Single Mode Fibers with both Bending Loss Insensitivity and High Strength Intensity and their Applications to Indoor-Outdoor Cables for FTTH

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Abstract

This paper describes designs of the single mode fibers with both bending loss insensitivity and high strength intensity. Single mode fibers with an inner cladding of depressed index have been designed to have both low macro-bending loss and high strength intensity. This type of fibers has been fabricated. The measurement results show that the bending induced attenuation at 1625nm for one turn around a mandrel of 15 mm diameter is less than 0.5dB/km. The typical dynamic stress corrosion susceptibility parameter n_d is 27.1. As applications of the new fibers, we have developed a series of overhead strippable drop cables with a "loose" or "semi-tight" structure for indoor-outdoor uses and distribution cables with micro-module structure for outdoor use in ducts, indoor use over a short distance and aerial use, which have been used in a series of FTTH projects in China successfully.

Keywords: Single mode fibers; bending loss; strength; dynamic stress corrosion susceptibility parameter; FTTH; distribution cables; Weibull distribution

1. Introduction

In recent years, the demand for the high speed broadband informational communication has increased rapidly. In order to satisfy this demand, FTTH systems are valuable means for the construction of advanced information networks. Due to the dense distribution and drop cable network, the limited space and the many manipulations in this part of the network, fiber and cable requirements may be optimized differently from the use in a general transport network. In order to support this optimization, the bending loss insensitive fibers have been developed to make installation and maintenance easier. The bending loss insensitive fibers, so-called G.657 fibers, have been investigated intensively. However, up to now, only a few people have paid attention to the single mode fibers with both bending loss insensitivity and high strength intensity. In fact, the high strength intensity fibers have a longer lifetime and allow a longer storage length per cassette for a bent fiber or much lower minimum radius for a single 180°bend deployment. This paper describes designs of the single mode fibers with both bending loss insensitivity and high strength intensity. Single mode fibers with an inner cladding of depressed index will be designed to have a low bending loss. We will also enhance the fiber strength intensity by optimizing both preform and draw technologies. The fibers with both bending loss insensitivity and high strength intensity will be fabricated. As applications of the new fibers, a series of overhead strippable drop cables with a "loose" or "semi-tight" structure for indoor-outdoor uses and distribution cables with micro-module structure for outdoor use in ducts, indoor use over a short distance and aerial use will be suggested. Finally, we will introduce their applications in a series of FTTH projects in China.

2. Bending Insensitive Fiber Design

2.1 Reducing Bending Loss in General

For a standard single mode fiber, the bending performance can be characterized by the relationship between the mode field diameter (MFD) and cut-off wavelength λ_c. This well known dimensionless parameter, known as MAC value, is given by:

$$MAC = MFD/\lambda_c \quad (1)$$

The MAC value will decrease by increasing cut-off wavelength and/or decreasing mode field diameter. Small MAC values result in a low bending loss. Figure 1 shows the measured bending loss at 1625nm for one turn around a mandrel of 50 mm diameter with relation of MAC values at 1550nm [1]:

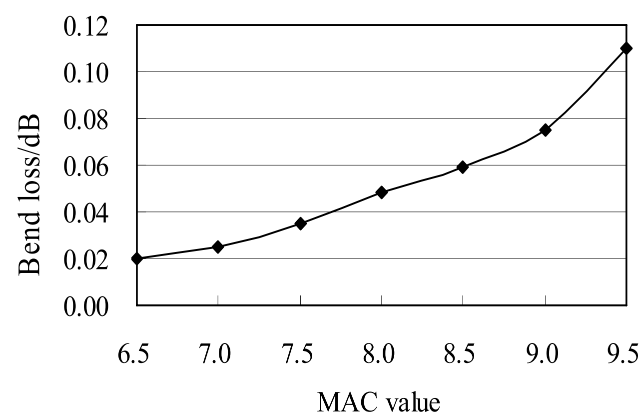

Figure 1. Bending loss with relation of MAC values

2.2 Fibers with an Inner Cladding of Depressed Index

We can decrease the bending loss by decreasing MFD or increasing cut-off wavelength according to figure 1. However, there are not much rooms to decrease MFD and increase cut-off wavelength if the fibers are to be kept compatible with ITU-T G. 652 standard. In order to keep a single mode operation, the maximum allowed cable cut-off wavelength is 1260nm. A too small MFD is hardly acceptable for applications in telecom networks due to the mismatch with the installed single mode fibers because it will cause higher splice and coupling losses. This is the reason why other types of structures have been proposed over the past few years. Single mode fibers with an inner cladding of depressed index have been often proposed [2, 3]. The intermediate cladding with its depressed index enhances the radial evanescence of the cladding fields of the fundamental mode so that they extend less into the outer cladding. Thus absorption and scattering in the outer cladding causes less fundamental mode loss, even when the inner cladding consists only of a few layers. At the same time this depressed index layer by confining the fundamental mode fields with their strong radial evanescence makes the fiber relatively insensitive with respect to bending. All these aims are achieved with a fairly large mode field diameter that eases splicing and launching of power into its fundamental mode.

3. Fibers with High Strength Intensity

When deploying a fiber in storage cassettes or in case of incidental bends, stress is applied to the outer of the fiber causing strain in the quartz material. Reducing the current minimum bend radius from 30mm to 15mm or even lower, might raise some concern on the lifetime of the fiber.

The lifetime of fibers can be estimated by [4]:

$$\frac{\sigma_r}{\sigma_p} = \left[\left\{ \left(1 - \frac{\ln(1-F_r)}{L_0 M_P} \right)^{\frac{n+1}{m}} - 1 \right\} \bullet \frac{t_p}{t_r} \right]^{\frac{1}{n}} \tag{2}$$

Where σ_p stands for the fiber strain during the producing process, and it is usually 1%; σ_r is the fiber strain during the working process. F_r is the probability for the fiber breaking; L_o is the total length of the fiber cable; M_p stands for the breaking times per kilometers during the producing process; n is fiber corrosion susceptibility parameter; m is the Weibull Probability for the optical fiber;. t_p is the continuous working time during rewind process; t_r; is the estimated lifetime for the fiber.

Applying the above life time formula, on current fibers with standard setting of the proof stress and normal proof-test performance, the resulting minimum bending radius for a 20 years lifetime as a function of the storage fiber length is indicated in figure 2 for different values of the static stress corrosion susceptibility coefficient or fatigue parameter n [5]:

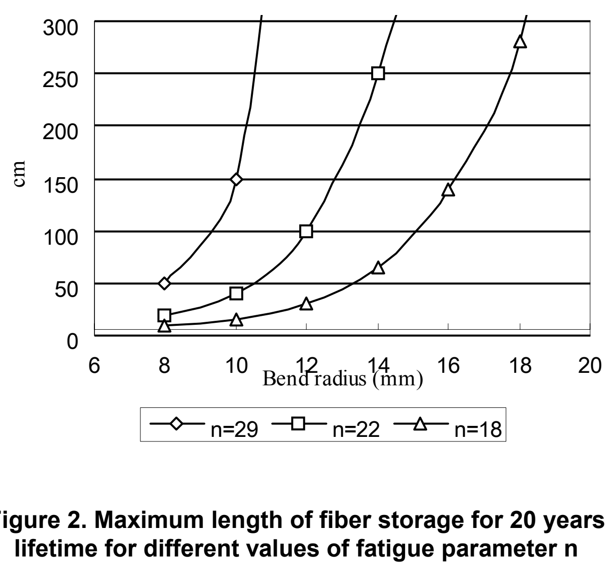

Figure 2. Maximum length of fiber storage for 20 years lifetime for different values of fatigue parameter n

In the calculation, the maximum failure rate per individual splice storage tray is 0.001%. For a storage length per cassette of 100cm, the bending radius can be lowered from the current 30mm value down to 15 or even 9mm dependent upon the guaranteed n value without violating the 0.001% failure rate per cassette in 20 years. Figure 2 shows clearly that for the fiber with a higher n value, a much lower bend radius is allowed without any reduction of lifetime. The fiber with high strength intensity has a higher n value, so it is reasonable to increase the strength intensity of the fiber. The high strength intensity fibers have a longer lifetime and allow a longer storage length per cassette for a bent fiber or much lower minimum radius for a single 180°bend deployment.

4. Properties of the Fibers

With MCVD method such fibers have been fabricated at reduce cost by depositing first a Fluorine doped layer of depressed index inside the substrate tube and then adding only a few SiO_2 layers for the inner cladding, before finally the Germanium doped core of raised index is deposited. The refractive index profile of the fiber with a depressed inner cladding is shown in figure 3.

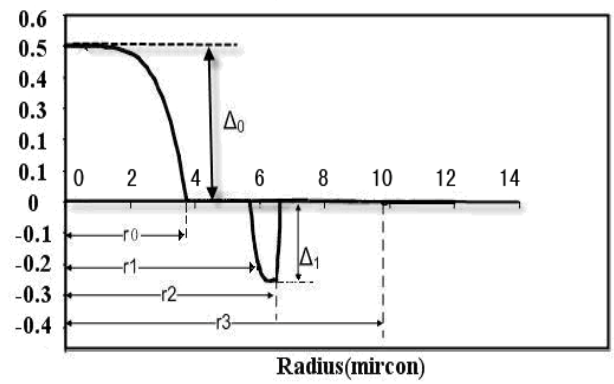

Figure 3. The index profile of fiber with a depressed inner cladding

Figure 4 shows the measured bending loss at a bend radius 7.5mm as a function of the wavelength for the standard single mode fibers and fabricated bending loss insensitivity fibers. The measurement results show that the bending loss at 1625nm for one turn around a mandrel of 15 mm diameter is less than 0.5dB for the bending loss insensitivity fibers. On the other hand, the bending loss at 1625nm for one turn around a mandrel of 15 mm diameter is 9dB for the standard single mode fibers.

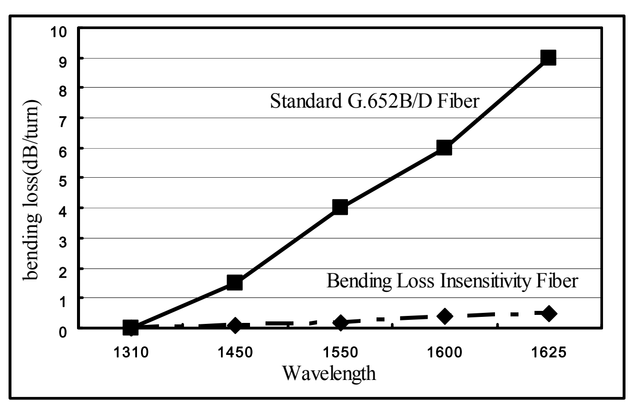

Figure 4. Measured bending loss at a bend radius 7.5mm for the standard and bending insensitivity SM fibers

By optimizing both preform and draw technologies, the fiber strength intensity has been enhanced significantly. Through research and practice, we have already found an integrated high strength fiber producing process. First, we take a series of steps to control the quality of preform. Because the uniformity of preform will impact the fiber strength very largely, and usually the surface of preform can be damaged very easily on the way of transportation and the other treatments. We use hydrogen oxygen fire to polish the surface of fiber, in this way, the tiny crack and other flaw will be repaired very well and then it's beneficial for fiber mechanical character and also strength. On the other hand, we improve the fiber strength through the coating. Optical fibers are coated with a low-modulus primary buffer coating and a thermoplastic secondary coating. To obtain suitable viscosities and mechanical strength, we choose the reasonable parameter of coating material. Finally, the fiber strength intensity has been further enhanced .by optimizing the draw technologies. The entire length of fibers has passed a proof-test of 2% strain.

An experiment was performed to examine the strength and dynamic fatigue performance of fibers. Dynamic fatigue testing was performed on 10 meter samples using 2.5% strain rate/minute. Figure 5 shows the distribution of Weibull probability of the fabricated fibers.

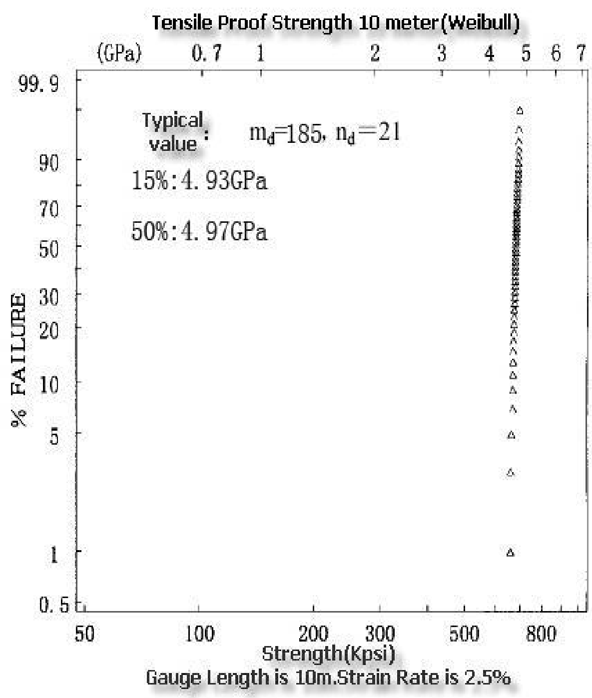

Figure 5. Distribution of Weibull probability

The dynamic stress corrosion susceptibility parameter or dynamic fatigue parameter n_d is 27.1. This indicates that the maximum storage length for a bend radius of 10mm for 20 years lifetime can reach 130cm, which is three times longer than that of the conventional bending loss insensitive fibers with a n_d value of 22.

5. Indoor-Outdoor Cables for FTTH

As applications of the new fibers, we have developed a series of overhead strippable drop cables with a "loose" or "semi-tight" structure for indoor-outdoor uses and distribution cables with micro-module structure for outdoor use in ducts, indoor use over a short distance and aerial use, which have been used in a series of FTTH projects in China successfully.

Figure 6 shows a drop cable GJPFJH with a loose or semi-tight structure for indoor–outdoor uses.

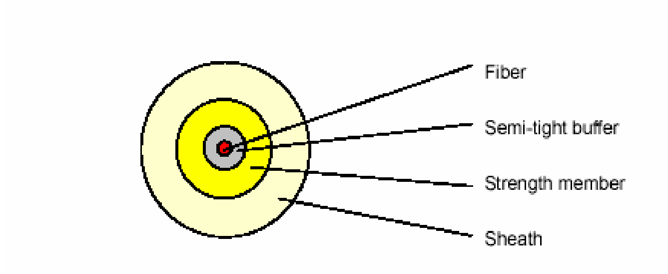

Figure 6. Structure of a drop cable GJPFJH

Figure 7 shows a distribution cables with micro-module structure. This type of cable is suitable for outdoor use in ducts, overhead use and indoor use over a short distance.

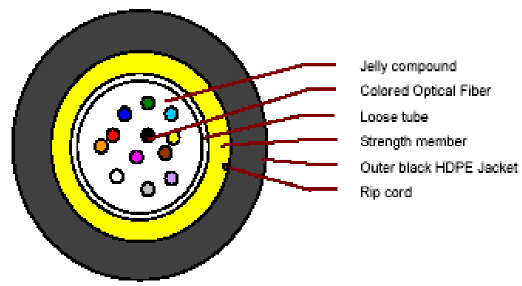

Figure 7. Structure of a distribution cable GYXTKY

A figure 8 cable with 12 fibers is shown in figure 8. This is a distribution cable for aerial use.

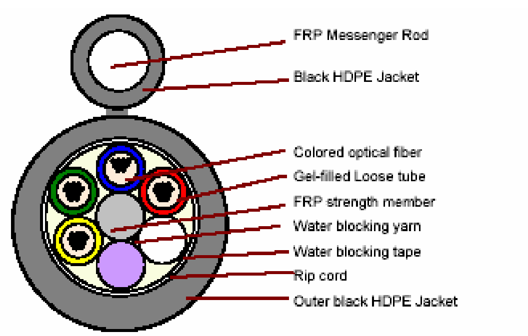

Figure 8. Structure of a figure 8 distribution cable

6. Conclusions

Single mode fibers with an inner cladding of depressed index have been designed to have both low bending loss and high strength intensity. The intermediate cladding with its depressed index enhances the radial evanescence of the cladding fields of the fundamental mode so that they extend less into the outer cladding. At the same time this depressed index layer by confining the fundamental mode fields with their strong radial evanescence makes the fiber relatively insensitive with respect to bending. We have also enhanced the fiber strength intensity by optimizing both preform and draw technologies. The fibers with both bending loss insensitivity and high strength intensity have been fabricated using MCVD technology. The entire lengths of the produced fibers have passed a proof-test of 2% strain. The measurement results show that the bending induced attenuation at 1625nm for one turn around a mandrel of 15 mm diameter is less than 0.5dB. By optimizing both preform and draw technologies the fiber strength intensity has been enhanced significantly. An experiment was performed to examine the strength and dynamic fatigue performance of fibers. The typical dynamic stress corrosion susceptibility parameter or dynamic fatigue parameter n_d is 27.1. This indicates that the maximum storage length for a bend radius of 10mm for 20 years lifetime can reach 130cm, which is three times longer than that of the conventional bending loss insensitive fibers with a n_d value of 22. As applications of the new fibers, we have developed a series of overhead strippable drop cables with a "loose" or "semi-tight" structure for indoor-outdoor uses and distribution cables with micro-module structure for outdoor use in ducts, indoor use over a short distance and aerial use, which have been used in a series of FTTH projects in China successfully.

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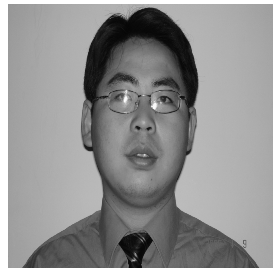

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