Table 3 shows the mechanical test results of the developed 1728-fiber cable with 160-μm fibers. Test methods were based on Telcordia GR-20, and a measurement wavelength for mechanical test was 1550 nm. The cable showed an excellent mechanical performance.

4.3 Handling performance

160-μm fiber enables cross sectional area of cable to become smaller than that with 200-μm or 250-μm fibers. This cable not only improves the conduit utilization efficiency in wiring between data center buildings, but also increases the cable length on the drum. We measured the

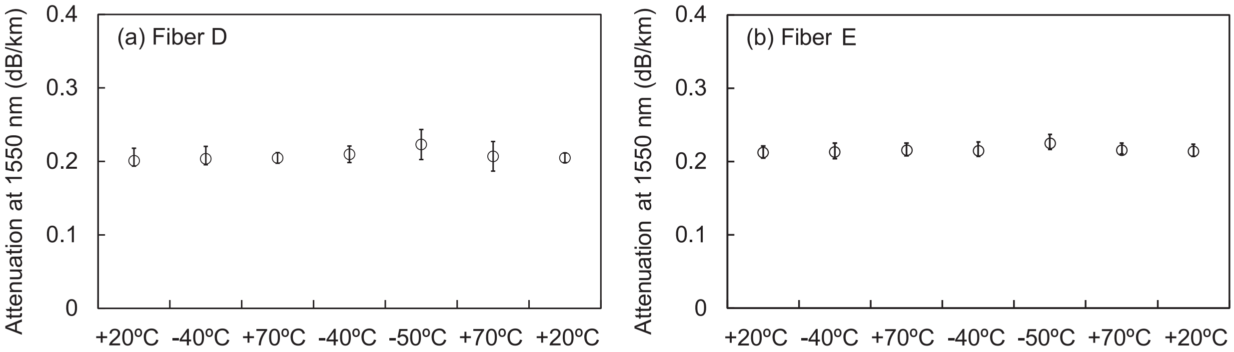

Fig. 8. Attenuation characteristics of fabricated 1728-fiber WTC using fabricated 160-µm fibers.

Table 3. Mechanical test results.

Item	Condition	Result
Cable Cyclic Flexing	Bending radius : 10D , Cycle : 25	< 0.1 dB
Impact	Striking surface : 12.5 mm , energy : 4.4 J	< 0.1 dB
Tensile Strength		
	Load : 2700 N - 1h (Short Term)	< 0.2 %
	Load : 810 N (Long Term)	< 0.2 % < 0.1 dB
Compressive strength	110 N/cm 10 min. after 220 N/cm 1min.	< 0.1 dB No Damage
Cable Twist	±180 deg. / 2m, Cycle : 10	< 0.1 dB No Damage
Water Penetration	Height of water : 1 m, 24 hr, 3 m, Tap water	< 3 m

length that can be wound on the drum. A cable comprising 160-μm fibers can be wound 1.6 times more on the drum than that with 200-μm fibers. Furthermore, handling performance was greatly improved with the smaller diameter of the cable. The bending diameter of the developed 1728-fiber cable is 20% smaller than that of the cable with 200-μm diameter fiber. This enables the cable to be easily installed in a handhole in the cable laying conduit, as shown in Figure 9.

5. Conclusions

We have demonstrated the possibility of a 160-μm fiber with an 80-μm cladding for ultra-high density cables. The fabricated 1728-fiber cable comprising 160-μm fibers has 26% smaller in diameter and 42% lighter in weight than the cable with 250-μm fibers, and showed good performance in optical transmission characteristics. The unprecedented ultra-high density cable with these new fibers will make substantial contribution to economical and effective optical fiber networks, which will continue to develop in the future.

Fig. 9. View of installation in a handhole.

References

1) S. Matsuo, *et al.* : "1,728-Fiber Cable With 12-Fiber Ribbons Comprising 160-μm-Coating Fiber With 80-μm Cladding", Journal of Lightwave Technology, Vol.40, No.5, pp. 1552-1559, Mar. 2022
2) J. Baldauf, *et al.* : "Relationship of Mechanical Characteristics of Dual Coated Single Mode Optical Fibers and Microbending Loss", IEICE Tras. Commun., Vol.E-76-B, No.4, pp. 352-357, Apr. 1993
3) Optical fibres – Measurement methods – Microbending sensitivity, IEC TR62221, 2012
4) G. Scott Glaesemann, "Optical Fiber Mechanical Reliability — Review on Research at Corning's Optical Fiber Strength Laboratory White Paper" WP8002, pp.45-47, July 2017
5) Characteristics of a bending-loss insensitive single-mode optical fiber and cable, ITU-T Recommendation G.657, 2016
6) Optical fibres — Part 1-31: Measurement methods and test procedures — Tensile strength – IEC 60793-1-31, 2019
7) M. Yamanaka, *et al.* : "Ultra-High Density Optical Fiber Cable with "Spider Web Ribbon"", Proceedings of the 61st IWCS, 2-4, 2012
8) Y. Sajima, *et al.* : "Key Technology of Spider Web Ribbon (SWR) and the SZ Bunching Unit", Proceedings of the 68th IWCS, 11-3, 2019