Single-Mode Fiber

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BendBright-XS

Macrobending Insensitive Single-Mode Fiber

Application Note

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Introduction

Draka's ***BendBright-XS*** macrobending insensitive single mode fibers (SMF) answers the market demand for bend-optimized SMF. This fiber shows perfect performance for the stringent needs in modern Fiber-To-The Home (FTTH) networks or in more general access networks (**XS=access**). The aim of this Application Note (AN) is to support the user in the various applications of ***BendBright-XS*** in telecom cables and networks, especially when they are mixed with conventional SMF. This Application Note starts with an overview section on the growing impact of macrobending loss throughout the years and the importance of backwards compatibility with the SMF applied in the "installed base" networks. Sections 3, 4, 5 and 6 describe the particular issues related to *macrobending*, *microbending*, *fiber connection* and *lifetime aspects*, respectively. Section 6 covers some miscellaneous subjects, including an item, dealing with a new characterization parameter of Multi-Path Interference (MPI). Specific fiber data and detailed specifications can be found in the *product datasheet*.

1. Macrobending Loss: Growing Impact

For telecom networks bend loss has hardly been an issue for many years. Bending the fiber into a helical path is needed to create fiber over-length allowing cable elongation during installation and a suitable temperature operating window. This requirement was met quite easily. Bend radii well over 100 mm did not put high demands on the fiber bend loss. A further requirement was in the need to have storage of the fiber over-length in the splice enclosures along a route. The well-known "100 turns" requirement was created to represent the total number of fiber storage loops in a route. Radii of interest decreased to 30 mm, but for a limited length only. A more severe tightening occurred from the increase of operational wavelength into the long wavelength 1625 nm band.

The associated extending optical field width at higher wavelengths makes the fiber more sensitive to bending. This ended up in the ITU-T Recommendations and IEC standards with the current requirement of a maximum added loss of 0.1 dB at 1625 nm for 100 turns with a 30 mm radius.

First generation bend performance improvements were addressed by standard single mode fiber (SMF) with its simple step-index profile of the core. The only measures taken by the fiber manufacturers were the gradual decrease of the nominal mode-field diameter (MFD) at 1310 nm down to about 9 µm and an increase of the average cable cut-off wavelength to a value not far below the lower limit of the operating wavelength window. These transitions were supported by narrowing production tolerances allowing prevention of worst case fibers.

The minimum bend radius of 30 mm has had a big impact. In most fiber management systems this minimum radius can be recognized in storage cassettes as well as in entrance and exit guides, resulting in voluminous distribution frames requiring costly space. More or less, the 30 mm radius has been considered as being a "natural law" which should not be violated. However, this situation has come to an end.

Component volume is becoming more and more a decisive factor in telecom offices, in cabinets and especially in access points and customer connection boxes in Fiber-To-The-Home networks. Smaller bending radii may reduce component size and lower the total **cost** of ownership further.

Another issue that developed is the ability of the fiber to cope with installation errors like short radius partial bends and/or "kinks" in the fiber. For higher level networks these are usually prevented by requiring well trained installation crews and/or by costly commissioning procedures. This is no longer affordable in the optical access networks, where labor and productivity impacts are much heavier due to the many splitting points and the frequent network changes inherent to the nature of direct service delivery to individual end customers. Fast, efficient and **low cost** installation is of even more importance here.

Cables with macrobending insensitive fibers will allow typical indoor installation methods like tight bending around corners, clamping and even stapling, for which round staples are recommended.

Furthermore such cables will be of smaller size than cables with standard fibers because less protection is needed to realize the required cable specifications.

2. Backwards Compatibility and Compliance with International Standards

In the development of low bend loss SMF, Draka has considered backwards compatibility a key requirement for network operators. Usually low bend loss is realized by using core modified profiles or by using the simplest approach, the "high delta" SMF (e.g. pay-off fibers used in military applications).

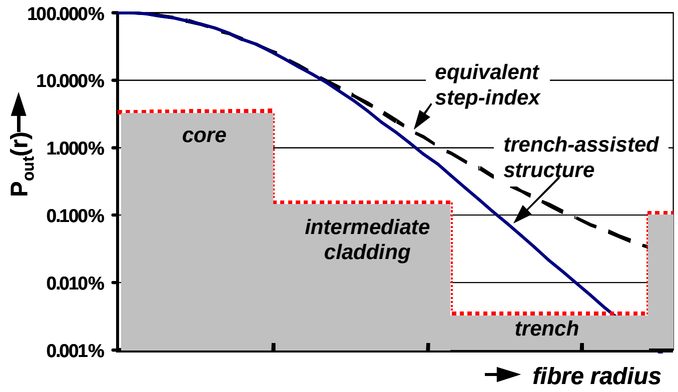


Fig. 1 Trench assisted ***BendBright-XS*** index profile and modeled fundamental power Pout(r) in % propagating outside radius r for this profile and for an equivalent step-index profile.
(Note: 0.5 % power loss corresponds with 0.02 dB)

In this latter case, the refractive index step of conventional step-index SMF is increased significantly with a simultaneous reduction of the core size. The resulting low MFD (5 to 6 µm) is hardly acceptable for applications in telecom networks due to the mismatch with the SMF *installed base*. Apart from technical problems with increased coupling losses, an accompanying **cost** factor is in the need for precise registration of the use and stock of these cables as they should not be mixed with conventional cables.

The first generation of bend loss improved SMF, Draka's classical BendBright^{TM} ESMF, referred to here as BendBright, was launched in 2002. Its concept is based on the selection process of standard fibers in combination with some specific in-process conditions. As a subset of SMF, BendBright fibers are fully backwards compatible with SMF in all aspects since they are part of the standard product line. For the ***BendBright-XS***, targeting also the tough requirements of the access network application, the condition of backwards compatibility is also maintained. Although this restricted the development process severely, it showed that the slight reduction of the MFD to an average value of about 8.8 µm together with the addition of an optical field confining *trench in the optical cladding* just outside of the core (see Figure 1 and Ref. [1]) provided the required significant bend loss improvement.

As a result, the trench-assisted ***BendBright-XS*** can be mixed with conventional standard SMF, Draka BendBright and/or ESMF, without violating the requirements for practical installation, maintenance or operation of the optical network.

Referring to international standards, the trench-assisted ***BendBright-XS*** is fully compliant with the current ITU-T G.652D Recommendation. With respect to the macrobending loss requirements, it is evident that ***BendBright-XS*** shows characteristics far beyond this standard. For this characteristic it provides full compliance with the ITU-T G.657 recommended bend-insensitive SMF classes. It is superior with respect to the "G.657_class A" performance and coincides with the much more stringent "G.657_class B" requirements as indicated at 1550 nm in Figure 2, which also shows the typical bend loss *of* ***BendBright-XS***.

Since its introduction in September 2006, ***BendBright-XS*** has demonstrated a remarkable growth (end of 2009: over 330.000 km of sold fiber), showing the large need for such a robust fiber in FTTH outdoor and indoor applications. Herewith it shows to be a leading industrial product, even gathering international recognition e.g. by being nominated for the best Telecom product in Denmark at the 2008 Brendsbanddagen. (Denmark is in the leading top five European FTTH countries).

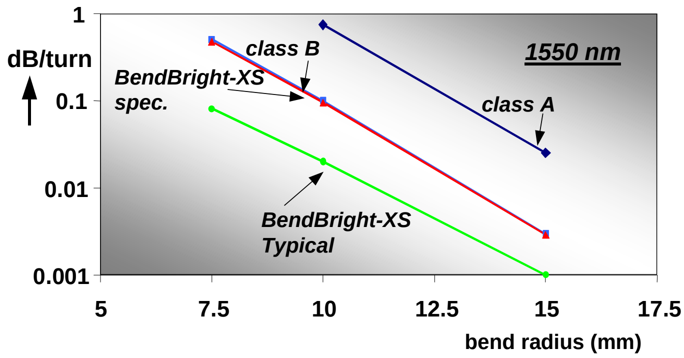


Fig. 2 ***BendBright-XS*** complies with the ITU-T G.657 Recommendation on bend-insensitive SMF for both class A and class B.

The strength of this product is the excellent quality [see Ref. 2] based on the mature technique by which it is easily produced using the well known PCVD deposition process. This process offers high efficiency and large production flexibility; it also releases the lowest waste to the environment compared to other fiber deposition processes.

3. Macrobending Loss

Low macrobending loss is needed

i) for storage of fiber, cord or cable over-length in patch-panels or in splicing cassettes and

ii) in case of single low radius bends as occurring in entrance and exit guides of fiber management systems and in indoor cable installations.

For SMF, a commonly applied specification for bending loss is in the _added loss per turn_ at a given wavelength. This loss increases _linearly_ with the number of turns, so the specified loss for any number of turns can be calculated quite easily. As SMF bend loss increases with wavelength, the specification at the highest envisioned wavelength, i.e. 1625 nm is most critical. For applications where 1550 nm is considered as the highest operational wavelength a specification at this wavelength suffices. For ***BendBright-XS***, the loss at both wavelengths has been specified. The ratio between the losses at both wavelengths is not constant but depends on the bending radius. For 15 mm radius this ratio is about 5 and for 7.5 mm it has decreased to 2.5.

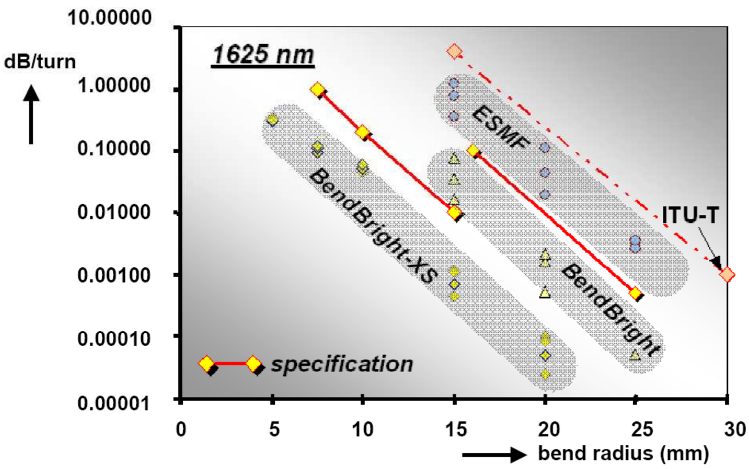


Fig.3 Comparative macrobending loss overview. The dotted curve represents the maximum bend loss of a SMF just answering the ITU-T G.652 specification at a 30 mm bend radius.

In Figure 3 an overview is given of the bend loss specification at 1625 nm of ***BendBright-XS*** compared with classical BendBright, standard ESMF and the ITU-T G.652D Recommendation.

Improvement is clearly visible and ranges up to a factor of 100 at a 15 mm radius.

In specifying bend loss in dB/turn, the user must take into account that the fiber length in the turn is linearly dependent upon the bend radius. This means that for storage of a fixed length at a lower bend radius a higher number of turns must be accounted for. In practice however, the required storage length is decreasing due to ongoing miniaturization of all components, including the connector patch panels and splicing sets.

A further effect to be highlighted has to do with the very nature of bend loss and might be of special relevance when considering low radius bends. The optical signal escaping from the core due to the bending of the fiber axis will be reflected at all interfaces with refractive index differences as e.g. the coating-cladding interface. Due to the curved reflection surfaces acting quite like a concave mirror, a significant part of the reflected power passes the core again and might interfere with the main power stream. As this interference is dependent upon bend radius and wavelength and might be either constructive or destructive, this results in a characteristic undulation (see Ref. [3]) of measured spectral bending loss curves as shown in Figure 4 for a 7.5 mm radius test.

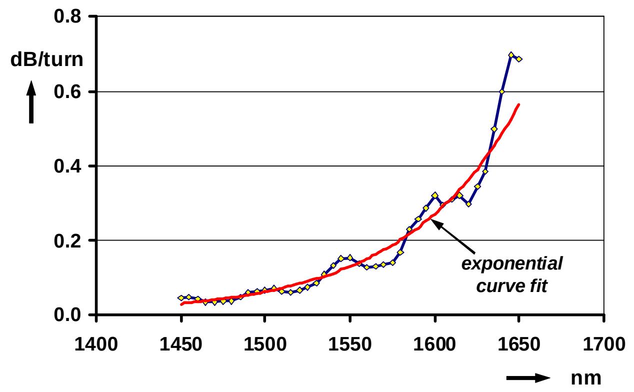


Fig.4 ***BendBright-XS*** spectral macrobending loss for a R=7.5 mm test with 6 full turns in the test set-up.

The undulation depth and the position of the tops are determined by the specific fiber geometry and core profile and by the specific fiber deployment. In spectral loss tests, as done for ***BendBright-XS***, simple curve fitting (*see IEC 60793-1-47 Macrobending loss test method*) results in the appropriate loss value. However, when measuring bend loss with an OTDR, quite large deviations can occur, especially in case of a single low radius bend where the undulation depth might be higher.

BendBright-XS fiber shows another strong feature as trench-assisted bend-insensitive SMF. The PCVD produced profile guarantees extremely well bending homogeneity. Quantitatively speaking, the trench-volume variations are lower than 0.1% in the radial dimension and lower than 0.1% after 1km in the longitudinal dimension. This extremely good homogeneity level ensures very stable and robust bend loss performance of ***BendBright-XS*** fibers for indoor application.

4. Microbending Loss

Microbending loss is reduced with a higher fiber MAC value, i.e. the ratio MFD/CO, just like macrobending loss (see Ref. [4]). As extensive testing has shown, the optical field confining effect of the refractive index trench near to the core has a positive effect on microbending loss as well.

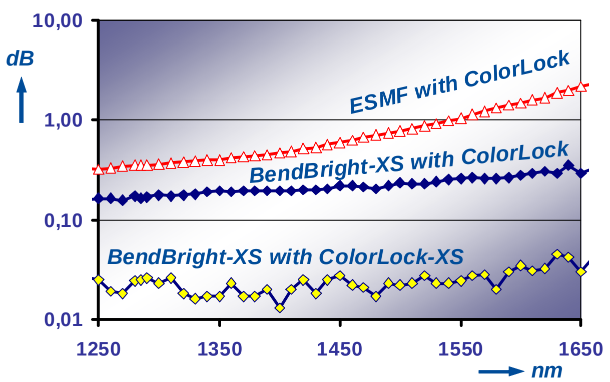


Fig.5 Spectral micobending loss for ESMF and ***BendBright-XS*** with ColorLock coating and ***BendBright-XS*** with improved ***ColorLock-XS*** coating.

Figure 5 shows spectral loss curves from fiber subjected to the standard Draka microbending test. In this test, 400 m fiber is wound with high tension on a 60 cm diameter reel covered with low grain size sandpaper. ***BendBright-XS*** fibers show reduced microbending sensitivity compared to standard ESMF (including a lower slope of loss versus wavelength), which is further enhanced with the highly microbending improved coating ColorLock-XS.

Microbending is a less defined deformation of the fiber axis for which some test methods are suggested in IEC Technical Report TR 62221.

Other test methods have also been applied to evaluate the losses originating from micro-deformations as can occur in practice. Some examples are the “pin-array” test and the “kink” test. The “kink test” might give a good impression of the effects occurring in case of possible sharp bending, e.g. in splice cassettes. In this test, a coated fiber is loosely pressed against a low radius pin over an angle of about 45 degrees. The fiber has some free space due to the distance of about 0.7 mm between the pin surface and the pressing surface resulting in a smaller effective bend angle as is the case in usual cable structures. The test is repeated several times and the results are averaged.

In Figure 6, some test results are shown applying a 1.5 and a 2 mm radius pin respectively. The tested fibers were nominal MAC value fibers from both ***BendBright-XS*** and the classical BendBright product line. The improvement originating from the trench is impressive.

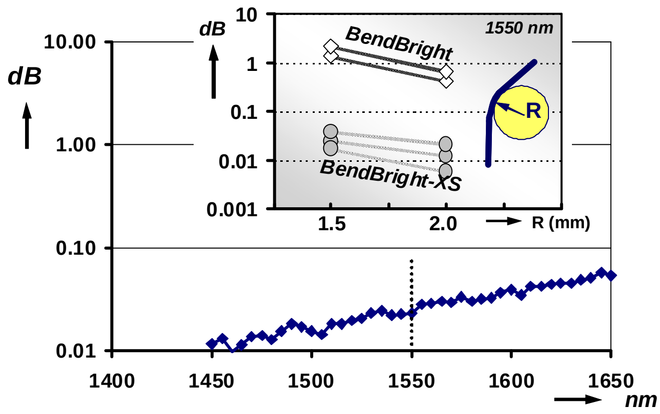


Fig.6 Spectral "kink loss" curve for a ***BendBright-XS*** fiber pressed against an R=1.5 mm pin. In the inset, the losses at 1550 nm are given for some nominal ***BendBright-XS*** and BendBright fibers.

In case of sharp incidental bends, ***BendBright-XS*** fiber responds with a limited excess loss only. In case of a standard step-index SMF, the inserted loss would certainly have initiated a system alarm.

Seen from this aspect, the new trench-assisted ***BendBright-XS*** fiber is very installer friendly and forgiving. However, this does not mean that fiber mounting should be done carelessly.

5. Fiber Connection

Fiber connection is of high relevance in installing, operating and maintaining an optical network. Not only for splicing consecutive or branched-out cable sections, but also in connecting cabled fibers to transceiver or splitter pigtails. The connection might be from connectors, mechanical splicing or fusion splices. The inter-compatibility of legacy fiber must always be considered when introducing a newer fiber type, even if improving its characteristics. Therefore, it makes sense to check the impact of the ***BendBright-XS*** on each of these methods.

5.1: connectors

In cleaving, polishing and processing of the fiber end-face, ***BendBright-XS*** does not differ from standard SMF. The surface of the trench is very small compared with the total fiber surface, so the small differences in material do not affect any of the processing steps significantly. This has been verified by making a series of connectors and testing the connection results in terms of insertion and reflection loss. No differences in characteristics resulted.

As for the reflection loss it should be noted that one of the methods to suppress end face reflection i.e. by making one or more small radius loops in the fiber downstream the connector to be tested, does not work anymore. Alternative methods like the use of index matching oil or gels should be applied.

An interesting part of this test cycle is the tested patch-cord bend loss. In this procedure, a cord is bent over quite small radii at different angles as represented in Table I. The extremely low losses correspond fully with the results shown in Figure 3.

Table I: Results from bend loss tests at 1625 nm as part of a connector qualification program.

Angle	*Radius*	*ESMF*	*BendBright-XS*
1x180 °	9 mm	0.0 dB	0.0 dB
1x180 °	6.5 mm	0.2 dB	0.02 dB
1x180 °	4 mm	2.1 dB	0.2 dB
1x360 °	7 mm	12.5 dB	0.4 dB
1x360 °	5 mm	30 dB	1.0 dB
1x360 °	3 mm	38 dB	2.5 dB

5.2: mechanical splices

Just like the results for making connectors, the use of ***BendBright-XS*** does not differ from the use of standard SMF. For verification, a series of mechanical splices were been made, the result of which is represented in Table II. The average value and maximum value over 5 installations were both within the specifications for this type of mechanical splice.

Table II: Results from mechanical splice mounting trial series.

Wavelength	*Average loss*
1310 nm	0.09 dB
1550 nm	0.12 dB
1625 nm	0.12 dB
1250 – 1650 nm	0.12 dB

5.3: fusion splicing

Draka and all major splice machine manufacturers have conducted extensive splice testing of ***BendBright-XS*** and have found that all machines are capable of splicing ***BendBright-XS*** effectively. This includes splicing ***BendBright-XS*** to itself, to other bend-insensitive fibers, and to standard single-mode fibers. Some single fiber splice machines use (proprietary) profile or core recognition to align fibers. If these machines do not have updated software it is possible that ***BendBright-XS*** may not be recognized, because the trench in the profile may cause errors in the recognition software (see figure 7). If this is encountered, this can easily be overcome by simply changing the machine setting (see table III).

Table III lists most common splice machines on the market. It is intended to provide guidance and recommendations in case alternative settings are required. It should be noted that the splice machine manufacturers have already updated or are in the process of updating software to ***BendBright-XS***. Standard settings can be used for outside diameter/cladding alignment machines, including mass fusion splice machines.

Although good results can be achieved with older splicing sets applying the MMF arc settings, Draka recommends applying modern splicers that support ***BendBright-XS***, see Table III.

Note: Do not hesitate to contact the local distributor of the splicing equipment for up-to-date information and equipment updating procedures.

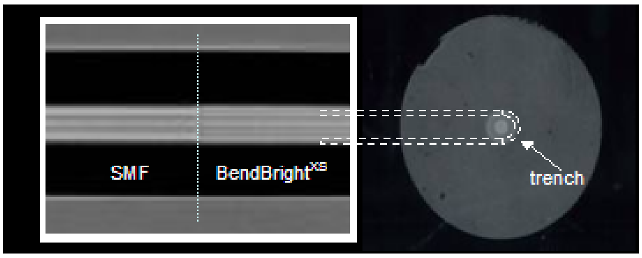


Fig. 7 The trench in ***BendBright-XS*** showing up on the fusion splicer visualization screen.

Splice test results:

As ***BendBright-XS*** allows a backwards compatibility with already deployed fibers (standard Single-mode fiber), it is also important to guarantee compatibility with existing deployment procedure. As far as fusion splicing operations is concerned, it is important to ensure that splicing conditions do not differ that much when ***BendBright-XS*** is spliced to another fiber. Two possible splicing cases are distinguished:

- Splicing ***BendBright-XS*** to standard single-mode fibers
- Splicing ***BendBright-XS*** to itself

5.3-1: splicing BendBright-XS to ESMF

Splicing the trench-assisted ***BendBright-XS*** fiber to a standard SMF will occur frequently at the edge of an access network or when splicing fiber pigtails in passive components like power splitters. Figure 8 shows the result of splice test performed by Draka between different commercial available G.652D fibers and ***BendBright-XS***, performed with several fusion splicers. Measurement performed with bi-directional OTDR method.

5.3-2: splicing BendBright-XS to BendBright-XS

Splicing ***BendBright-XS*** to itself works like splicing every other standard SMF in nowadays installation practice. Given that spliced fibers have identical chemical compositions, splicing conditions are usually more relaxed than splicing with dissimilar fiber. As a result, fusion splicing usually exhibits slightly better performance than when splicing with heterogeneous fibers. This is proven by below Figure 8 showing statistics of a large amount of splicing tests on different commercially available splicing machines. Measurement performed with bi-directional OTDR method.

Note: Individual results for particular splice machines are available on request.

Table III: Recommended splice machine settings for ***BendBright-XS*****.**

	MODEL	RECOMMENDED PROGRAM	CORRESPONDING ALIGNMENT METHOD	ALTERNATIVE SETTING
FUJIKURA	FSM-11S	Automatic mode	Fixed V-Groove	-
FUJIKURA	FSM-17S	Automatic mode	Fixed V-Groove	-
FUJIKURA	FSM-18S	Automatic mode	Fixed V-Groove	-
FUJIKURA	FSM-30S	SMF	Core alignment	MMF
FUJIKURA	FSM-40S	MMF	Cladding alignment	-
FUJIKURA	FSM 50S	BendBright-XS	Core alignment	Automatic mode
FUJIKURA	FSM 60S	BendBright-XS	Core alignment	Automatic mode
FURUKAWA FITEL	S122A	Standard SM	Fixed V-Groove	-
FURUKAWA FITEL	S175 (All version)	BendBright-XS (US only)	Cladding alignment	SM with clad alignment
FURUKAWA FITEL	S176	Standard SM with cladding alignment*	Cladding alignment	-
FURUKAWA FITEL	S177A	BendBright-XS	Core alignment	SM with clad alignment
SUMITOMO	Type-25	SM settings	Fixed V-Groove	-
SUMITOMO	Type-45	SM settings	Fixed V-Groove	-
SUMITOMO	Type-37	SM Diameter Alignment*	Cladding alignment	-
SUMITOMO	Type-39	BBxs Diam	Cladding alignment	-
SUMITOMO	Type-65	Standard SM	Fixed V-Groove	-
SUMITOMO	Type-66	Standard SM	Fixed V-Groove	-
CORNING (SIECOR)	M90i	MMF (VIDEO mode)	Cladding alignment	-
CORNING (SIECOR)	OptiSplice™ LID Micro	MMF (VIDEO unequal pairs)	Cladding alignment	-
ERICSSON	RSU12	Standard SM	Fixed V-groove	
ERICSSON	FSU995	Standard SM	Core alignment	-

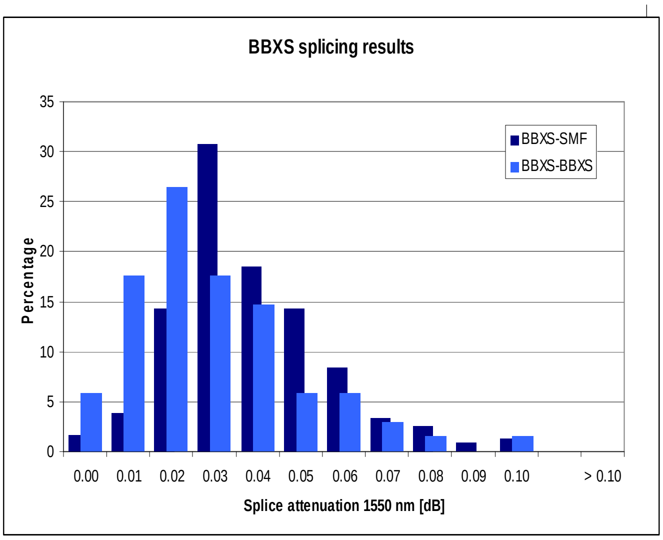


Fig. 8 Splice loss distribution of ***BendBright-XS*** to itself and to multiple commercial G.652D fibers using different splice machines at 1550nm.

The above reported splice test results (Figure 8) are obtained in a laboratory. Splicing in field circumstances will result in the same values when it has been secured that all equipment is well maintained and in good condition, operators are well-trained and splicing is performed in a clean environment.

5.3-3: OTDR commissioning procedure

During installation, the splice loss is predicted by the optical image processing system of the splicer unit. Based on this prediction the splice can be approved or rejected. When commissioning an optical link, splice losses usually are checked again by OTDR testing from either one side or from two sides of the fiber link. For testing splices in networks with optical splitters special procedures do exist.

When measuring splice loss with an OTDR, peculiar effects can occur. Depending upon the direction of testing, *apparent gain* or *apparent high losses* can be observed. The main reason for this is in the strong dependency of backscatter level on the MFD value. If the spliced fibers have different MFD values the backscatter level of both fibers will differ. This impacts the ability of the OTDR to measure the splice loss from one direction. More details are given in Refs [5] and [6].

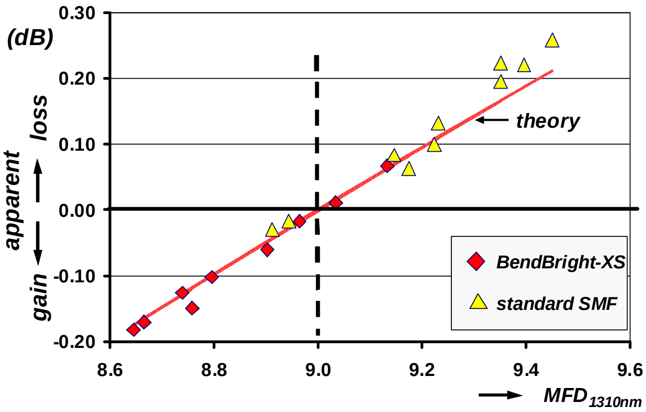


Fig. 9 Measured uni-directional OTDR gain or loss for an ideal splice at 1550 nm determined from a 9.0 µm MFD standard SMF launching into other standard SMF and into ***BendBright-XS*** fibers with various MFD values indicated on the horizontal axis.

Also for ***BendBright-XS***, backscatter level is mainly determined by MFD. This is depicted in more detail in Figure 9. A standard SMF launch fiber with a 9.0 µm MFD is spliced to a series of other SMF with deviating MFD values. Applying the method used in Ref [7], the apparent loss (dB >0) or gain (dB <0), referred to the launch fiber can be derived for each fiber. Good correspondence shows with the expected theoretical value based on MFD differences (see Ref [5], Eq. 5), which is also represented in Figure 9. These results show that the trench-assisted ***BendBright-XS*** behaves just like a standard SMF with respect to OTDR splice monitoring.

Since ***BendBright-XS*** has a slightly lower nominal MFD then conventional SMF, more splices will be noticed with an apparent gain when testing from the side of the conventional SMF. In case of a commissioning procedure requiring the use of cost-effective single sided OTDR monitoring, this difference in average value of MFD distribution has to be taken into account. Methods to cope with this do not differ from situations where different standard SMF fibers with a difference in nominal MFD value are spliced (see also Ref. [5]).

6. Lifetime Aspects

When deploying SMF in storage cassettes or in case of incidental bends, stress is applied to the outer circumference of the fiber causing strain in the glass material (see Figure 10).

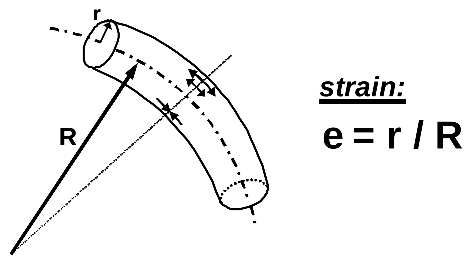


Fig. 10 Strain in the outer surface of the fiber by bending the fiber axis with a radius

Reducing the current minimum bend radius from 30 mm to 15 mm or even lower, might raise some questions on the lifetime of the fiber. For modern SMF however, there is no reason for this concern With respect to strength, ***BendBright-XS*** gets the same high quality processing as the Draka standard SMF. This is sufficient to guarantee its lifetime in all situations in a telecom network, including access networks with much more rugged environments. To explain this, let's start with an assessment of current strength requirements.

These requirements have been derived from a worst case network situation defined as:

> **"all fibers in a cable observe over the entire length and during the entire lifetime of e.g. 20 years, a constant strain of maximum 1/3 of the 1% proof-test value"**

For modern optical fibers this requirement is met by applying high quality materials and clean processes. Verification is done by proof-testing the fibers resulting in a sufficiently low number of breaks per preform pull. Meeting this requirement for a 1% strain at proof-test, insures that the fiber can withstand a 1/3 % strain over its whole cross-section, length and lifetime.

When bending a fiber in a storage cassette the following main considerations apply:

1- Usually there is no axial stress on the fiber, so consequently the main cause for strain is the bending itself. By simple geometrical rules it can be calculated that a 1/3 % strain is reached at the outer circumference of a 125 µm OD fiber for a bend radius of 18.75 mm. Bending the fiber over its whole length on this diameter will not impose any additional impact on the lifetime compared with the criteria mentioned above. On the contrary, the average stress is even less as the 1/3 % strain is present in a very small part of the fiber's outer surface only.

2- The bent fiber length in a storage cassette is a very short section of the total fiber length only. So, the failure probability is accordingly lower.

Both considerations apply when calculating the failure probability of a short fiber length stored in a cassette of a fiber management system. In Ref. [8] a more complete model has been described starting from the outside plant failure probability as indicated by the network operator. For a rather extended network containing 5000 storage cassettes and a failure probability per cassette of 0.001 % in 20 years, *i.e. one single spontaneous breakage in one of the cassettes in 20 years in 20 of these networks*, the minimum bend radius is represented in Figure 11.

It is evident that this minimum radius depends upon the length of the stored fiber in the cassette. The other parameter that governs the minimum bending radius is the *stress corrosion susceptibility n* (fatigue parameter). For ***BendBright-XS*** the value of the "dynamic" susceptibility is >20 (see datasheet) whereas the "static" value is >23. Note that the minimum dynamic stress corrosion susceptibility coefficient is 18 according to IEC product specification 60793-2-50 and Telcordia GR-20-CORE specifications.

Depending upon the envisioned safety margin, different values can be used. Since storage aging in most cases is a static phenomenon, the use of the higher static fatigue parameter n=29 might be justified. The lower value of n=18 might be used as a "worst case". Dependent upon these considerations the curves in Figure 11 demonstrate that for this typical network and the accepted very low failure rate a storage length of, for example, 100 cm of fiber at a 15 mm radius is a safe situation. However, storage of 100 cm of fiber at a radius of 10 mm is also safe if the higher n-values are ascertained *).

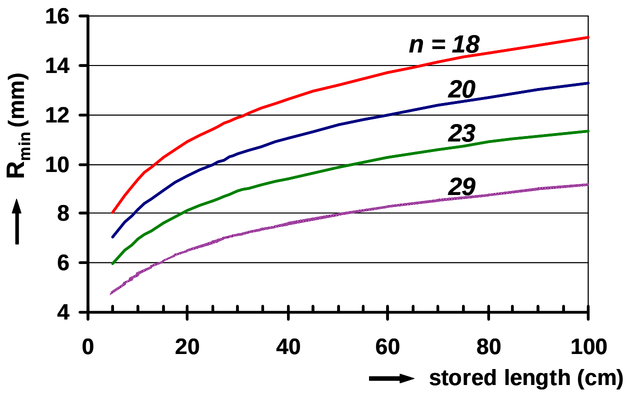


Fig. 11 Minimum bending radius for storage of the ***BendBright-XS*** with a 20 years failure probability of < 0.001.

The curves in Figure 11 also show that for much *shorter bend lengths*, such as 90 degree bends in exit and entrance ports of a fiber management system the minimum radius can be much shorter. Referring to the kink loss situation as indicated in Figure 6, detailed calculations reveal that even in these cases, lifetime is not significantly affected (see e.g. Ref. [9]; Fig. 9). A nice illustration of this comes from a simple long term experiment started at Draka Denmark in the early nineties of the last century. A series of different diameter mandrels, diameters ranging from 2.8 to 4.2 mm, 10 of each and each mandrel with 30 windings were stored in a room temperature environment. In the D=2.8 mm and D=3.0 mm series mandrels 5 breaks occurred after 11 and 28 days, respectively. However, from the D ≥ 3.4 mm mandrels no breaks were detected up till now, i.e. 16 years later!

In general it can be stated that lifetime considerations on fibers stored in short bend radius fiber management systems differ significantly from lifetime considerations of cabled fibers. For storage in fiber management systems, a higher strain may be present on short lengths, whereas for cables a lower strain and a much longer length apply. As for lifetime prediction however, similar calculation models can be applied.

*) *Note that at this specific bend radius, the bend loss in "live" fibers cannot be neglected anymore. For a for 100 cm storage with a bend radius of 10 mm, the specified maximum bend loss becomes as high as 0.8 dB at 1550 nm.*

Single bend failure rate.

Based on Ref. [10] Draka calculated the failure rate at the various bend radii. The Parts Per Million (PPM) rate is the most straightforward way to explain the reliability in small bends. Table IV quantifies the risks of failure at various bend radii. For example, for every one million bends at a 10 mm bare fiber bend radius, there is 0.8 predicted failures over a 25 years life. This assumes the fiber is bent at that radius over the entire 25 years.

Table IV Failure rate (PPM) for single turns over 25 years service

Bend Radius (mm)	Failure Rate (PPM)
7.5	1.20
10	0.80
15	0.30
20	0.03
30	<< 0.01

7. Miscellaneous

The improved macrobending behavior of ***BendBright-XS*** can also have impact other areas aspects, which are highlighted below.

7.1 Fiber and cable cut-off measurement.

In the cut-off region of a SMF, optical power is propagated not only by the fundamental mode, but also by higher order modes. For a standard step-index SMF the two LP_{11} higher order modes are the dominant ones just below the cut-off wavelength. In the *bend reference method of IEC and ITU-T standardized cut-off wavelength test methods* power is split in equal parts over the three propagating modes. This results in a spectral curve "hump" with a top value of 10xlog(3) = 4.7 dB. The cut-off wavelength follows from the higher wavelength at 0.1 dB height of this hump.

For trench-assisted ***BendBright-XS***, the cut-off phenomena differ significantly from those for a conventional step-index core profile SMF. As the bend loss of the higher order modes is influenced by the trench also, the wavelength width of the cut-off region is broadened significantly leading to a much lower "hump" value when applying the bend reference method. In addition, due to interference undulation in the measured cut-off curve can occur resulting in a "dispersed hump" with a much lower maximum value, even far below the minimum height of 2 dB as required in the IEC standard for this test method. Applying the *multimode reference method* (see Ref. [11]) does not have this drawback and is recommended for this test, both for the fiber and for the cable cut-off wavelength. This recommendation will also be implemented in next edition of the indicated IEC standard.

7.2 Multi-Path Interference

Multi Path Interference (MPI) has been discussed for the last 20 years and the term encompasses a wide variety of phenomena which translate in interferences between the optical signal and weak, parasitic time-delayed replica. The induced fluctuations act as noise in transmission and therefore degrade the system performances.

MPI has recently received a renewed attention in the access network context. In this case, one refers to coherent MPI because interferences occur between co-propagating modes (Fig.12).

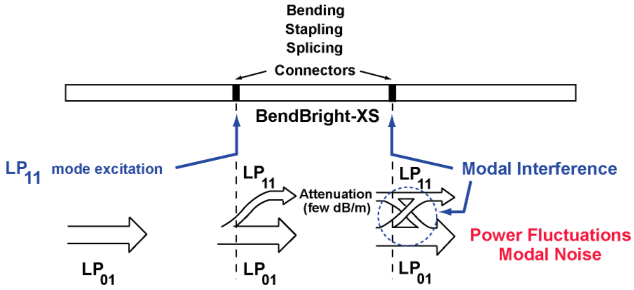


Fig. 12 MPI/Modal noise in FTTH context.

The interest expressed comes from the fact that MPI is a well-known way to estimate the impact of a few mode behavior when the system is operated lower or close to the cut-off wavelength. MPI gives a better view on systems impairments than just a cut-off characterization. In other words, a known MPI level relates to a power penalty and therefore to a system budget.

Simulating extreme field installations (see Figures 13-14), ***BendBright-XS*** cables have been submitted to various tests, each one investigating a particular source of MPI that will be encountered in real systems (see Ref. [12]).

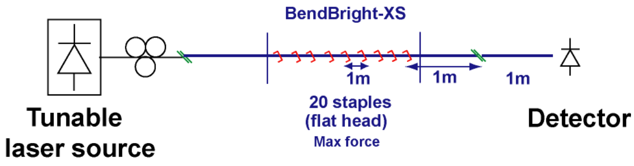


Fig. 13 MPI testing of multiple stapled cable.

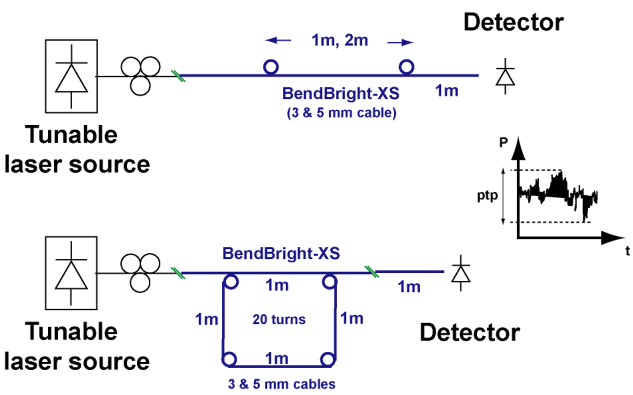


Fig. 14 MPI testing on 5 mm radius cabled fiber loops and tight 90 degree bends.

All these measurements have been performed using the power fluctuation method (see Ref. [13], known among the classical MPI characterization techniques to be the best one to capture the true essence of coherent MPI, all the other ones leading to severe underestimations.

Table V MPI levels measured at 1310 nm for cable stapling, bending and sharp turns experiments

1310 nm	Stapling	Loops	Sharp Turns
3 mm cable	< -45 dB	< -40 dB	< -40 dB
5 mm cable	< - 40dB	< -40 dB	< -40 dB

Table V lists all the MPI values measured for the 3 and 5 mm ***BendBright-XS*** indoor cables. Even though these experiments represent extreme installation conditions, the MPI levels found are well below –30 dB which makes ***BendBright-XS*** fully compatible with successful FTTH deployments (see Ref. [12]).

7.3 Use of fiber identifiers

The enhanced bending performance of ***BendBright-XS*** will diminish the signal received with fiber identifiers. This might cause a sensitivity problem dependent upon the type of use and the type of tap-off mechanism. To investigate this, several identifiers were tested:

- Tests with the Wilcom F 6225 identifier showed that working with ***BendBright-XS*** is possible with normal identifier settings for both the 250 µm OD primary coated fiber and a 2 mm buffered patch-cord.
- Tests with done also with the EXFO LFD-250 "clip-on" detector and the LFD-300 FiberFinder. Both work well as clip-on device to a sensitivity level of about -30 dBm at 1550 nm. For providing the appropriate power level software modifications will be required.

7.4 High power induced aging

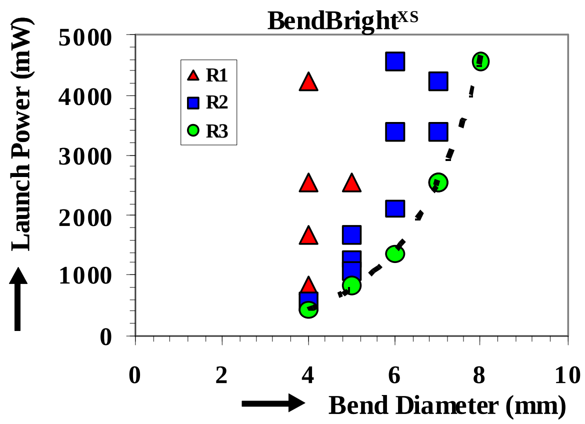
In view of the foreseen up-grading of networks with distributed or lumped Raman amplifiers, much attention is given currently to the effect of the use of high power pump lasers at e.g. 1460 nm. An annoying side effect might be that loss of power at low radius bends can initiate an accelerated aging of the coating and in some cases eventually lead to fiber breakage or even start of fire in some older types of tightly coated fiber.

It will be evident that the use of fibers with improved macrobending behavior, like trench-assisted ***BendBright-XS*** are much less vulnerable to this effect, see Figure 15 showing ***BendBright-XS*** in comparison with a regular G.652 fiber (see also Ref. [2, 14]. In this figure different failure definitions have been applied (see Ref. [15]):

R1: catastrophic failure of the glass fiber mimicking a fiber break;

R2: catastrophic damage to the fiber coating;

R3: accelerated ageing of the coating.



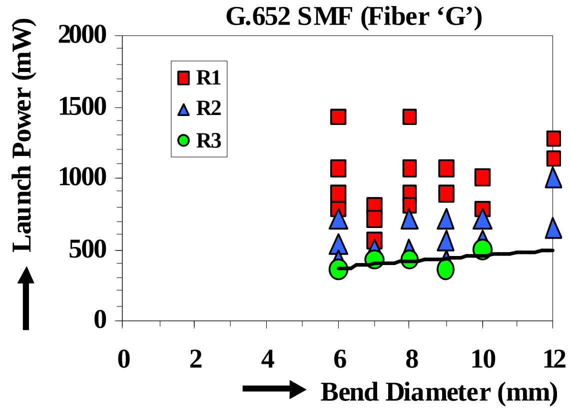


Fig. 15 Launch power (1480 nm) for different failure regimes (R1 – R2 – R3), tested in 180 degree 2-point bends.

Top: ***BendBright-XS*** withstands up to about ten times higher launch power (R3) at 8 mm diameter compared to G.652 fiber (bottom).

References

[1] L.A. de Montmorillon, P. Matthijsse et al, “Next generation SMF with reduced bend sensitivity for FttH networks”; Proc. ECOC, paper Mo 3.3.2, Cannes, 2006.

[2] Gerard Kuyt, Piet Matthijsse, Laurent Gasca, Louis-Anne de Montmorillon, Arnie Berkers, Mijndert Doorn, Klaus Nothofer, Alexander Weiss, “The impact of new bend-insensitive single mode fibers on FTTH connectivity and cable designs”, Proc. 56th IWCS Conference, November 2007.

[3] L.Faustini and G. Martini, “ Bend Loss in Single Mode Fibers”, Journal of Lightwave Technology, Vol 15, No 4, April 1997; pp 671-679.

[4] C.Unger and W.Stöcklein, “Investigation of the Microbending Sensitivity of fibers”, Journal of Lightwave Technology, Vol 12, No 4, April 1994; pp 591-596.

[5] Draka Application Note: “SM OTDRs, Apparent Gain, Loss and other surprises”; August 2006.

[6] IEC 62316 TR Ed. 2.0: “Guidance for the interpretation of OTDR backscattering traces”.

[7] P.Matthijsse and C.M. de Blok, “Field measurement of splice loss applying the backscattering method”, Electronics Letters, Vol. 15, No 24, pp 795-6, (1979).

[8] P.Matthijsse and W.Griffioen, “Matching Optical Fiber Lifetime and Bend-loss Limits for Optimized Local Loop Fiber Storage”, Optical Fiber Technology, Vol 11, pp 92-99, (2005).

[9] P.Matthijsse, L.A. de Montmorillon et al, “Bend-Optimized G.652 compatible Single Mode Fibers”, Proc. 54th IWCS Conference, pp 327-331, November 2005.

[10] IEC 62048 TR Ed. 1.0: “Optical fibres – Reliability – Power law theory”.

[11] IEC 60793-1-44 Optical fibres – Part 1-44: Measurement methods and test procedures – Cut-off wavelength.

[12] D. Z. Chen, D. Boivin et al, “Testing MPI Threshold in Bend Insensitive Fiber using Coherent Peak-To-Peak Power Method”, OFC/NFOEC2009, paper NTuC5.

[13] Ramachandran et al, “Measurement of Multipath Interference in the Coherent Crosstalk Regime », IEEE Photonics Technology Letters, 2003, 15, 1171-1173.

[14] E.S.R. Sikora. D.J. McCartney : Private communication. BT plc UK. August 2007.

[15] IEC 62547 TR Ed. 1.0: Guideline document for the measurement of high power damage sensitivity of single mode fibre to bends and guidance for interpretation of results.

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