Macro- and Micro-Bending Performances of Uncoupled 200 μm-Coated Multi-Core Fibers

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Abstract: We investigate bending performances of 200μm-coated multi-core fibers and show the bending losses were equivalent to those of single-core fibers and the crosstalk induced by wire-mesh micro-bending was as low as -52dB@100 km in counter-propagation.

1. Introduction

Spatial division multiplexing (SDM) is now the most promising way to increase the capacity and improve the power efficiency of submarine cables. To increase the number of fibers packed in a cable, 24 fiber pair (FP) submarine cable was developed [1]. To realize the cables with further higher fiber count, 200 μm-diameter-coated fibers were developed [2,3]. The cross-sectional area of the 200 μm diameter fiber is 1/1.5 times that of conventional 250 μm diameter fibers, therefore, the maximum number of FP can be scaled by a factor of 1.5 under the constant cable size. It was also reported that the submarine cables with 200 μm diameter fibers performed excellently [4,5]. Recently, uncoupled 2-core fibers (2CFs) with 250 μm diameter have been developed [6]. Therefore, it should be natural that 200 μm diameter multi-core fibers (MCFs) should come as the next generation SDM.

In this paper, we investigated the bending performances of 200 μm 2CFs and 4-core fibers (4CFs) since 200 μm diameter fiber is anticipated to experience severer micro-bending and macro-bending in cables. The micro-bending losses of 200 μm 2CFs and 4CFs were confirmed to be equivalent to those of 200 μm single-core fibers (SCFs) with the same effective areas, and their macro-bending losses were also equivalent to those of 200 μm SCFs. We also investigated the micro-bending induced inter-core crosstalk (XT) of 2CFs with 200 μm and 250 μm diameter and the measured XT were around -50 dB/km, which corresponds to an estimated XT of -52 dB at 100 km in counter-propagation. These results show the 200 μm diameter 2CFs and 4CFs are promising for advanced SDM submarine cables in the near future.

2. Bending loss characteristics of 200 μm MCFs

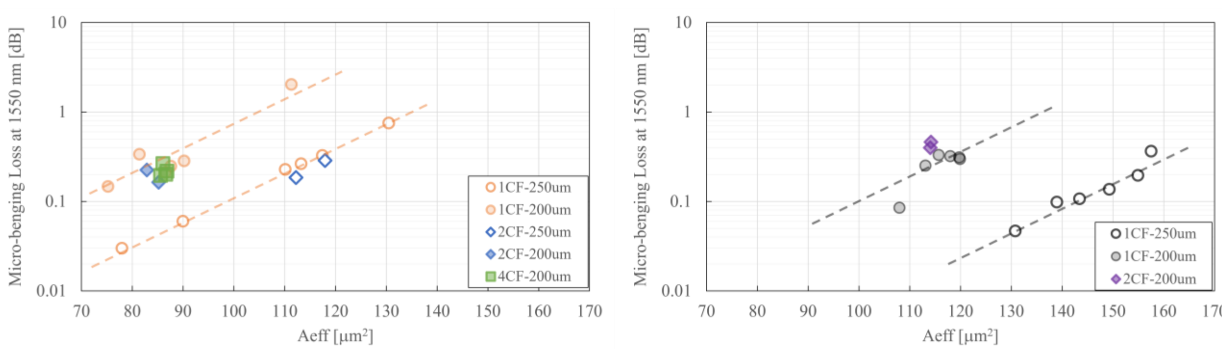
We fabricated 2CF and 4CF with 200 μm outer diameter. In addition, we also fabricated 250 μm 2CF for comparison. Table 1 summarizes the characteristics of the MCFs. Two types of 2CF were fabricated, one was 2CF with the effective area (Aeff) of 85 μm^2 and the other was 2CF with Aeff of 112 μm^2. A heterogeneous-core configuration was applied for the 2CF. A heterogeneous core MCF that applies a slight difference between the refractive indexes of the cores is anticipated to be effective for preventing XT degradation in the actual submarine cable production because it causes the XT to decrease as the bending radius increases [7,8]. The Aeff of the 4CF was designed as 85 μm^2 in order to suppress the XT while keeping a cladding diameter of 125 μm. The cores of 4CF were arranged in a square lattice and designed with a hybrid configuration, where the neighboring cores were heterogeneous cores and the diagonal cores were homogeneous cores, assuming that the optical signals propagate in the same direction between the diagonal cores, on the other hand, the optical signals propagate in the opposite direction between the neighboring cores. The optical characteristics of the MCFs are summarized in Table 1. The optical characteristics of 2CF and 4CF with Aeff of 85 μm^2 were compliant with the ITU-T G.654.C recommendation and those of 2CF with Aeff of 112 μm^2 were compliant with the ITU-T G.654.B recommendation. The macro-bending losses of 200 μm MCFs were negligibly small.

Reducing a coating thickness may cause additional fiber loss in cabling due to high micro-bending sensitivity. Then we measured the micro-bending losses of the MCFs with a wire mesh drum method [9]. Figure 1(a) shows the micro-bending losses of SCFs and MCFs with our conventional coatings with 250 μm and 200 μm diameters as a function of Aeff. The micro-bending losses of MCFs with 200 μm coatings and 85 μm^2 Aeffs were measured to be around 0.2-0.3 dB/km, which agree well with the Aeff-dependence of the micro-bending loss for the SCFs. However, that Aeff-dependence of the micro-bending loss implies the micro-bending losses of the 200 μm coating and 112 μm^2 Aeff would be as high as around 2 dB/km. In order to improve the micro-bending losses at larger Aeffs, we adopted the improved coating with a primary layer with reduced elastic modulus [10]. Figure 1(b) shows the micro-bending losses of SCFs and MCFs with the improved coating as a function of Aeff The micro-bending losses of the 2CF with 112 μm^2 Aeff were as low as 0.5 dB/km, which also agree with those of SCFs with similar Aeff.

Table 1. The characteristics of fabricated MCFs
(measured at 1550 nm wavelength unless specified otherwise)

	2CF-85μm^2		2CF-112μm^2		2CF-112μm^2		4CF-85μm^2			
Outer diameter [μm]	200		200		250		200			
	Core1	Core2	Core1	Core2	Core1	Core2	Core1	Core2	Core3	Core4
Mode field diameter [μm]	10.2	10.1	11.4	11.7	11.6	11.6	10.0	10.0	10.0	10.0
Aeff [μm^2]	85	83	114	114	118	112	86	87	87	86
λcc [nm]	1390	1296	1451	1418	1407	1326	1413	1467	1418	1466
Loss [dB/km]	0.171	0.172	0.157	0.157	0.157	0.154	0.167	0.168	0.166	0.167
Chromatic dispersion [ps/nm/km]	19	18	21	21	21	21	20	20	20	20
Dispersion slope [ps/nm^2/km]	0.054	0.053	0.058	0.056	0.058	0.056	0.055	0.056	0.056	0.056
Macro-bend loss*1 [dB]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polarization mode dispersion*2 [ps/rkm]	0.07	0.04	0.02	0.03	0.01	0.06	0.14	0.16	0.18	0.18
XT*3 [dB/km]	-42		-50		-43		-48 (Between neighboring cores)		-77 (Between diagonal cores)	

*1 Bending radius: 30 mm, wavelength: 1625 nm, 100 turns
*2 Bending radius: 140 mm, free of tension
*3 Spooled on a bobbin with an inner diameter of 168 mm



(a) (b)

Fig.1 The results of the wire mesh drum test on micro-bending losses of the SCFs and MCFs with (a) the conventional coating, and (b) the improved coating, shown as a function of Aeff.

3. Micro-bend induced XT in 2CF

Understanding the behavior of XT before and after cabling is important for applying MCFs to the cables because high XT causes additional noise and degrades the system SNR. There are some reports of the XTs in 4CFs after the cabling [11,12]. In ref. [11], the 288 fibers including partially bonded 4CF ribbons were cabled and the XT increased around 3 dB after cabling. In ref. [12], a jelly-filled loose-tube cable with an outer diameter of 6 mm was fabricated and the XT increased around 5 dB after cabling. Theoretical investigation of XT induced by micro-bending was also reported [13]. It was expected that the XT of MCFs with heterogeneous core configuration would increase due to the micro-bending while that with homogeneous core configuration would not increase. The 4CFs in ref. [11,12] were homogeneous core configurations.

Here we investigated the impact of the micro-bending on the XT as a basic study. The 200 μm and 250 μm 2CFs with Aeff of 112 μm^2 in Table 1 were wound on a wire mesh drum with a diameter of 405 mm, then the XTs were measured. The measured results are summarized in Table 2. Since the XT would vary depending on the bending diameter, the XT without the micro-bending was measured by winding the 2CFs on a smooth-surface drum with the same diameter as the wire mesh drum. The micro-bending-induced XTs, defined as the difference in the dB-scale XTs between with and without micro-bending, were around 15 dB for both 200 μm and 250 μm 2CFs. However, the XTs under micro-bending were around -50 dB/km in co-propagation configuration, which corresponds to the XT in a counter-propagation configuration as low as -52 dB at 100 km, according to the theory in ref. [14]. The degradation of the XTs in the MCFs with heterogeneous-core configuration was agreed with the expectation from the known measurement and theory [13]. Considering the wire mesh method caused a loss increase of as large as 0.5 dB/km on the 2CF with Aeff of 112 μm^2, which would be significantly higher than the loss increases in actual cables, the wire mesh drum method would be fairly severe test conditions compared with the actually induced micro-bending in a cable. The XTs of the submarine-cabled MCFs would be lower than the present XTs measured on the wire mesh drum and need to be confirmed.

Table 2. Comparison of XTs of the 2CF without and with micro-bending by wire mesh drum.

	XT without micro-bending* at 1550 nm [dB/km]	XT with micro-bending at 1550 nm [dB/km]	ΔXT at 1550 nm [dB]
2CF-112μm^2 with 250 μm diameter	-64	-48	16
2CF-112μm^2 with 200 μm diameter	-63	-49	14

* Spooled on a bobbin with a diameter of 405 mm.

4. Conclusions

We investigated bending performances of 200 μm 2CFs and 4CFs. The macro- and micro-bending losses of 200 μm MCFs were confirmed to be equivalent to those of 200 μm single-core fibers. The micro-bend induced XTs of the 2CFs were also investigated and found that the XTs were increased by 15 dB for both 200 μm and 250 μm fibers, however, the XTs were still low, around -52 dB at 100 km in counter propagation. These results show the 200 μm diameter 2CFs and 4CFs are promising for the next-generation SDM submarine cables.

5. References

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