Development of Optical Fiber Cables for Access Networks

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ABSTRACT In an effort to promote implementation of FTTH (Fiber To The Home), the authors have been developing optical fiber cables for access networks. The development at this time includes: 1) Optical fiber cables and terminations that help improve the installation efficiency by enabling multi-cable laying, 2) Low-cost cables that permit one-step manufacturing after fiber ribbon, and 3) Flame-retardant optical fiber cables with environment-friendliness. The development program thus provided the optical fiber cables that had been developed three years ago with additional improvements in terms of cost and function. It can be said, as the result, early implementation of FTTH has been promoted.

1. INTRODUCTION

The authors have been developing optical fiber cables for access networks since three years ago, making a significant contribution to the construction of optical fiber access networks that is aimed at coping with the rapid growth of the Internet accompanied by an increasing volume of data traffic.

The number of Internet users in Japan is estimated to reach 27 million at the end of 1999 (a 59.7% increase over the previous year), rising to 77 million at the end of 2005 1).

Data communication is predicted to keep growing, expanding to the areas of not only web content access and electronic mail exchange in these days but also integration of digitized broadcasting and telecommunications together with circulation of such mass-media contents as music, computer games, and broadcasting in the future; which leads to an explosion of information distribution in around 2005, encompassing the SOHO, local community, and home information contents. In order for such a developing optical access network to expand economically and rapidly, it is essential that optical access cables developed heretofore should be improved in terms of performance, function, and cost.

This paper reports on the study of upgrading the installation efficiency of multi-fiber cables, investigation on the new cable structures with small fiber counts, and the development of subscriber cables with environment-friendliness.

2. DEVELOPMENT OF CABLES WITH IMPROVED INSTALLATION PERFORMANCE

With the increase of communication traffic, there is a need for optical access networks to be constructed at an economical cost. To meet this requirement, not only cable cost reduction but also total cost reduction should be considered including such cable installation and connection technologies as long-length laying and multi-cable laying. When it comes to the cost reduction of cable installation, both shortening working hours and lessening working materials contribute greatly to this target, and one of the most effective measures to achieve this is to decrease the laying tension of optical fiber cables, involving reduction of the friction coefficient of the cable sheath as well as lightening cable weight and upgrading cable flexibility. The results of investigations on these measures will be reported below.

2.1 Investigation on Reducing Friction Coefficient of Cable Sheath

Possible techniques for friction coefficient reduction come in two ways: changing the constituting material to the one with a lower friction coefficient and using lubricant to decrease the friction.

2.1.1 Investigation on Sheath Material

The sheathing materials suitable for multi-cable laying were investigated. Various polyethylene (PE) materials were compared in terms of requisite properties of cable sheath including low friction coefficient against cable duct, abrasion resistance, rigidity, and cost; and the results are shown in Table 1.

Referring to the above mentioned results, linear low density PE (hereafter called L-LDPE) was selected for its excellent wear resistance and low friction coefficient.

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2.1.2 Application of Lubricant

Lubricants to be applied onto cables and ducts for decreasing friction coefficient should be optimally selected considering such factors as the method of application, lubricant type, effectiveness, and long-term reliability. As for the method of application, both compounding at the time of manufacturing and surface application at the time of cable laying were tested for the sheath material and the duct material, respectively; and comparing the obtained results in terms of reduction effectiveness, workability, and reliability, it was determined to use the compounding method for the sheath material. As for the type of lubricant, fatty acid amide was selected for the following reasons.

(1) It is used in processed foods, so that health safety is ensured.
(2) It is readily available, effective with a small amount of usage, and thus is economical.
(3) By adjusting the compounding concentration, the friction coefficient can be adjusted.

2.1.3 Long-Term Reliability of Sheath Material and Lubricant Characteristics

The reliability of the new sheath material was verified to meet the performance requirements of sheath material with regard to basic characteristics, aging characteristics, ultraviolet-ray deterioration, oil resistance, etc.

It was also confirmed that when the bled lubricant was wiped off using alcohol, it re-bled within about two weeks, thereby recovering an original friction coefficient needed for cable laying; and that the bled lubricant did not go moldy when tested in accordance with JIS Z 2911 (1922). Moreover, the inwardly bled lubricant was found to have little influence on the cable core, exhibiting a core pull-out force equivalent to that of the cable in current use.

2.1.4 Verification of Installation Performance

The prototype of a 640-fiber cable was manufactured and experimentally installed in order to verify the investigations described above. The results about the cable laying tension are shown in Figure 1.

From the results shown in the Figure, it is seen that the cable using sheath material comprised of L-LDPE with compounded fatty acid amide can reduce the cable laying tension by about 30 % in comparison to conventional cables using LDPE. Thus, the effectiveness of the new sheath material composition was demonstrated.

2.2 Investigation on Lightweight Cable Structure

An alternative technique to reduce the cable laying tension is to reduce the cable weight itself, including such means as using a slotted rod of decreased diameter resulting in a reduced designed weight, using a foamed slotted rod leading to a reduced cable weight, and using a tension member of reduced diameter or of nonmetallic material. The results of these investigations will be described below.

Table 1 Comparison of various sheath materials' properties

Material	Low friction co-efficient against duct	Wear resistance	Rigidity	Cost
Low-density PE	○	△	○	Present
Linear low-density PE	○	○	○	Comparable
Medium-density PE	◎	◎	△	High
High-density PE	◎	◎	×	High

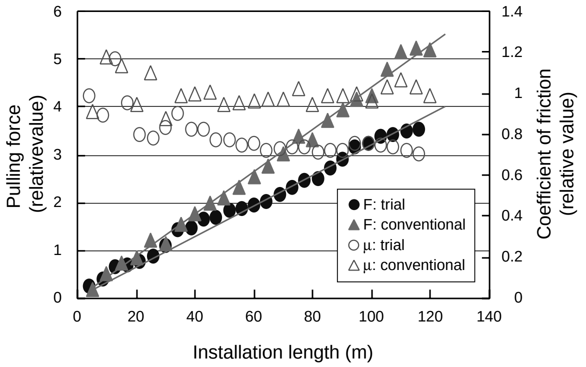


Figure 1 Relationship between cable length and pulling tension at installation

2.2.1 Reduction of Slotted Rod Diameter

Reduction of the slotted rod diameter results in also the reduction of the design weight of slotted rod, wrapping, and sheath material, thus enabling the reduction of costs. Viable measures to reduce the diameter include reexamination of the slot dimensions, the tension member thickness, the slot bottom thickness, and the rib thickness. Among these, the former three were discarded because of concerns about large influence on cable's optical performance, so that the reduction of the rib thickness was investigated. Conventionally, the slotted rod was fabricated by extrusion, and the minimum thickness of the rib was limited to about 1.3 mm due to engineering reasons. Accordingly, we changed the method to shaving, which was able to decrease the minimum thickness by half. Since the rib thickness decrease was expected to incur deterioration in various mechanical characteristics of the cable, we simultaneously carried out mechanical tests to confirm structural integrity. It was confirmed that, although some dependence on the rib thickness was seen, the mechanical characteristics were equivalent to those of conventional cables, thereby meeting the performance requirements with a sufficient margin.

2.2.2 Reduction of Tension Member Diameter

Due to the enhancement of fiber screening level from 0.5 % to 1.0 %, the allowable elongation during cable laying has been increased from 0.2 % to 0.3 %. This relaxation of requirements permits the reduction of the tension member diameter by 60 % in Furukawa's case or the use of aramid fiber FRP in place of bluing-steel stranded wire now in use. It was confirmed that the cables using the two

Table 2 **Comparison and breakdown of weight reduction in 1000-fiber cables (kg/m)**

Conventional structure	0.76	
Light-weight structure	0.49	
Reduced weight	0.27	0.10: Slotted rod diameter reduction 0.15: Tension member diameter reduction 0.02: Reduction by foaming

tension members mentioned above showed an elongation of 0.3 % or less for the slotted rod under a load of 3980 N, thus demonstrating sufficient performance in terms of reliability.

2.2.3 Slotted Rod with Foamed Inner Layer

Foamed polyethylene is a cable insulation material that has established a substantial track record in the PEC and the CCP cables. This technology was applied to reduce the weight of the slotted rod whereby a cable consisting of a slotted rod with a 40 % foamed inner layer was investigated. The cable was confirmed to provide sufficient performance with regard to the temperature and mechanical characteristics.

2.2.4 Summary of Weight Reduction

Table 2 compares the weights of two 1000-fiber cables; one is the conventional and the other is the new one in which various weight-reduction measures hereto mentioned are applied. It is seen that the reduction in both the slotted rod diameter and the tension member makes a major contribution.

2.3 Summary of Cables with Improved Installation Performance

Reduction of both the friction coefficient of the sheath material and the weight of the cable was investigated, demonstrating that the both techniques made a major contribution in reducing the cable laying tension. Moreover, the cable characteristics were confirmed to be equivalent to those of conventional cables, thus giving ample performance.

3. DEVELOPMENT OF AERIAL CABLES WITHOUT SLOTTED ROD

In order to promote implementation of fiber-optic access networks economically, there is a need for optical fiber cables with compactness, lightweight, and better installation performance. Although single-tube cable and loose-tube cable represented optical fiber cables for access network heretofore, these cables had difficulties in handling due to the use of jelly and so forth.

In Japan in the meantime, SZ slotted rod cables have been developed and put into practical use for aerial distribution. While cables with three slots are used up to 24 fibers and five slots up to 100 fibers, there is an increasing need for cable downsizing toward the cables with less than 40 fibers so as to promote FTTH. Accordingly, we have developed new types of optical fiber cables in this cable category at this time, which feature compactness, lightweight, and ease of handling.

3.1 Required Characteristics for Optical Fiber Aerial Distribution Cables

3.1.1 Cable Structure Using Optical Fiber Ribbon

Aerial distribution cables are required to use optical fiber ribbons so as to facilitate jointing with trunk line cables and other distribution cables.

3.1.2 Long-Term Reliability in Aerial Environments

Whereas aerial distribution cables are installed on telephone poles, the cable-supporting member undergoes tensile strain due to temperature change and wind load under such aerial environments. Thus, the cable structure has to be such that the fibers contained would not suffer from degradation when the supporting member elongates.

3.1.3 Mid-Span, Post Branching Capability

Aerial distribution cables are required to permit mid-span, post branching at arbitrary points easily, allowing subscriber drops at any point after installation.

3.1.4 Cost Efficiency

Construction of fiber-optic access networks should be economical so as to promote implementation of these networks, requiring also aerial distribution cables to be low in cost by downsizing.

3.2 Cable Design

Aerial distribution cables with new structure that meets the above mentioned requirements have been designed as described below.

3.2.1 Self-Supporting Structure with Excess Cable Length

Self-supporting structure with excess cable length relative to the suspension member was adopted so that optical fibers would not be subjected to excessive strain due to suspension member elongation caused by cable laying tension, temperature change, and wind load under aerial environments. Two tension members were provided in the cable for reinforcement.

3.2.2 Reduced Diameter Structure by Optimizing Fiber Count

Cable structures consisting of optical fiber ribbon stack and two tension members were designed, in which two types were investigated: Type 1 prevents rotation of the ribbon stack within the cable cross section, while Type 2 permits rotation. Letting n be the fiber count within the fiber ribbon and N be the number of ribbons within the cable, the cross sectional area of the ribbon stack S_1 for Type 1 and S_2 for Type 2 can be calculated as follows.

$$S_1 = W \times H$$
$$S_2 = \pi(W^2 + H^2)/4$$

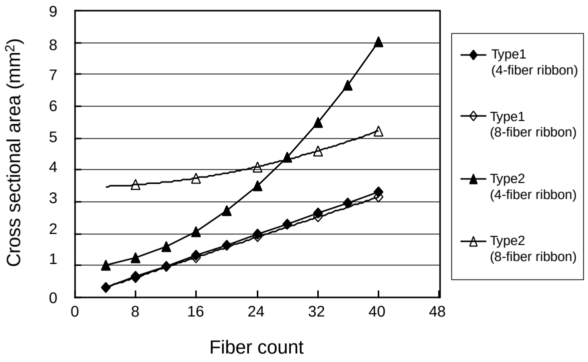


Figure 2 Cross sectional area of ribbon stack vs. fiber count

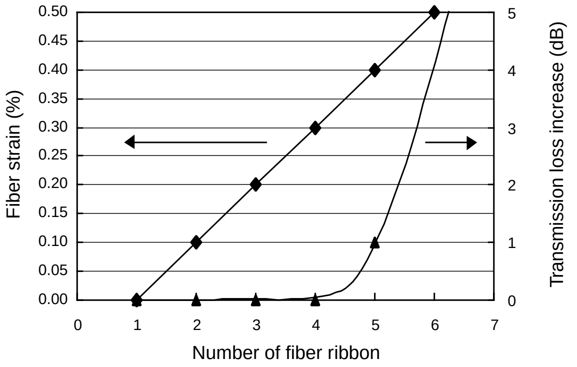


Figure 3 Fiber strain vs. the number of fiber ribbon for Type 1 cable

where, W and H are respectively,

$$W = 0.25 \times n + 0.1 \qquad \text{(in mm)}$$
$$H = 0.3 \times N \qquad \text{(in mm)}$$

Figure 2 shows the calculated results up to 40 fibers. It can be seen that, in the entire range of fiber count, Type 1 gives smaller cross sectional areas of the ribbon stack, enabling downsizing of the cable. As for Type 2, the 4-fiber ribbon can downsize the cable up to 28 fibers, while 8-fiber ribbon above 32 fibers.

3.2.3 Fiber Strain and Loss Increase under Cable Bending

In Type 1 cable, fiber strain ε at the outermost layer of the ribbon stack under cable bending can be represented by the following equation, letting R be the cable bending radius.

$$\varepsilon = (0.3 \times (N - 2)/2 + 0.15)/R \qquad \text{(in mm)}$$

Figure 3 shows the fiber strain ε with increasing number of fiber ribbon at a cable bending radius of R = 150 mm. When fiber ribbon increases in number, the fiber strain in the outermost ribbon stack increases, resulting in an increase in the force working to rotate the ribbon stack so as to relax the strain. If the force exceeds the constraining force due to the buffer layer, there arises bending in the fiber. Figure 3 also shows the results of transmission loss measurements in which a prototype cable using 4-fiber ribbon was kept in a temperature range of -30°C~70°C with a bending radius of R = 150 mm. A loss increase due to fiber bending was seen to arise with the number of fiber ribbons over five.

Thus, it was shown that Type 1 was most suitable for cable downsizing and was practicable for cables with 16 fibers or less, while Type 2 was suitable for cables with 20 fibers or more.

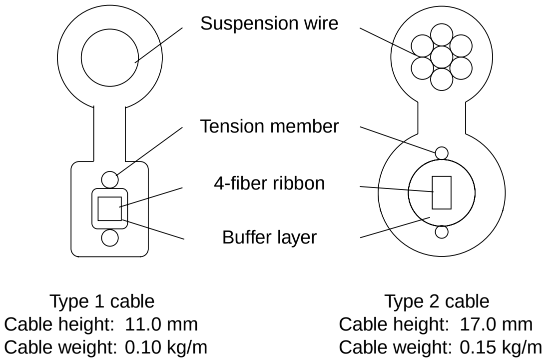


Figure 4 Cross sections of Type 1 and Type 2 cables

3.3 Cable Structure

Based on the cable design described above, two types of prototype cables were manufactured as described below. It should be noted that the both cables enable one-step manufacturing whereby the fiber ribbon and the tension member are incorporated by PE extrusion during the sheathing process.

3.3.1 Type 1 Cable

Figure 4 shows the cross section of Type 1 cable developed at this time. The 4-fiber ribbon stack is bulk sheathed together with the buffer layer and two tension members. The cable portion is intermittently connected with the suspension wire to form the cable neck, and excess cable length is provided between the two.

3.3.2 Type 2 Cable

Figure 4 also shows Type 2 cable. The structure is basically the same as that of Type 1 cable.

3.4 Cable Characteristics

The characteristics of the two prototype cables have been evaluated and the results are shown in Table 3. The results show that the cables meet the requirements for general optical fiber cables satisfactorily.

3.5 Summary of Aerial Cables without Slotted Rod

New types of aerial distribution optical fiber cables have been developed featuring compactness and lightweight. To be more precise, the cables are characterized by:

- One-step manufacturing process is permitted due to their simple structure
- Due to their compactness and lightweight, they

enable economical implementation of access networks
- Due to their dry cable structure eliminating jelly, they provide superior installation performance in terms of mid-span, post branching and so forth
- The prototype cables showed excellent mechanical characteristics, thus verifying their practicability

4. DEVELOPMENT OF HALOGEN-FREE CABLES FOR SUBSCRIBER USE

Cables for subscriber use such as for office building and housing comprise drop cables to subscribers' premises, indoor cables for indoor wiring, and termination cables for connection with optical network unit, etc. See Figure 5. While PVC was used for the sheath of these cables conventionally, the material is known to release toxic gases when combusted thereby contaminating the environment since it contains halogens. Accordingly, we have developed drop cables and indoor cables using halogen-free materials.

4.1 Requirements for Halogen-Free Cables for Subscriber Use

Common requirements for halogen-free cables for subscriber use are

(1) Flame retardance, and
(2) Halogen-freeness

Other requirements depend on the service environment.

4.1.1 Requirements for Outdoor Specification Cables (Drop Cables)

(1) Resistance against ultraviolet ray
(2) Low-temperature resistance down to -30°C
(3) Resistance against chemicals

4.1.2 Requirements for Indoor Specification Cables (Indoor Cables and Termination Cables)

(1) Have to be available in pale colors such as cream so as to harmonize with indoor environments.

4.2 Cable Design

4.2.1 Design of Aerial Drop Cables

(1) Investigation on cable sheath material

In view of the requirements for outdoor use, the cables were designed putting emphasis on the long-term reliability of the sheath material. Polyolefin was adopted as a base material and a flame-retardant agent of high flame-retardance was selected so as not to degrade the intrinsic characteristics of polyolefin by adding a large amount of the agent. Thus, a sheath material with sufficient mechanical strength and ample environment resistance was developed.

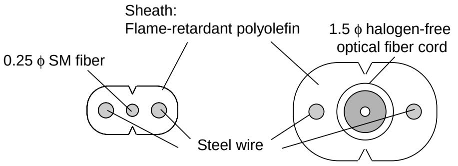
4.2.2 Design of Indoor and Termination Cables

(1) Investigation on cable sheath material

The sheath material for indoor and termination cables for indoor use was developed putting emphasis on harmonization with indoor environments such that the material would be available in pale colors such as cream. Polyolefin was adopted for the sheathing material and a pale-colored flame-retardant agent was selected to match the color of the sheath.

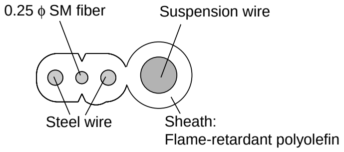
Table 3 **Optical and mechanical characteristics of prototype cables (Wavelength is 1.55 μm unless otherwise stated)**

Test item	Test conditions	Results
Transmission characteristics		
Attenuation (dB/km)	Max./Ave. at 1.31 μm	0.33/0.32
	Max./Ave. at 1.55 μm	0.22/0.20
Temp. dependence (dB/km)	-30~70°C	<0.05
Mechanical characteristics		
Tension	Fiber elongation and loss change at a suspension wire elongation of 0.2 %	<0.001 % <0.01 dB
Bending	R=160 mm x 10 repetitions	<0.01 dB
Lateral force	1960 N / 100 mm x 1 min	<0.02 dB
Squeezing	1960 N using R=250 mm gage, 4 repetitions	<0.01 dB
Twist	98 N ±360° /m x 10 repetitions	<0.01 dB
Dynamic load	1 kg x 1 m	<0.01 dB
Core pulling force	Using 10-m cable	>58.8 N
	Using 30-m cable	>98 N
Mid-span, post branching	Loss change due to core withdrawal	<0.01 dB
Fiber strain	Residual strain after cabling process, measured using BOTD	<0.01 %



Cable Size: 1.6×3.0 mm
(a) Indoor cable

Cable Size: 2.6×3.8 mm
(b) Termination cable



Cable Size: 2.0×4.5 mm
(c) Aerial drop cable

Figure 5 **Structures of halogen-free, flame-retardant cables for subscriber use**

(2) Improvement in lateral load performance of indoor cables

The flame-retardant agent used in the indoor cables had a smaller flame-retardance than that used in the outdoor cables so that the amount of addition had to be increased. This brought about a change in the material characteristics of polyolefin, whereby the Young's modulus, in particular, was decreased leading to degradation in the lateral load performance of the cable.

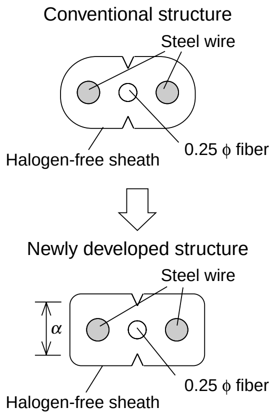


Figure 6 Cross sections of indoor cables

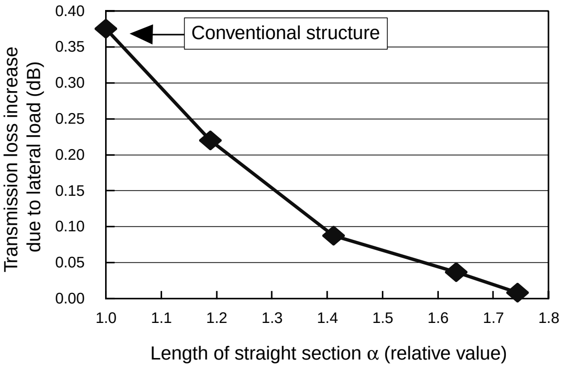


Figure 7 Improvement of lateral load performance by using a cable cross section approximating a rectangle

(a) Mechanism of indoor cables' loss increase due to lateral load

When indoor cables are trodden on by the leg of a desk or by human foot, their sheath will bend causing the fiber inside to bend. This bend will increase transmission loss. Since the halogen-free material adopted this time has a smaller Young's modulus than the conventional material of PVC, the bending rigidity of the sheath is lower than the conventional. Thus, the new cable is easily bent resulting in large loss increase when subjected to lateral load.

(b) Improvement in lateral load performance

The cross section of the cables was investigated so as to improve lateral load performance by changing the shape. In order to suppress small bending of the sheath, the cross sectional shape was changed to approximate a rectangle as illustrated in Figure 6, thus upgrading the bending rigidity of the cable.

(c) Design of cable cross section

The bending rigidity of the cable sheath can be increased by making the cable cross section approximate a rectangle, i.e., by enlarging the straight section α shown in Figure 6. Figure 7 shows the dependence of loss increase due to lateral load on α. The cable cross section was designed using an α that can sufficiently suppress a transmission loss increase due to lateral load.

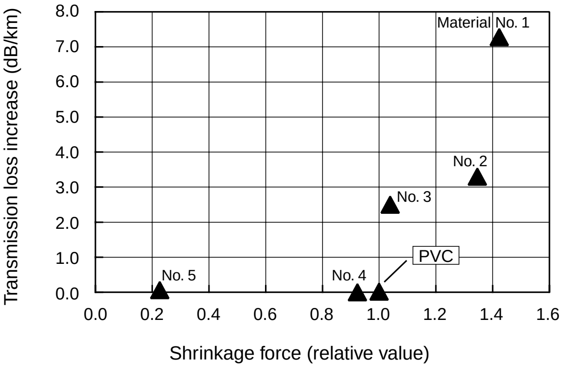


Figure 8 Relationship between shrinkage force of cord sheath material and transmission loss increase (at -10°C)

Table 4 Mechanical characteristics test results for halogen-free, flame-retardant cables (at 1.55 µm)

Test item and test conditions	Results	
	Cable	Cord
Transmission characteristics		
Attenuation(dB/km) 1.31 µm	≤0.22 dB/km	≤0.22 dB/km
1.55 µm	≤0.33 dB/km	≤0.33 dB/km
Temp. dependence(dB/km)		
-10~40°C for indoor	≤0.1 dB/km	≤0.1 dB/km
-30~70°C for outdoor		
Mechanical characteristics		
Bending R=30 mm	≤0.02 dB	≤0.02 dB
Lateral force 1200 N/25 mm for cable	≤0.02 dB	≤0.02 dB
4.9 N/mm for cord		
Twist ±180°	≤0.02 dB	—
Dynamic load 300 g x 1 m	≤0.02 dB	—
Flame-retardance JIS C 3005	Extinguished spontaneously (60° inclined)	Extinguished spontaneously (level)

(3) Investigation on termination optical cord

If the sheath of a termination optical cord shows a high shrinkage force at low temperatures, the fibers contained become serpentine thus increasing in its transmission loss. Five kinds of materials were used to manufacture termination optical cords and their transmission loss changes at a low temperature were measured as shown in Figure 8. It is seen from the Figure that the materials No. 1 to 3 that have a shrinkage force exceeding that of PVC conventionally in use give a significant increase in the transmission loss. Generally speaking, the shrinkage ratio of a material is proportional to the Young's modulus, so that the use of a material having lower Young's modulus is desirable to reduce shrinkage. However, too small a Young's modulus will degrade lateral load performance. Material No. 5 in the Figure actually gave a loss increase of 0.1 dB and more at a lateral load of 4.9 N/mm. Accordingly, material No. 4 was selected as the sheath material for the cord, in which a good balance in performance between loss increase at low temperatures and lateral load resistance is achieved.

4.3 Cable Characteristics

Table 4 shows the results of mechanical tests for the cables. Each cable achieved excellent mechanical characteristics. In addition, the cables passed the flame-retardance tests in accordance with JIS C 3005, thereby realizing a high level of flame-retardance comparable to that of PVC in earlier use.

5. CONCLUSION

The results of development of fiber-optic access cables including multi-fiber cables, small fiber-count cables, and subscriber cables were described.

As for multi-fiber cables, it was verified that improvement in installation performance was possible through downsizing, weight reduction, and friction coefficient reduction. As for small fiber-count cables, a new structure of slot-less type was proved to satisfy characteristic requirements without using slot or jelly. These cables are excellent in installation performance enabling construction of optical access networks at an economical cost. In addition, halogen-free subscriber cables were developed, in which characteristics equivalent to conventional cables were obtained and harmonization with environment was satisfactorily achieved thus realizing the development concept of environment-friendliness with increasing importance in the future.

It is believed that these achievements lead to practical application of the products for fiber-optic access networks thereby contributing to early implementation and expansion of such networks.

REFERENCES

1) Ministry of Posts and Telecommunications; White Paper on Infocommunications in Japan, 2000 (in Japanese)

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