Standard Coating Diameter Uncoupled 19-Core Multicore Fiber with Highest Core Density for Optical Wiring

Yusuke Matsuno, Ryuichi Sugizaki, and Masanori Takahashi
Furukawa Electric Co., Ltd., 6 Yawata-kaigandori, Ichihara, Chiba, Japan
yusuke.matsuno@furukawaelectric.com

Abstract: 19-core MCF with standard coating diameter was fabricated. Highest core density was achieved compared with that of reported uncoupled MCFs using homogeneous cores. r=7.5mm bending can be applied to the MCF with certain mechanical reliability.

1. Introduction

Transmission demand is expanding at an annual rate of about 40% while transmission capacity of single-mode fiber (SMF) is limited to 100 Tbit/s. Therefore, it was suggested that the transmission demand reaches the limit of transmission capacity of SMF in the 2030s. To overcome the limit, Space Division Multiplexing (SDM) technology has been developing as one of the most promising solutions to exceed the limit [1]. To use SDM technologies for practical applications, one of the important issues is the optical switches. Currently, Wavelength Selective Switches (WSSs) are used in optical networks. If the SDM technology is applied to optical networks, significantly large number of WSSs required. Increasing the number of WSSs will cause some problems in terms of cost and space, thus there is a demand to develop high-capacity and economical optical switches. As a solution to this problem, a Core Selective Switch (CSS) has been proposed [2]. As Multicore Fibers (MCFs) have a higher core density comparing to SMF, MCFs are effective for high density optical wiring inside of the switches. To apply MCFs for optical wiring inside of the CSS, uncoupled MCF is desired rather than coupled MCF to avoid complex signal processing such as MIMO/DSP [3]. Uncoupled MCFs need to maintain core pitch to avoid core-to-core crosstalk (XT). Therefore, an increase in the number of cores leads to an increase in cladding diameter. If the cladding diameter becomes large, minimum bending radius becomes large in terms of mechanical reliability. Therefore, MCF with large cladding diameter is inappropriate for optical wiring under small bending used inside of optical devices. Considering above points, MCF with high core density and small cladding diameter is desired. In addition, regarding productivity of fiber modules using MCFs, it is important to fabricate MCFs with the same coating diameter as standard SMF. The reason is that it is possible to use design and parts equivalent to the widespread standard SMF. Therefore, MCFs with high core density and standard coating diameter 250 μm has a great advantage.

In this paper, we report the design and the characteristics of 19-core MCF (19c-MCF) with standard coating diameter. It has been confirmed that the fiber satisfies the requirements of macro-bending loss and mechanical reliability.

2. Design of 19-core MCF

Design of the MCF with high core density for optical wiring was optimized. Fig. 1 shows the design of 19c-MCF. In this design, uncoupled MCF which doesn't require complex signal processing was used. To achieve high core density, hexagonal close-packed structure which has the theoretically highest core density and applicability for low-loss fiber bundle type FIFOs [4] was applied. Fiber bundle type FIFOs consists of bundles of thin cladding fibers with cladding diameter equal to the core pitch of the MCF. Therefore, if the core pitch becomes smaller, the cladding diameter of the thin cladding fiber also becomes smaller. Difficulty of the fabrication process of the FIFO is increased if the cladding diameter of the thin cladding fiber becomes small. Lower limit of the cladding diameter of the bundle fiber is 30 μm at this moment, therefore, core pitch of MCF and FIFO was set at 30 μm. Minimum cladding diameter of the MCF is determined by the core geometry and minimum cladding thickness. If the cladding thickness becomes thin, minimum cladding diameter becomes small. However, thin cladding causes increase of excess loss. In this design, the minimum cladding thickness was set to 30 μm in order to keep the excess loss below 1.0×10^{-3} dB/km, resulting in a minimum cladding diameter of 180 μm. Coating diameter of

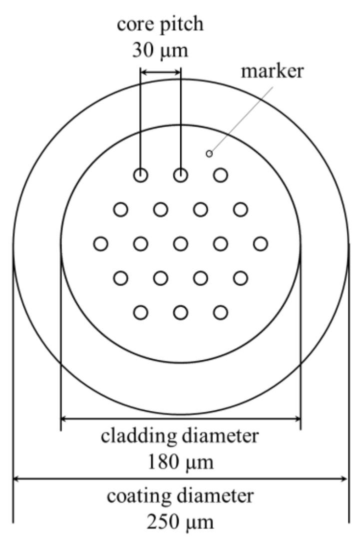

Fig. 1 Design of 19c-MCF

the MCF was set to 250 μm, which is the same coating diameter as the standard SMF. It is known that the cutoff wavelength is dependent on the length of fiber. Considering use of C-band and possibility of using MCF with a length of less than 2 m, 2 m cutoff wavelength was set to be less than 1400 nm based on the cutoff wavelength depending on the fiber length. Macro-bending loss was designed to meet the G.657.B2 standard because the MCF is expected to be installed inside of the devices with tight bending. Target XT was set at -50 dB/m. When MCF is applied to optical wiring inside of the CSS, large MFD may cause interference between each core. On the other hand, small MFD results in a large MFD mismatch to the SMF. Considering this trade-off, the MFD was set to 7 μm at wavelength of 1550 nm. In addition, a marker was used for core identification.

3. Characteristics of fabricated 19-core MCF

Fig. 2 shows the cross section of the fabricated 19c-MCF. Table 1 shows the characteristics of the fabricated 19c-MCF. The cladding diameter, the coating diameter, and the core pitch were 180 μm, 250 μm, and 30.1 μm on average respectively, as designed. Average 2 m cutoff wavelength was 1240 nm, indicating single-mode propagation in the C-band even if the fiber length is shorter than 2 m. The attenuation loss was 0.25 dB/km on average. When bending diameter is ϕ20 mm, bending loss at the wavelength of 1550 nm and 1625 nm were 0.001 dB/1 turn and 0.005 dB/1 turn. The bending losses were confirmed to be lower than ITU-T G.657.B2 standard. The core-to-core crosstalk was −52 dB/m, which satisfies the design target of −50 dB/m.

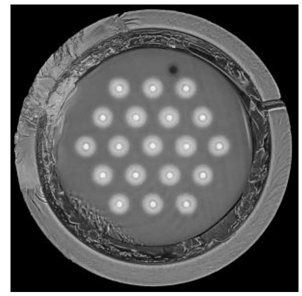

Fig. 2 Cross section of fabricated 19c-MCF

Table. 1 Characteristics of fabricated 19c-MCF

	Unit	Wavelength	Target	Average value
Cladding diameter	μm	-	180	180
Coating diameter	μm	-	250	250
Core pitch	μm	-	30	30.1
MFD	μm	1550	7.0	7.1
Fiber Cutoff wavelength	nm	-	< 1400	1240
Attenuation loss	dB/km	1550	< 0.30	0.25
Macrobending loss@ϕ20 mm	dB/1 turn	1550	< 0.1	0.001
		1625	< 0.2	0.005
Core to core crosstalk (co-propagation)	dB/m	1550	−50	−52

Fig. 3 shows a relationship between the core density and the number of cores for the fabricated 19c-MCF and previously reported uncoupled MCFs [5-9]. The core density shows the value when the SMF with a cladding diameter of 125 μm is set to 1. For example, the core density of the 12-core fiber in the previous report [5] is 5.8, that of the 19-core fiber [6] is 7.4, and that of the 22-core fiber [7] is 5.1, while the core density of this fiber is 9.2, which is the highest core density among reported fibers using homogeneous cores. The core density of the 37-core fiber [9] with heterogeneous core is 9.4, slightly higher than that of this fabricated 19-core fiber. However, when a lens system is used for optical devices such as CSS, the uniform MFD and NA are required for all cores. Therefore, MCFs with high core density using homogeneous cores are desirable to use inside of the optical devices such as CSS.

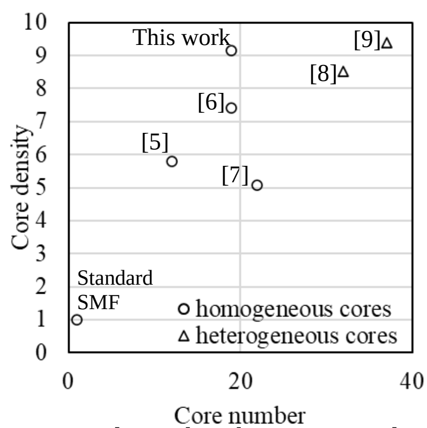

Fig. 3 Relationships between core density and core number for various MCFs

4. Mechanical properties

The Weibull distribution coefficient m_1 of the high-strength section and the dynamic fatigue coefficient n_d were measured by the 2-point bend method. Fig. 4 shows the Weibull plot of fabricated 19c-MCF. From this result, m_1 was 82.3, which is higher than the desired m_1 for standard SMF. Fig. 5 shows results of the dynamic fatigue tests. The breaking stress σ_f is measured 15 times each under 4 conditions of the velocity V where two points advance like 1 μm/s, 10 μm/s, 100 μm/s, and 1000 μm/s. The r is radius of the cladding diameter. The equation between σ_f, V, r, and n_d is as follows,

$$\ln\sigma_f = 1/(n_d - 1) \times \ln(V/r) + \text{intercept} \qquad (1)$$

From the slope derived by the least-squares method, n_d was 23.8, which is larger than the desired value for SiO_2 fiber (n_d = 18) described in IEC60793-1-33 standard. Fig. 6 shows the relationships between bending diameter and failure probability based on Griffioen's equation [10]. Using m_1 and n_d obtained from the strength tests described above, we calculated the failure probability for this 19c-MCF. At a bending radius of 7 mm, which is smaller than that of G.657.B2 standard (r = 7.5 mm), we calculated the required proof level for this 19c-MCF to have a failure probability equivalent to that of 1.0% proof tested 125 μm SMF. Calculated proof test level for this 19c-MCF was 2.1%. 2.1% proof test was applied to the 19c-MCF and we confirmed that the 19c-MCF has sufficient mechanical strength for 2.1% proof test. These results shows that the 19c-MCF has sufficient mechanical strength under small bending conditions such as r = 7 mm. Under r = 7 mm bending condition, macro-bending loss of this 19c-MCF at the wavelength of 1550 nm was 0.001 dB/1 turn. This result implies the 19c-MCF has sufficient bend-insensitivity.

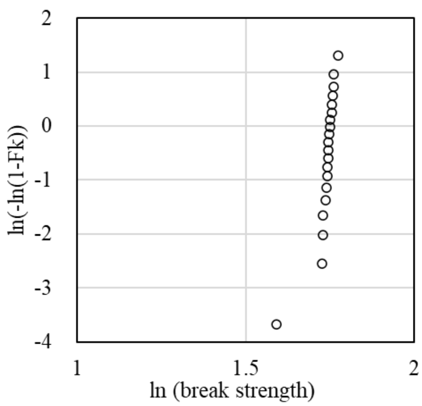

Fig. 4 Weibull plot

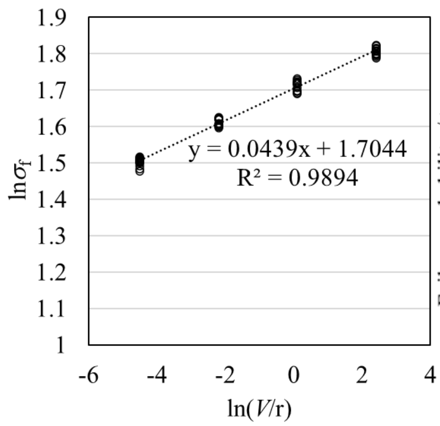

Fig. 5 Dynamic fatigue data

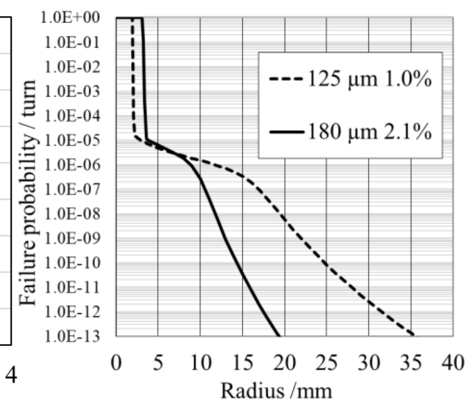

Fig. 6 Failure probability under bending

5. Conclusion

A 19c-MCF with a standard coating diameter for optical wiring was fabricated. This 19-core MCF has the highest core density compared to previously reported uncoupled MCFs using homogeneous cores. It was confirmed that this 19-core MCF has the low macro-bending loss required for optical wiring and has certain mechanical reliability under r = 7.5 mm bending condition.

6. Acknowledgements

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