Ultra-High-Fiber-Count Optical Cable for Data Center Applications

Fumiaki SATO*, Kenta TSUCHIYA, Yoshiaki NAGAO, Takao HIRAMA, Ryoei OKA, and Ken TAKAHASHI

This paper describes a newly designed ultra-high-fiber-count (UHFC) optical fiber cable for data center applications. The UHFC cable employs Freeform Ribbon, in which fibers meet and split out in turns in a longitudinal and transverse direction, thus allowing high fiber density and mass fusion splicing. Having a non-preferential bend axis, the cable can easily be installed in space-constrained areas. We combined the Freeform Ribbon technology with a new cable design to significantly increase fiber density compared to conventional underground cables while retaining their advantageous features such as easy handling, identification, and mass fusion splicing.

Keywords: ultra-high-fiber-count, pliable 12-fiber ribbon, nonmetallic, slotted core cable, cable installability

1. Introduction

Recently, a growing number of large-scale data centers (DCs) have been constructed due mainly to the advancement of cloud computing. Demand for high-count, high-density optical fiber cables that connect DCs has been growing to meet the need for increased transmission capacity.

Cables that connect DCs are usually installed in outdoor ducts. Technology for achieving high-density installation of optical fiber cables in limited duct space plays a key role (see Fig. 1).

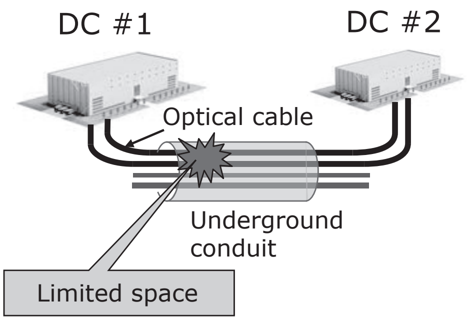
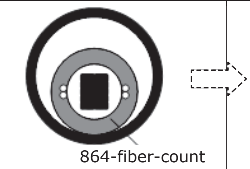
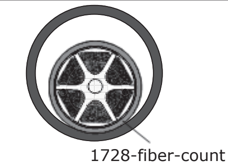
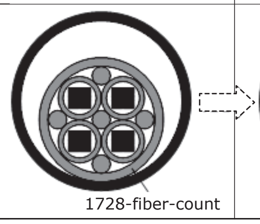
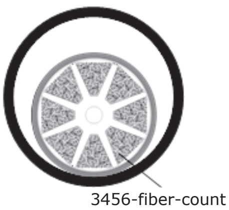


Fig. 1. Schematic diagram of wiring between DC buildings

Against this backdrop, we have developed a series of high-count, high-density optical fiber cables by using 12-fiber Freeform Ribbons*1 that help ensure high flexibility and facilitate mass fusion splicing. Notably, these optical fiber cables are highly flexible in all directions by using a slotted core cable structure with a strength member*2 passing through the center of the core.

We have developed 1728- and 3456-fiber-count optical cables (see Table 1) to increase the fiber density in 1.5-inch and 2.0-inch cable ducts that are in wide use outside Japan.

Table 1. Schematic diagram of wiring between DC buildings

	Conventional optical cable	New optical cable
1.5-inch cable duct		
2.0-inch cable duct		

2. Design and Characteristics of Freeform Ribbon

2-1 Design of Freeform Ribbons

We used 12-fiber pliable ribbons that are mainly used outside Japan. The schematic diagram is shown in Fig. 2.

The flexibility of pliable ribbons and ribbon alignment for mass fusion splicing can be controlled by changing the slit length/non-slit length ratio and length.(1)-(8) The slit length/non-slit length ratio of the structure was optimized by taking into account ribbon flexibility based on the mass fusion splicing workability and cable characteristics.

2-2 Splicing characteristics of the Freeform Ribbons

Figure 3 shows the mass fusion splicing procedure for the Freeform Ribbons.

A two-fiber type pliable ribbon (see Fig. 2) was used to improve the alignment when set on the fusion splicer holder compared to the one-fiber type pliable ribbon. It was confirmed that the mass fusion splicing workability is equivalent to that of conventional ribbon fibers.

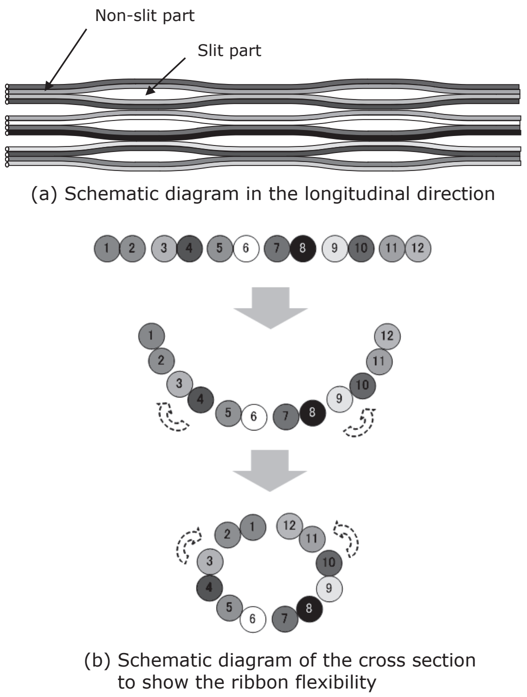


Fig. 2. Schematic diagram of the 12-fiber Freeform Ribbon

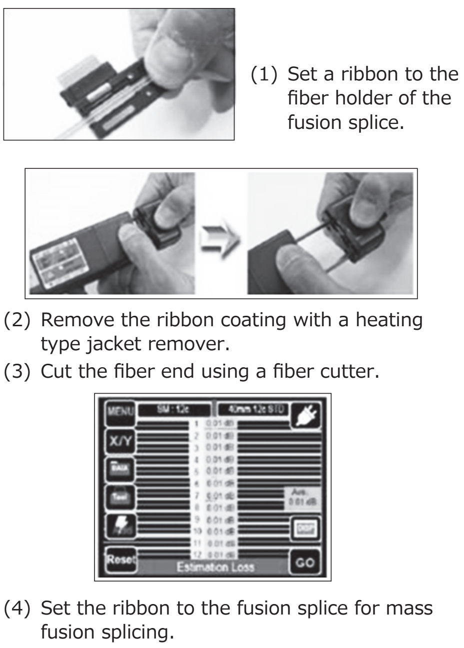


Fig. 3. Mass fusion splicing procedure for the 12-fiber Freeform Ribbon

The distribution of mass fusion loss (estimation method) of 12-fiber Freeform Ribbons and conventional 12-fiber ribbons is shown in Fig. 4.

It was confirmed that the mass fusion splicing loss is almost equivalent to that of conventional ribbons (see Fig. 4).

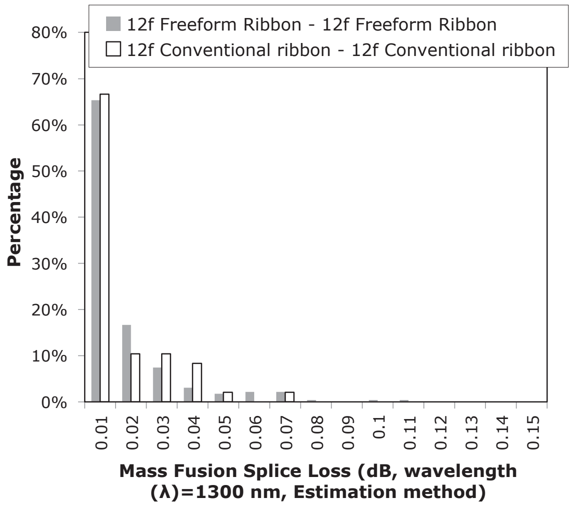


Fig. 4. Distribution of 12-fiber mass fusion splicing loss

3. Structure and Characteristics of the Optical Fiber Cable

3-1 Structure of the cable

The slotted core cable structure design has been used to ensure high flexibility in all directions by inserting a fiber reinforced plastic (FRP) strength member through the center of the core. This nonmetallic structure is expected to reduce cable weight by 10-15% compared to the conventional structure using a steel wire as the tension member.

Figure 5 shows the schematic diagram of the cross section of a 3456-fiber-count optical cable as an example of the structure.

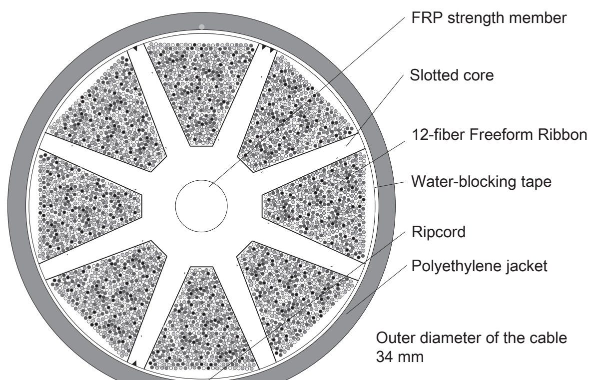


Fig. 5. Schematic diagram of the cross section of a 3456-fiber-count optical cable

The optical fibers used in these cables are single-mode fibers (ITU-T G.657A1, and G.652D standard) with enhanced bending property. These bendable fibers, in combination with pliable ribbons, have significantly increased the fiber density in the cable core, achieving a significant reduction in cable diameter and weight compared to conventional cables.

Each fiber ribbon needs to be identified in high-count optical fiber cables. A series of bars were printed on each pliable ribbon as shown in Fig. 6 so that they can be identified based on the number of the bars.

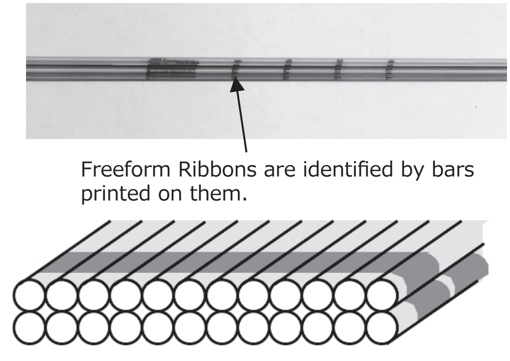


Fig. 6. Schematic diagram of the marking on a 12-fiber Freeform Ribbon

Printing bars in place of conventional numerals helps maintain identifiability in the use of Freeform Ribbons. It was confirmed that the fiber ribbons can be easily identified.

A 3456-fiber-count optical cable houses 36 12-fiber Freeform Ribbons in each groove. Each ribbon in the groove can be identified by the marking of 36 patterns. Each groove can be identified by an identification mark indicated at the top of the slot rib.

3-2 Comparison of fiber count of optical fiber cables

Figure 7 compares the new optical cables with conventional ribbon type loose tube optical cables*[3] in terms of the outer diameter and fiber count. As shown in Fig. 7, the fiber density of 1728-fiber-count and 3456-fiber-count optical cables is double that of a conventional optical cable of the same outer diameter.

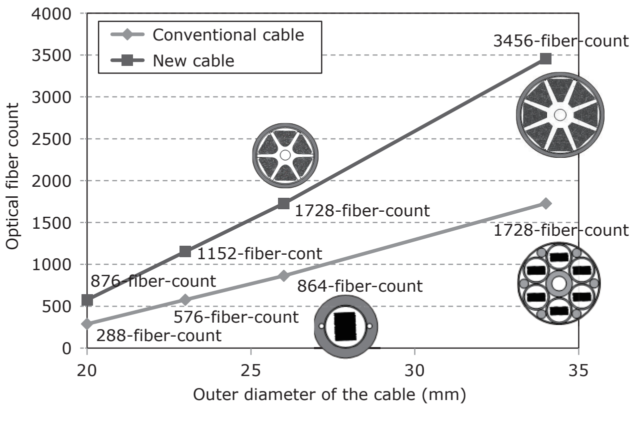


Fig. 7. Comparison of fiber count between conventional and new cables

3-3 Evaluation of the transmission and mechanical characteristics

The characteristics of the new 1728-fiber-count and 3456-fiber-count nonmetallic optical cables were evaluated.

Figure 8 shows the results of a heat cycle test on a prototype 3456-fiber-count optical cable (wound on a drum) at temperatures ranging between −40°C and +70°C.

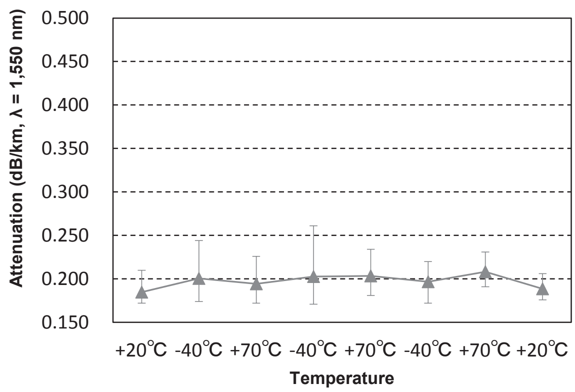


Fig. 8. Changes in attenuation of a 3456-fiber-count optical cable throughout the heat cycle

As shown in Fig. 8, the attenuation was confirmed to be stable throughout the heat cycle.

Table 2 summarizes the evaluation results (including a mechanical test). The characteristics of the 3456-fiber-count optical cable were found to be satisfactory in the mechanical test.

Table 2. Results of characteristics evaluation of 1728- and 3456-fiber-count cables

Item	Test method	Evaluation result
Attenuation Coefficient	IEC60793-1-40	< 0.25 dB/km (1550 nm)
Temperature Cycling	EIA/TIA-455-3 -40°C/+70°C, 2 cyc.	Changes in loss < 0.10 dB/km
Compressive Loading	EIA/TIA-455-41 220 N/cm, 1 minute followed by 110 N/cm, 10 minutes	Loss change < 0.1 dB No abnormality found on the appearance of the cable
Impact Test	EIA/TIA-455-25 Impact Energy: 4.4 N-m 2 drop impacts, 3 locations, λ = 1550 nm	
Cyclic Flexing	EIA/TIA-455-104 I and IV Sheave diameter ≤ 20 x cable diameter 25 cycles, λ = 1550 nm	
Cable Twist Test	EIA/TIA-455-85 Sample Length ≤ 2 m 10 cycles ± 180° λ = 1550 nm	
Long Tensile Loading and Fiber Strain Test	EIA/TIA-455-33 a) 600 Ib (rated) b) 180 Ib (residual)	Fiber strain (Rated) ≤ 60% fiber proof strain Fiber strain (Residual) ≤ 20% fiber proof strain Loss change < 0.1 dB

4. Verification of Cable Workability

In general, the higher the fiber count of an optical cable, the larger the outside diameter and higher the stiffness, making it difficult to install cables in a conduit and store the excess length in handhole enclosures, etc. due to the decreased cable stiffness, in particular.

Two types of ultra-high-fiber-count optical fiber cables were compared to verify the workability: a slotted core cable (flexible in all directions) and a non-slotted core cable (incorporating a tensile strength member on both sides).

Finally, an experiment was conducted using the cable blowing method which is the mainstream cable installation method outside Japan.

4-1 Investigation of cable stiffness

Higher bending stiffness requires more space for installation and storage (when coiling a cable in a figure of eight or storing the excess length). Thus, it is necessary to investigate the bending stiffness. In general, the bending stiffness can be calculated by the equation (1) below.

$$EI = E \bullet \pi \bullet d^4/64 \quad \cdots\cdots (1)$$

EI : bending stiffness
E : Young's modulus
d : diameter of the rigid body

The slotted core cable was deemed to be a composite structure, and its bending stiffness was calculated to investigate the correlation between the calculated and measured bending stiffness.

The bending stiffness test system is shown in Fig. 9, and the correlation between the simulated and measured values of bending stiffness is presented in Fig. 10.

Figure 10 suggests a correlation between the theoretical and measured values, indicating that the bending stiffness can be predicted in the design phase. The bending stiffness of the new 1728-fiber optical cable was compared with that of a conventional 864-fiber-count central-tube optical cable of the equivalent outside diameter (see Table 3).

As shown in Table 3, the bending stiffness of the new slotted core cable was about half that of the conventional central-tube optical cable, suggesting that the new cable offers an advantage in storing optical cables in limited spaces such as handhole enclosures.

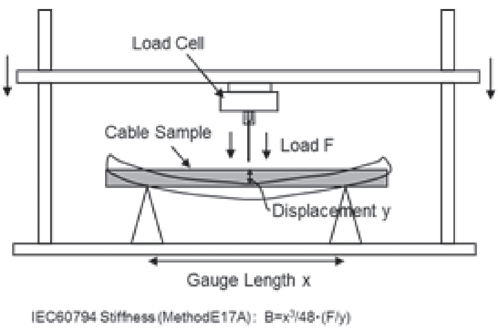


Fig. 9. Schematic diagram of bending stiffness evaluation

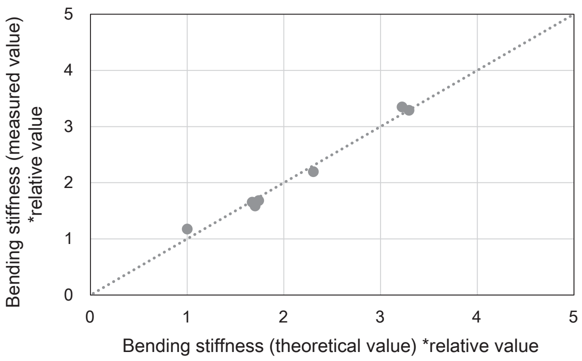
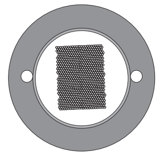
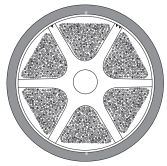


Fig. 10. Correlation between the theoretical value and measured value of bending stiffness

Table 3. Results of comparison of the bending stiffness of the optical cables

Conventional Cable	New Cable
864-fiber-count (O.D. 25 mm)	1728-fiber-count (O.D. 26 mm)
	
Bending Rigidity*1 = 11.4 N・m²	Bending Rigidity = 5.7 N・m²

*1: Bending stiffness value in the strength member diagonal direction (bendable direction) for the conventional cable

4-2 Evaluation of storage performance of excess length of cables

To investigate the influence of the specific bending direction on the storage of excess length in handhole enclosures, a slotted core cable and a non-slotted core cable shown in Fig. 11 below were used as specimens. Fig. 12 shows the experiment method that was used to compare the storage performance.

In the experiment, one end of the cable was assumed to have been installed and secured in the duct (see Fig. 12) to see whether the bundled cable could be neatly stored in the space of 1.2 m by 1.2 m.

The results of evaluation of storage performance for a slotted core cable and a non-slotted core cable are summarized in Fig. 13.

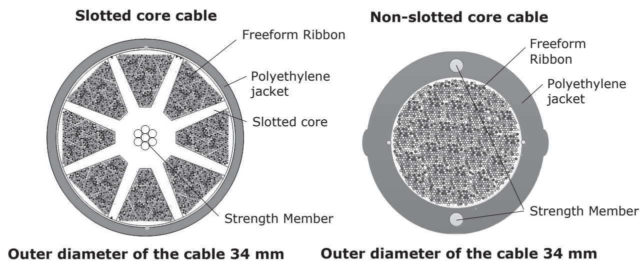


Fig. 11. Cable specimens for evaluating the excess length storage performance

The figures on the right in Fig. 13 show a cable stored with one cable end twisted by 180°. The bundled slotted core cable was not twisted considerably, while the bundled non-slotted core cable floated from the floor surface due to significant twisting.

The results indicate that a thick non-slotted core cable (equivalent to 34 mm in outside diameter) may not be able to be stored properly due to the influence of the specific bending direction attributed to the tension members provided on both sides. It was confirmed that the new slotted core cable does not pose any problem in storage.

4-3 Cable blowing test

At the end of the installability verification, a cable blowing method using a cable jetting machine (which is widely used in Europe and North America, etc. to fit optical fiber cables into ducts) was employed to conduct an experiment to install a 1728-fiber-count slotted core cable (see the figure on the right of Table 3).

A SuperJet cable blowing machine that is shown in Fig. 14 was used to conduct the experiment with cooperation from Plumettaz S.A., a cable blowing equipment manufacturer.

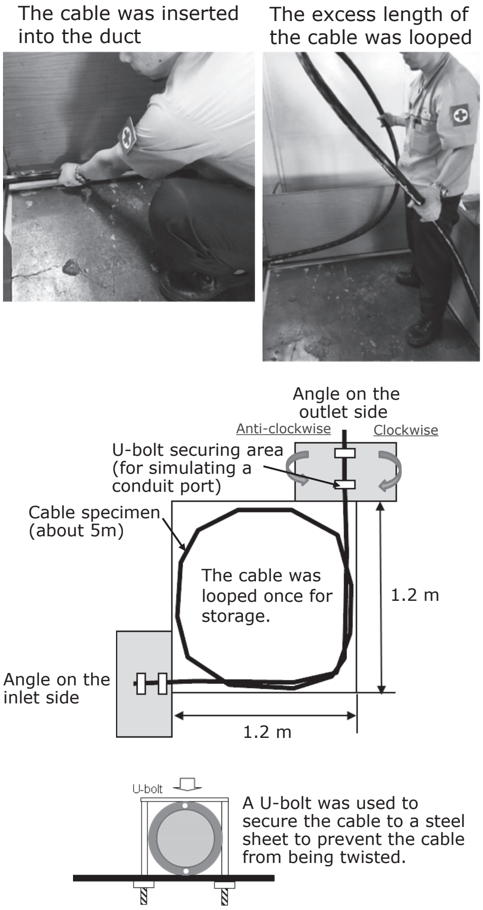


Fig. 12. Experiment system for evaluating the cable storage performance

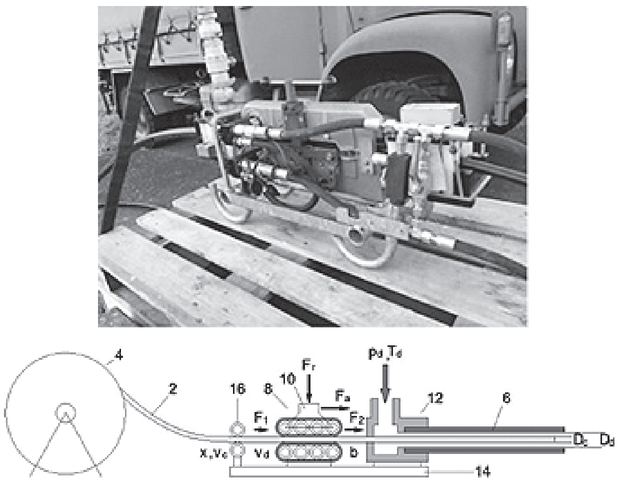


Fig. 14. Photo of a SuperJet and schematic diagram of the cable blowing test

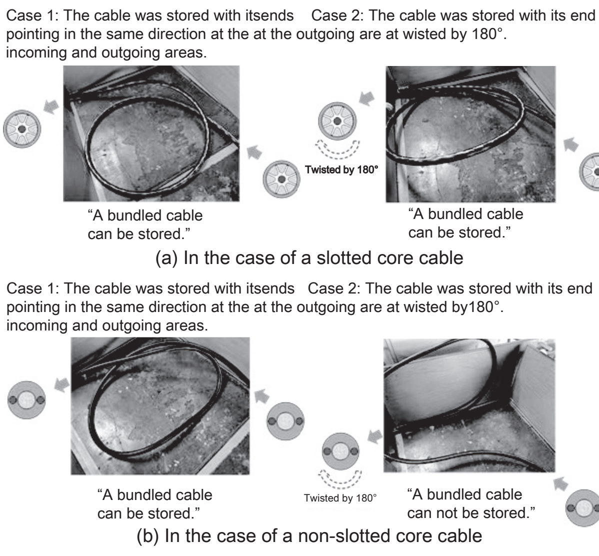


Fig. 13. Results of evaluation of the cable storage performance

The SuperJet machine was used in simulated difficult conduit conditions. Cable blowing could be performed for about 200 meters in the experiment system (inside diameter of the duct: 35 mm) including six elbows.

The simulation results also showed that cable blowing can be performed for about 1,100 meters in a general duct route. The distance was about 1.3-fold that of cable blowing using a non-slotted core cable of equivalent outside diameter (which has a specific bending direction). Cables are expected to be installed increasingly by means of cable blowing, mainly outside Japan.

5. Conclusion

We have developed a series of ultra-high-fiber-count optical cables using 12-fiber Freeform Ribbons for connecting DCs. We selected the ribbons that were designed to enable high-density packaging without undermining their fusion splicing workability.

The structure of the new slotted core cables was provided with a nonmetallic strength member passing through center of the core. We succeeded in developing 1728- and 3456-fiber-count optical cables whose fiber count is double that of conventional optical cables with equivalent outside diameter.

We also verified cable installability and confirmed the advantage of the slotted core cable structure (which is flexible in all directions) in installation.

These optical cables are expected to enhance optical transmission density and contribute to the effective use of limited installation spaces, in particular.

Technical Terms

∗1 Freeform Ribbon: A Freeform Ribbon refers to a flexible pliable ribbon.

∗2 Strength member: A strength member relieves the tension that is applied to optical fibers during installation.

∗3 Loose tube cable: Loose tube cable refers to a cable with optical fibers inserted and stranded within a protective resin tube.

References

(1) Y. Yamada et al, "Ultra-High-Density Optical Fiber Cable with Rollable Optical Fiber Ribbons," The Institute of Electronics, Information and Communication Engineers (2008), p.292

(2) Y. Yamada et al, "High-Fiber-Count and Ultra-High-Density Optical Fiber Cable with Rollable Optical Fiber Ribbons," The Institute of Electronics, Information and Communication Engineers (2009), p.503

(3) K. Okada et al, "Enhanced Peelable Ribbon and Its Application to Access Network Cables," Proc. of 53rd IWCS (2005), p.55-60

(4) F. Satou et al, "Low Polarization Mode Dispersion and Thin Ribbon Type Optical Cable with Peelable Ribbon 'EZbranch®'," Proc. of 55th IWCS (2007), p.55-60

(5) M. Takami et al, "Design of Ultra-High-Density Optical Fiber Cable with Rollable 4-Fiber Ribbons for Aerial Deployment," Proc. of 61st. IWCS (2012), p.433-436

(6) F. Satou et al, "Flame Retardant Optical Fiber Cords with Pliable Ribbons for Easy MPO terminations," Proc. of 63rd. IWCS (2014), p.742-746

(7) F. Sato et al, "Design of Ultra-High-Density 2000-Optical Fiber Cable with Pliable 8-fiber Ribbons for Underground Deployment," IWCS (2015), p.659

(8) F. Sato et al, "Ultra-High-Fiber-Count and High-Density Slotted Core Cables with Pliable 12-fiber Ribbons," IWCS (2016), p.604

Contributors

The lead author is indicated by an asterisk (∗).

F. SATO*
• Group Manager, Optical Fiber & Cable Division

K. TSUCHIYA
• Optical Fiber & Cable Division

Y. NAGAO
• Group Manager, Optical Fiber & Cable Division

T. HIRAMA
• Assistant Manager, Optical Fiber & Cable Division

R. OKA
• Plant Manager, Optical Fiber & Cable Division

K. TAKAHASHI
• Group Manager, Optical Fiber & Cable Division