Separable Optical Fiber Ribbons and Cables for Advanced Mid-span Branching

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ABSTRACT With the growing popularity of fiber-to-the-home (FTTH), installation work of optical fiber cables to each household is increasing in number. But in the mid-span branching of conventional aerial cables, improvement of low efficiency in fiber utilization has posed a problem to be solved. Accordingly, the authors have developed, with the aim of improving the fiber utilization efficiency in mid-span branching, both two-fiber and eight-fiber ribbons that enable ease of separating into specified number of fibers at the point of mid-span branching. This paper reports on the characteristics of the optical fiber ribbon of separable type and the optical cable based on the ribbon, along with a special tool for mid-span branching work that has been developed together.

1. INTRODUCTION

With the growing popularity of fiber-to-the-home (FTTH), installation work of optical fiber cables to each household is increasing in number. Implementation of FTTH requires construction of a dense optical fiber network using optical cables of small fiber counts, so that it inevitably needs mid-span branching and jointing of cables at intermediate points of distribution optical fiber cables. But in the mid-span branching of conventional aerial cables, low efficiency in fiber utilization has posed a problem to be improved. This is because, in the standard method for mid-span branching of conventional aerial cables, optical fibers contained in a fiber ribbon are cut en bloc to take out the required number of fibers, and the rest fibers are left unused resulting in a decrease in fiber utilization efficiency.

Accordingly we have previously developed, and have already reported [1], a separable four-fiber ribbon as well as an optical cable using the fiber ribbon, which permits easy separation of single fibers at intermediate positions.

In spite of the above mentioned, fiber branching scheme has been diversified in recent years. For example, whereas conventionally it was a mainstream practice to joint the separated single fibers to a drop cable, recently a number of cases are encountered where an aerial cable of multitudes of fibers is mid-span branched into an aerial cable of small numbers of fibers [2]. In order to deal with such cases, development of a new optical fiber ribbon together with an aerial cable using the ribbon is required, which is aimed at enabling mid-span branching of not only from a high-count ribbon to single fibers but also from a high-count ribbon to low-count ribbons.

To meet such a requirement, we have developed an eight-fiber ribbon of separable type, realizing mid-span branching from a high-count ribbon to a plurality of low-count ribbons, together with, taking into consideration branching from a low-count ribbon to single fibers, a separable type two-fiber ribbon. This paper reports on the superior characteristics obtained by the evaluation of slotted-core cables using these optical fiber ribbons. Also included are the development results of a special tool for ribbon separation that enables easy and safe mid-span branching.

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2. DESIGN OF SEPARABLE RIBBON

The separable optical fiber ribbon and the special tool for ribbon separation that have been developed here will be described in this Section.

2.1 Concept of Separable Ribbon

The optical fiber ribbons used in the current aerial cables are largely two-, four- and eight-fiber ribbons. Accordingly, we have studied, in the development of new separable ribbons, optical fiber ribbons of these fiber counts. Figure 1 shows cabling diagram for mid-span branching, and Table 1 shows the design concept for separable optical fiber ribbons to be developed here.

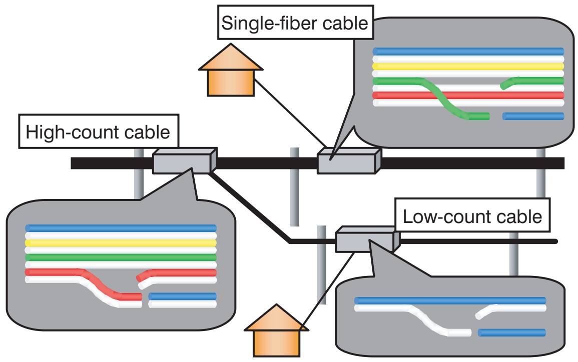

Figure 1 Cabling diagram for mid-span branching.

Table 1 Design concept of separable optical fiber ribbon.

Development objective	Mid-span branching	Remarks
Two-fiber ribbon	Separable to single fiber	—
Four-fiber ribbon	Separable to single fiber	Already developed
Eight-fiber ribbon	Separable to two-fiber ribbon	After separation, separable in turn to single fiber
	Separable to four-fiber ribbon	

The two- and four-fiber ribbons are mainly packaged in aerial cables of low-fiber counts, and their destinations of mid-span branching are mostly single-fiber drop cables to individual household. For this reason, the two- and four-fiber ribbons for mid-span branching have to be separable into single fibers.

On the other hand, the eight-fiber ribbon is packaged in aerial cables of high-fiber counts, and thus, besides being dropped as single fibers, it is sometimes mid-span branched into aerial cables of low-fiber counts as shown in Figure 1. Therefore, the eight-fiber ribbon of separable type has to be adapted to both of these branching schemes in order to improve the efficiency of fiber utilization as well as the work efficiency. To put it simply, the eight-fiber ribbon for mid-span branching has to be separable, at arbitrary intermediate points, to two- or four-fiber ribbons that are widely used in low-count fiber cables as well as to single fibers.

2.2 Special Tool for Mid-span Branching

A special tool was needed to carry out the mid-span branching work easily and safely.

Basically the branching work is performed as aerial work, so that the design is required to be such that the tool is compact and lightweight permitting operations using one hand. In addition, fiber separation work must be done quickly and yet safely, which suggests that materials raising the possibilities of damaging the fiber should be discarded in designing the tool. We accordingly selected sandpaper as the separating element for mid-span branching of optical fiber ribbons, and mounted it on the special tool developed here.

In order not to apply excessive forces on the optical fiber ribbon at the time of scraping, the tool was also provided with a gap adjustment mechanism to enable scraping with a suitable working gap.

Moreover, with the aim of carrying out single-fiber separation in safety after the optical fiber ribbon is scraped using the sandpaper, a separation element made of plastic mesh was added to the special tool. It is thought that scraping the ribbon using the mesh element will complete, after the separable ribbon is pre-treated using the sandpaper to trigger fiber separation, the single fiber separation safely and easily. Thus, it is expected that adverse effects such as fiber breakage and loss increase are eliminated while at the same time the work time is reduced.

Figure 2 shows the special tool developed here.

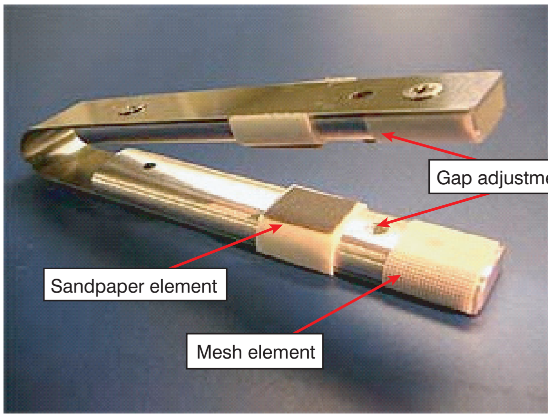

Figure 2 Fiber ribbon separation tool for mid-span branching.

2.3 Separable Four-fiber Ribbon

The four-fiber ribbon was investigated for its material and structure in order to make single-fiber separation using the special tool possible. The structure of the ribbon is shown in Figure 3. Generally speaking, the lower the adhesion between the colored layer and the ribbon matrix, the easier becomes peeling, thereby improving the ease of single-fiber separation. And, thinner the thickness of the ribbon matrix, the higher becomes the ease of taking out fibers. We accordingly studied the four-fiber ribbon of single-layered structure with different thickness levels of the colored layer and the ribbon matrix, and obtained an optimized solution that permits single-fiber separation using the special tool. The details have been reported elsewhere [1].

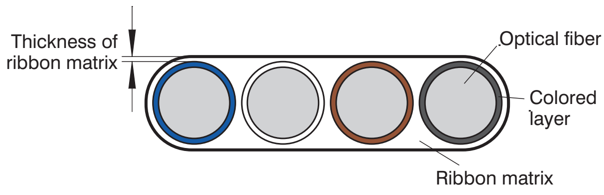

Figure 3 Structure of four-fiber ribbon.

2.4 Design of Separable Two-fiber Ribbon

Based on the design concept of the separable four-fiber ribbon described in Section 2.3, a separable two-fiber ribbon was studied. Ease of single-fiber separation was evaluated for the ribbon matrices of different thicknesses using the same material as for the four-fiber ribbon. In the evaluation, the ribbon was scraped once using the sandpaper element then several times using the mesh element to carry out fiber separation. The results are shown in Table 2, from which it is clearly shown that the ease of separation is dependent on the matrix thickness, and that the matrix thickness has to be 0.6 or lower in relative value to achieve good single-fiber separation.

Table 2 Success rate of ribbon separation.

Matrix thickness (relative value)	Use of special tool Sandpaper plus mesh
0.1	Separation possible
0.3	Separation possible
0.6	Separation possible
1.0	Separation impossible

2.5 Design of Separable Eight-fiber Ribbon

Conventionally, the destination of mid-span branching of aerial cables was mainly drop cables containing a single fiber, so that single-fiber mid-span branching was generally required. Recently, however, cases of mid-span branching to drop cables containing multiple numbers of fibers and to aerial cables containing small numbers of fibers occur, raising requirements such that an eight-fiber ribbon is branched into two- or four-fiber ribbons, which are in turn jointed to other optical fiber ribbons in another cable. Thus, development of optical fiber ribbons for mid-span branching is required that are separable to low-count ribbons.

Separable multi-fiber ribbons can be realized by combining the single-layered ribbons described in Sections 2.3 and 2.4, whereby a plurality of single-layered ribbons are arrayed followed by covering them en bloc to make a double-layered multi-fiber ribbon. An eight-fiber ribbon of double-layered structure that is separable to two- or four-fiber ribbon was investigated here. Figure 4 shows an example of separable eight-fiber ribbon of double-layered structure that is separable via two-fiber ribbons to single fibers.

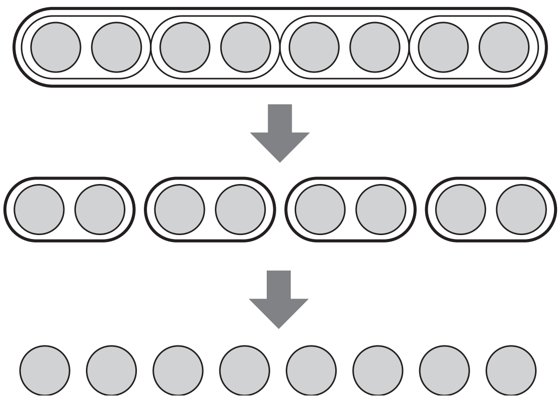

Figure 4 Structure of separable eight-fiber ribbon.

It was thought that an important point in designing the separation from a double-layered ribbon to single-layered ribbon is the material property of the second layer and its thickness. We accordingly prototyped samples for the second layer in six levels in total, i.e. three different Young's modulus and two different thicknesses, and evaluated their ease of separation using the special tool. Table 3 shows the three materials with different Young's modulus. Two methods of separation were evaluated, i.e. scraping by sandpaper followed by mesh, and scraping by mesh only. The separation performance was evaluated based on the number of times of tool usage required until separation to ribbons but not until separation to fiber, and the results are shown in Table 4.

Table 3 Material property for the second layer.

Material	Young's modulus (relative value)	Manufacturability
A	1.0	○
B	0.4	○
C	0.3	△

Table 4 Separation performance of separable eight-fiber ribbon.

Layer material	Sandpaper plus mesh		Mesh only	
	Relative layer thickness 0.2	Relative layer thickness 1.0	Relative layer thickness 0.2	Relative layer thickness 1.0
A	×*1	×*2	×*2	×*2
B	×*1	○	◎	○
C	×*1	○	◎	○

Note *1: Separated into single fibers before separating into ribbons.
*2: Impossible to be separated into either ribbon or fiber.

The results show that, in spite of the fact that a thinner layer generally leads to superior ribbon separation, the thinner layers tested here results in separation into fibers when processed by the sandpaper. While materials B and C showed good separation performance by the mesh-only method, it can be said that material B with a moderate Young's modulus is the best suited taking manufacturability into consideration.

The single-layered ribbon separated from the separable double-layered ribbon is based on the same design as for the ribbons separable into single fibers described in Section 2.3 or 2.4. Thus, the ribbon is separable, after ribbon separation, into single fibers using the sandpaper and mesh elements on the special tool. Hence, the separable double-layered ribbon permits both separation schemes for either ribbon jointing or fiber jointing, by selecting a suitable separation method in the aerial mid-span branching.

3. CHARACTERISTICS OF SEPARABLE RIBBONS

The separable two- and eight-fiber ribbon developed here are required to exhibit a level of characteristics equivalent to that of conventional optical fiber ribbons. Accordingly, we have evaluated the main characteristics of the developed optical fiber ribbons. In addition, in order to evaluate their workability for mid-span branching, changes in transmission loss and optical fiber reliability due to branching work were also measured.

3.1 Main Characteristics of Separable Fiber Ribbons

3.1.1. Characteristics of Separable Two-fiber Ribbon
Based on the design described in Section 2.3, a separable two-fiber ribbon was developed which permits separation into single fibers for single-fiber jointing at an intermediate point in an aerial span. The developed ribbon was evaluated for its initial characteristics, crush resistance, temperature stability and long-term reliability. The results are shown in Table 5. It was confirmed that the separable two-fiber ribbon developed here exhibited a level of characteristics equivalent to that of conventional fiber ribbons.

Table 5 Characteristics of separable two-fiber ribbon.

Test item	Test condition	Test results	
Transmission loss	λ=1550 nm	≤0.21	dB/km
Crush resistance	500 N/100 mm	≤0.02	dB
Temperature/humidity aging	85°C x 85%, 30 days	≤0.05	dB/km
Temperature cycling	−40∼+70°C, 10 cycle	≤0.05	dB/km
Fusion splice loss	MFD: 8.6±0.4 μm	≤0.10	dB

3.1.2. Characteristics of Separable Eight-fiber Ribbon
Based on the design described in Section 2.5, a separable eight-fiber ribbon was prototyped which permits separation into two- or four-fiber ribbon as well as into single fibers at an intermediate point in an aerial span. Its characteristics were also evaluated in the same way as described in Section 3.1.1 and the results are shown in Table 6. The fusion splicing loss with conventional ribbons and two- and four-fiber ribbons after mid-span branching is satisfactory. It was confirmed that other the characteristics are equivalent to that of conventional ribbons.

Table 6 Characteristics of separable eight-fiber ribbon.

Test item	Test condition	Test results	
Transmission loss	λ=1550 nm	≤0.21	dB/km
Crush resistance	500 N/100 mm	≤0.02	dB
Temperature/humidity aging	85°C x 85%, 30 days	≤0.05	dB/km
Temperature cycling	−40∼+70°C, 10 cycle	≤0.05	dB/km
Fusion splice loss	MFD: 8.6±0.4 μm	≤0.10	dB

3.2 Transmission Loss Changes at Mid-span Branching

The separable optical fiber ribbons developed here were evaluated for transmission loss changes during mid-span branching work. The evaluation method is as follows. As illustrated in Figure 5, the two-fiber ribbon was scraped at its intermediate point once using the sandpaper element on the special tool, followed by scraping the same portion with the mesh element on the tool, thereby being separated into single fibers. The optical fiber ribbon of double-layered structure was, as illustrated in Figure 6, scraped using the mesh on the special tool to be separated into ribbons of single-layered structure, which in turn were scraped at its intermediate point using the sandpaper and then mesh, thereby being separated into single fibers. Table 7 shows the attenuation loss changes occurred at each work step. The measurement was carried out at a wavelength of 1550 nm and a measurement interval of 10 msec. From the results, it was confirmed that the loss changes were small, thus posing no problems.

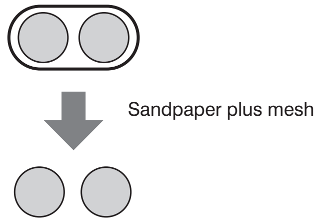

Figure 5 Separation of separable two-fiber ribbon.

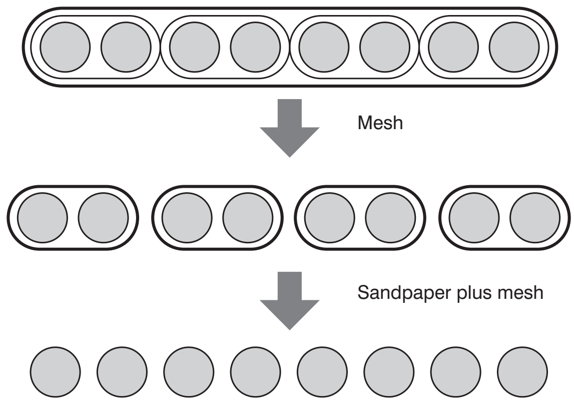

Figure 6 Separation of separable eight-fiber ribbon.

Table 7 Loss increase during ribbon separation.

Type of separation	Method	Two-fiber ribbon	Eight-fiber ribbon
Ribbon	Mesh	—	≤0.3 dB
Single fiber	Sandpaper	≤0.1 dB	≤0.1 dB
	Mesh	≤1.0 dB	≤0.1 dB

3.3 Evaluation of Reliability after Mid-span Branching

In order to verify whether fibers were damaged during the mid-span branching work, the tensile fracture strength of two groups of fibers were measured to evaluate the possible degradation in strength. The first group comprised fibers before ribbon forming, and the second group comprised those after separation using the sandpaper and mesh elements on the special tool. Figures 7 and 8 show the test results, i.e. the Weibull distribution of fracture strength of two groups of fibers, respectively. Since the fibers before ribbon forming and those after separation using the special tool both exhibited comparable Weibull distributions, it was confirmed that no strength degradation occurred due to the mid-span branching using the special tool.

4. CHARACTERISTICS OF CABLES FOR MID-SPAN BRANCHING

Aerial cables for mid-span branching were developed using the separable optical fiber ribbons described above,

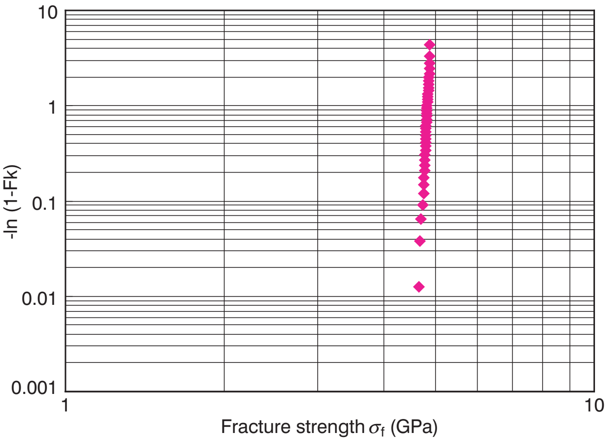

Figure 7 Weibull distribution of fiber fracture strength before separation.

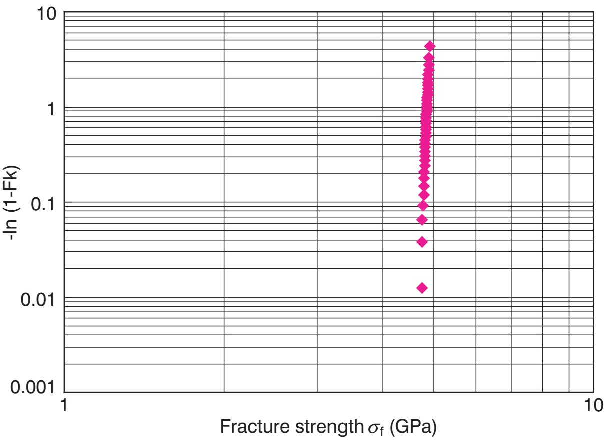

Figure 8 Weibull distribution of fiber fracture strength after separation.

and cables using the two-fiber and eight-fiber ribbons were evaluated for main cable characteristics.

4.1 Mid-span Branching Cable Using Two-fiber Ribbon

Figure 9 shows the mid-span branching cable using the two-fiber ribbon developed here. A tension member is located at the center, and separable two-fiber ribbons are accommodated in each groove of the SZ slot. The 24-fiber and 48-fiber type of the cable were developed.

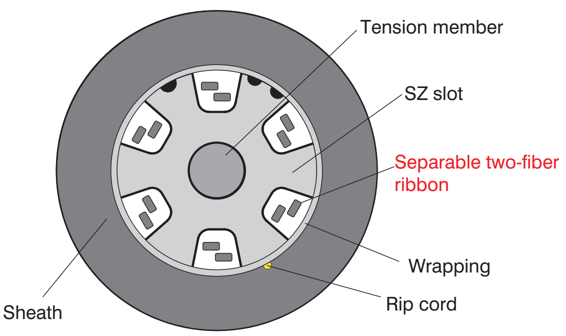

Figure 9 Structure of SZ cable using two-fiber ribbon. (24-fiber cable)

Main characteristics of the developed cable described above were evaluated, and the results are shown in Table 8. Both 24-fiber type and 48-fiber type showed good performance in terms of transmission loss, mechanical characteristics and temperature stability, and it was confirmed that the obtained characteristics are comparable to those of SZ cables using conventional optical fiber ribbons.

Table 8 Characteristics of SZ cable using two-fiber ribbon.

Test item	Test condition	Measurement wavelength (nm)	Test results		
			24-fiber	48-fiber	Unit
Transmission loss	—	1310	≤0.34	≤0.34	dB/km
		1550	≤0.21	≤0.20	dB/km
Temperature cycling	−30∼+70°C x 3 cycles	1550	≤0.01	≤0.01	dB/km
Tensile performance	0.2% elongation		≤0.01	≤0.01	dB
Squeezing	1.47 kN, 90° R=300nm		≤0.01	≤0.01	dB
Bending	R=10D·10 cycles		≤0.01	≤0.01	dB
Crush resistance	1960 N/100 mm		≤0.01	≤0.01	dB
Impact	500g·1m falling		≤0.01	≤0.01	dB
Twist	245 N, ±180°		≤0.01	≤0.01	dB

4.2 Mid-span Branching Cable Using Eight-fiber Ribbon

Figure 10 shows the structure of 640-fiber cable for mid-span branching using the separable eight-fiber ribbon developed here. Ten separable eight-fiber ribbons are stacked in each groove of the SZ slot. The slot pitch and the slot turning angle were optimized in design so as to satisfy both fiber strain and ease of taking out of fiber.

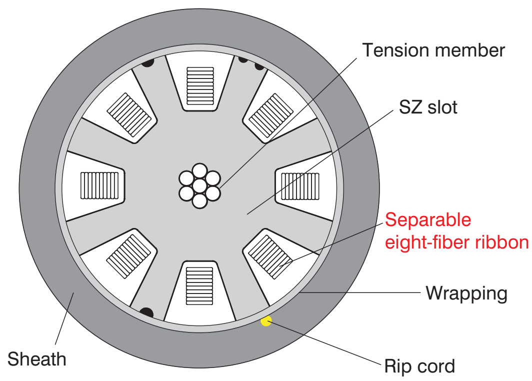

Figure 10 Structure of 640-fiber SZ cable using eight-fiber ribbon.

Main characteristics of the developed cable described above were evaluated, and the results are shown in Table 9. The cable exhibited good performance in terms of transmission loss, mechanical characteristics and temperature stability, and it was confirmed that the obtained characteristics are comparable to those of SZ cables using conventional optical fiber ribbons.

Table 9 Characteristics of SZ cable using eight-fiber ribbon.

Test item	Test condition	Measurement wavelength (nm)	Test results	
Transmission loss	—	1310	≤0.36	dB/km
		1550	≤0.25	dB/km
Temperature cycling	–30∼+70°C x 3 cycles	1550	≤0.06	dB/km
Tensile performance	0.2% elongation		≤0.01	dB
Squeezing	1.47 kN, 90° R=300nm		≤0.01	dB
Bending	R=10D·10 cycles		≤0.01	dB
Crush resistance	1960 N/100 mm		≤0.01	dB
Impact	500g·1m falling		≤0.01	dB
Twist	245 N, ±180°		≤0.01	dB

5. CONCLUSION

Optical fiber ribbons for mid-span branching have been developed including two-fiber ribbon and eight-fiber ribbon that are separable to either ribbons or single fibers, together with a special tool that can separate these optical fiber ribbons easily and safely. It was confirmed that the optical fiber ribbons prototyped showed the characteristics comparable to those of conventional ribbons, thus posing no problems in terms of attenuation loss increase and fiber strength degradation during the branching work. Moreover, optical cables using these optical fiber ribbons showed the characteristics comparable to those of conventional aerial optical cables.

Thus it is expected that the cables for mid-span branching developed here can improve the efficiency of fiber utilization at mid-span branching, making themselves a useful optical fiber in the implementation of the FTTH infrastructure.

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