Flexible Optical Fiber Curl Cord

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Abstract

We have developed an optical fiber curl cord that makes it easy to construct various wiring configurations for optical fiber networks in the home. It is flexible and fire retarding and has a connector at each end.

1. Introduction

Although the core network has already been converted to optical fiber, the end user side network still consists of combinations of metal, wireless, and optical fiber technologies. Of these, optical fiber is spreading rapidly among home and business users through the popularity of fiber to the home (FTTH) because of its superior speed, bandwidth, and security. This rapid spread of optical fiber networking is predicted to continue. Less-expensive and easier-to-wire networking components are now needed to support the conversion from existing metal and wireless networks to optical fiber networks and expand the available service area. Currently, only highly trained engineers can perform optical fiber installation and great care is required in handling the cable. One of the main reasons for this is that optical fiber suffers from attenuation if bent with a small radius and is difficult to connect. This article introduces an optical fiber curl cord that has been developed to overcome these difficulties and enable rapid expansion of FTTH [1].

2. Development targets

Our aim is to produce an optical fiber cord for connecting an information technology device (terminal) to a wall outlet in the home as shown in **Fig. 1**. For this purpose, there are several requirements. The fiber cord must be robust at temperatures between –10 and 60°C and humidity of up to 90%. It should have a 20-year lifetime, and its optical and mechanical properties must be as good as those of existing optical fiber cord. It should withstand being accidentally trodden on or tripped over, have good fire retardant characteristics, not cause any attenuation change when moved a short distance, and be easy to connect. Our optical fiber curl cord, shown in **Fig. 2**, meets all these requirements.

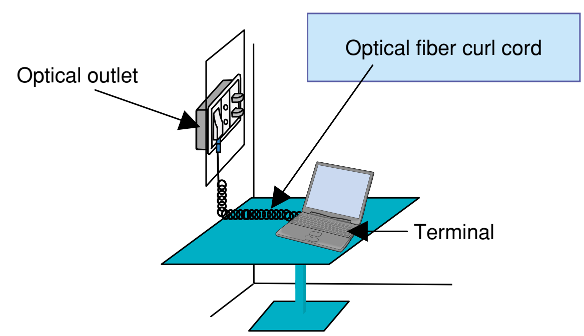

Fig. 1. Example of the use of an optical fiber curl cord.

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2.1 Cord core

We specified a minimum bending radius of 30 mm because the optical loss would be too large if the cable core of the present optical fiber cord were bent with a small radius. Recently, however, optical fibers that have excellent bending characteristics have been proposed. These are holey fiber (photonic crystal

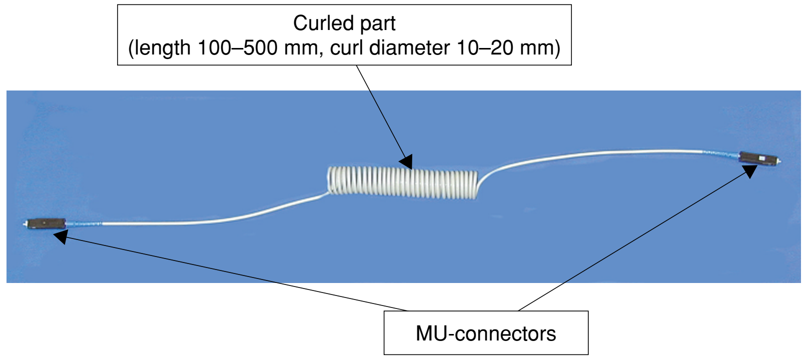

Fig. 2. Optical fiber curl cord.

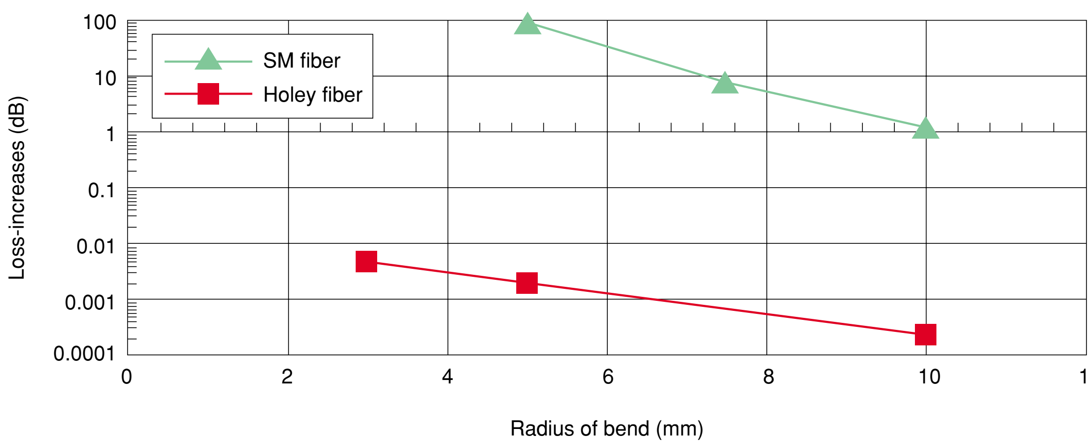

Fig. 3. Bending characteristics of holey fiber.

Table 1. Comparison of fibers with low bending loss.

Type	Loss	Connection	Cost
Holey fiber (PCF)	Excellent	Poor	Poor
Holey fiber (HAF)	Excellent	Good	Good
Fiber with high refractive index core	Good	Fair	Good

fiber (PCF) and hole-assisted fiber (HAF)) and fiber with a high refractive index core. The features of these fibers are compared in **Table 1**. They all have good loss characteristics. We chose to use HAF for our work because of its excellent compatibility with existing fiber and its low cost. Although the attenuation is slightly greater than that of widely used optical fibers, this is not a serious problem if the fiber is limited to home use. Its bending loss is superior to that of existing single-mode (SM) optical fiber, as shown in **Fig. 3**.

2.2 Tensile strength

To increase the cord's resistance to mechanical stress, we attached a longitudinal high-tensile-strength body fiber made of aramid fiber, which exhibits excellent resistance to mechanical stress and temperature.

2.3 Covering

In a conventional optical fiber cord, general-purpose plastics such as polyvinyl chloride (PVC) and polyethylene are used as covering materials. However, considering environmental issues, we decided to use materials free of halogens and organic phosphorus. The goals were to ensure that the fiber cord is protected against deterioration of its mechanical properties by trampling and to make certain that it is fire retardant. After examining various plastics, we chose thermoplastic elastomer for the covering.

2.4 Shape

With existing optical fiber, bending must be controlled because it affects both attenuation and long-term reliability. However, holey fiber features an extremely small radius bending loss, so we can ignore attenuation caused by bending in home-use installa-

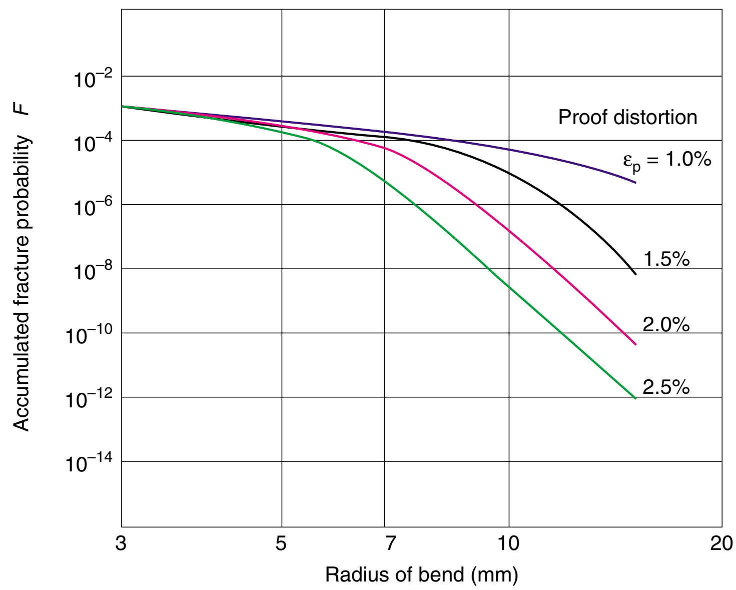

Fig. 4. Fracture probability of optical fiber (with 250 turns after 20 years).

tion. Therefore, we only need to be concerned with long-term reliability. **Figure 4** shows the calculated reliability of optical fiber [2]. This shows that fiber with a bending radius of 10 mm has a fracture probability of 10^{-4} or less over twenty years of use, which is our design target. Considering the intended usage we selected a cord diameter of 2.0 mm (**Fig. 5**), a curl diameter of 10 to 20 mm, and a curled part length of 100 to 500 mm (see Fig. 2).

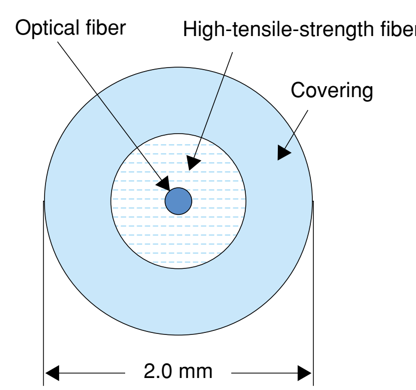

Fig. 5. Cross-section of optical fiber curl cord.

3. Actual characteristics

The properties of the manufactured optical fiber curl cord are given in **Table 2**.

3.1 Optical properties

The manufactured optical fiber curl cord has an MU connector at each end. Its total attenuation is 0.73 dB on average, which satisfies the attenuation loss requirement for the connector. There is no increase in loss in the curled part.

3.2 Characteristics when used with Ethernet

We tested the compatibility of the optical fiber curl cord with Ethernet by connecting it to a gigabit Ethernet circuit tester. No bit errors occurred during the 24-hour test. Moreover, there were no errors when the cord was pulled or moved a short distance.

3.3 Thermal properties

The optical fiber curl cord was subjected to a temperature cycle test in the range from –20 to +60°C. The results show that the loss variation was less than 0.1 dB and very stable.

3.4 Fire retardation

The optical fiber curl cord met the requirements of the thermal burning test at an inclination of 60° (JIS C3005). The covering consisted of non-halogen materials to make the cord environmentally friendly and it was made fire retardant by using a non-organic phosphorus compound as an additive.

3.5 Elasticity

The relationship between pulling force and stretching length is shown in **Fig. 6**. In Region A, little force was required to stretch the cord and when the force

Table 2. Properties of optical fiber curl cord.

Property	Test conditions	Value
Insertion loss	With MU-connector at each end	≤1 dB
Circuit	Ethernet bit errors	No errors
Temperature	–20 to +60°C cycle	Loss variation ≤0.1 dB
Combustion	JIS C3005 60° inclination combustion	Self reduction
Elasticity	1000% pull (Region A)	Loss variation ≤0.1 dB Stress ≤200 g
Instantaneous pulling	Pulled 1000% in 0.5 s	Loss variation ≤0.1 dB
Pressure	100 kg applied radially	No breakage Loss variation ≤0.1 dB
Curl retention	200% extension and release: one cycle per second for 24 hours	≥90% of curl remained immediately after test
Rupture	Pulled until failure	≥30 kg

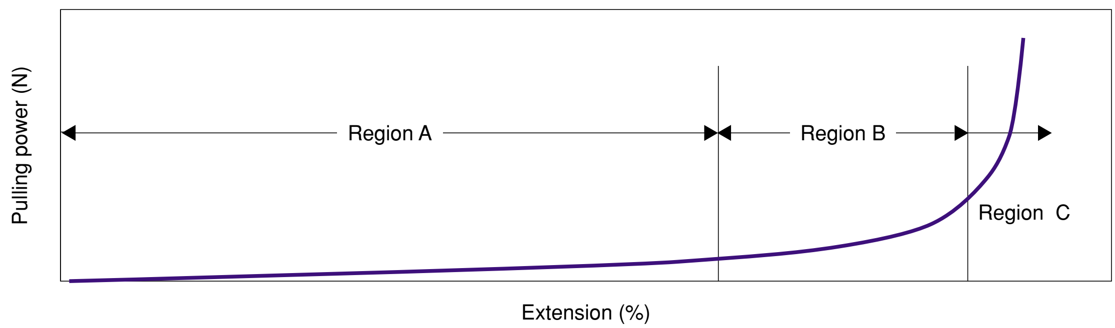

Fig. 6. Stretching characteristics of curl cord.

was released, restoration was instantaneous and spring-like. When pulled with greater force, the cord became almost straight. However, in Regions B and C, after being pulled with great force, the cord did not regain its shape instantaneously. Within Regions A and B, the loss variation was very small: less than 0.1 dB. When stretched to Region C, the attenuation increased just prior to failure. For example, if we wish to manufacture a curl cord that is 3 m long and 2 mm in diameter with a curl diameter of 15 mm, the curled section will be around 13 cm long. For this optical fiber curl cord, Region A will be up to about 200 cm (around 1500% of the curled part) and Region B will be around 200–250 cm (1900% of the curled part).

3.6 Robustness

We assumed that a curl cord may get accidentally caught and tugged during normal use. We measured the attenuation and stress caused by instantaneous (about 0.5 s) pulling to a distance of about 1 m and release. The measurement revealed no change in attenuation, and the stress was small (under 2 N), as shown in **Fig. 7**. This means that even if a cord is accidentally caught and tugged, it will not break, the connectors will not be disconnected, and the information terminal will not be moved.

3.7 Pressure resistance

We assumed that a curl cord may get accidentally stepped on when it is on the floor. We tested the cords under such conditions and found that they could withstand a pressure of 100 kg.

3.8 Curl retention

The cord will undergo many cycles of expansion and contraction in daily use. We looked for any loosening of the cord that might occur under such conditions by pulling and releasing it. The test we used measured the slackness resulting after we had stretched the cord to 200% by pulling and releasing it once per second continuously over a 24-hour period. The cord exhibited a shape recovery rate of over 90% immediately after testing, and the rate increased to 100% after a rest period.

3.9 Rupture properties

The curl cord was not broken even when it was

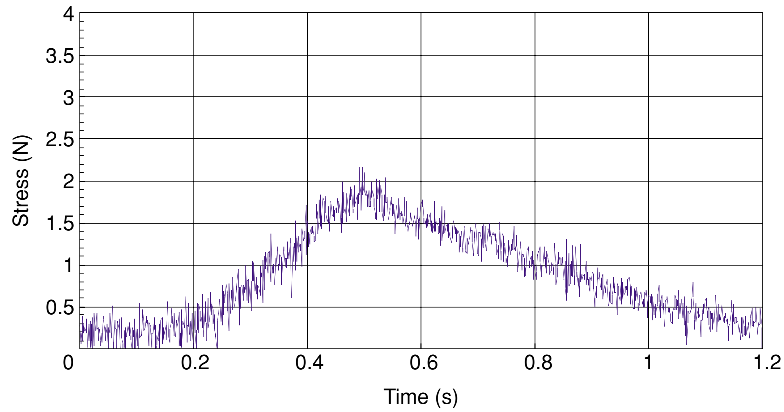

Fig. 7. Instantaneous pulling.

pulled from one end (with the other end fixed) until it became straight. The force required to break the cord was greater than 30 kg, which is almost the same as that for a non-curled optical fiber cord.

4. Future plans

The development of the optical fiber curl cord is now complete. We are proceeding with commercialization to make this cord available as a home network wiring component. We plan to continue our studies and develop additional novel optical fiber components.

References

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[2] Y. Mitsunaga, Y. Katsuyama, H. Kobayashi, and Y. Ishida, "Strength Assurance of Optical Fiber Based on Screening Test," IEICE, Vol. J-66-B, No. 7, 1983 (in Japanese).

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