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A new approach to evaluate macro and microbending sensitivity of single mode optical fiber

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Abstract
Multiple bends in fiber contribute significantly to the increase in power loss in optical fiber cables. Bending losses are influenced by different optical parameters like Mode Field Diameter (MFD), Cut-off wavelength and MAC value. This paper highlights the results of a series of tests conducted, to determine the power loss of matched clad step index Single Mode Optical Fiber (SMF). The effect of MFD, Cut-off wavelength and MAC value have been studied with various macro and micro bend testing techniques. The testing techniques and relevant parameters, which effectively measure the bend sensitivity of SMF, have been identified.

Key Words
MFD, Cut-off, MAC value, Macrobending, Microbending, Fluid immersion test, Optical fiber coatings, Acrylic resins.

Introduction

One of the primary causes for increase in attenuation in optical fiber cables is multiple bends in fiber. Hence, it becomes very critical to understand the bend sensitivity of fiber. The two predominant types of bends in optical fiber, i.e micro and macro bending, have significant impact on the reliability. If macrobending is more predominant then, it is possible to measure the equivalent bend radius. However, if microbending and macrobending co-exist then, it may not be possible to easily determine the equivalent bend radius. In such cases it becomes mandatory to perform various physical tests in order to determine the bend sensitivity, as it relates to various parameters such as MFD, Cut-off, MAC value and coating adhesion to glass and its properties [1]. The loss due to bending can be calculated by determining the equivalent bend radius and the fiber design parameters at the desired wavelength [2].

With regard to the geometrical and optical parameters, MAC value may be defined as the ratio of MFD and Cut-off wavelength. The study shows that, the MAC value can be used as a reliable parameter for the characterization of the bend sensitivity of SMF [3].

In order to reduce the microbending loss, low modulus, primary coating is applied directly on the glass surface. In order to assure long-term reliability in the performance of optical fibers, the coating system must adhere well to the fiber and retain adhesion during service. If the adhesion is reduced below a critical level, de -lamination of coating can occur resulting in microbending loss. Adhesion of coating is greatly dependent upon the degree of cure and presence of adhesion promoters in primary coating.

Microbending effects in SMF may arise after immersion in water due to unbalanced stresses. Asymmetric stresses between different layers of coating and glass can add more microbending transmission loss. These losses can be minimized by decreasing the presence of water extractable & water absorption and increasing the threshold strength of coating materials. [4] This paper describes a series of tests carried out on matched clad step index SMF coated with same coating material & cured to the same extent and having different MFD, Cut-off and MAC values.

Fiber Design

Macrobend loss which is caused by loss of power due to radiation, increases exponentially with the radius of bending. Below a critical radius of bending, the loss becomes significant and noticeable. Bending sensitivity is greatly dependent upon the fiber design in addition to the composition of glass and coating material.

Although fibers produced in a well-controlled drawing process are axial, nonuniformities of the fiber sheath ,a nonuniform lateral pressure applied to it or a differential expansion or contraction due to environmental effects can cause microscopic deviations of the fiber axis from the straight condition. These microscopic random deviations are called “micro bends”. Micro bend losses are dependent upon a number of modes and wavelength [5]. Micro-bend loss for SMF increases exponentially at longer wavelengths. Rapid increase in bend loss has been predicted at wavelengths above 1550 nm [6].

Despite its small diameter, the glass in SMF exhibits a very good resistance to deformation due to their high Young's Modulus. This property is more effective against deformations at shorter wavelengths [7]. More specifically, a fiber with a radius 'b' and modulus 'Ef' embedded in a soft jacket of modulus 'Ej' will resist deformations with frequencies higher than

= (1/b) [(4/ π) x (Ej / Ef)] 1/4

Acrylic resins are most commonly used coating and jacketing materials for optical fibers worldwide. Coating materials have very low value of water absorption (as low as 1.5 %) and consequently prevent swelling while immersed in water. Coating material also provides good cushioning effect to protect the fiber against micro-bending.

Experiments

Macro bend tests:
Optical power loss (in dB) has been measured at 1550 nm by using standard spectral loss measuring equipment. Matched clad step index SMF samples with various MFD, Cut-off and MAC values have been tested. The bend diameters used were 32 and 60 mm. The number of turns was one for 32 mm diameter mandrel and 100 for 60 mm diameter mandrel.

Micro bend tests:

(a) Lateral loading test
Fiber samples had been loaded by 1 kg /m and sandwiched in between 100 μm sand papers pasted on glass plate. This test is commonly known as Lateral Loading Test (LLT). Figure1 the set-up for LLT.

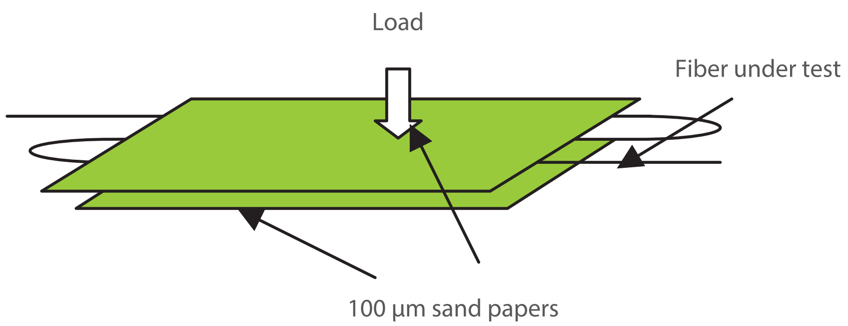


Fig. 1 Set up for Lateral Loading Test

(b) Pin-Array test
Another test to evaluate micro bending sensitivity is Pin Array Test (PAT) where the fiber is placed in a zigzag motion in an array of ten pins. The diameter of the pins being 0.8 mm with 9 mms gap in between them. This experimental set-up illustrates the position of fibers inside the loose tube. Figure 2 shows the set –up for PAT.

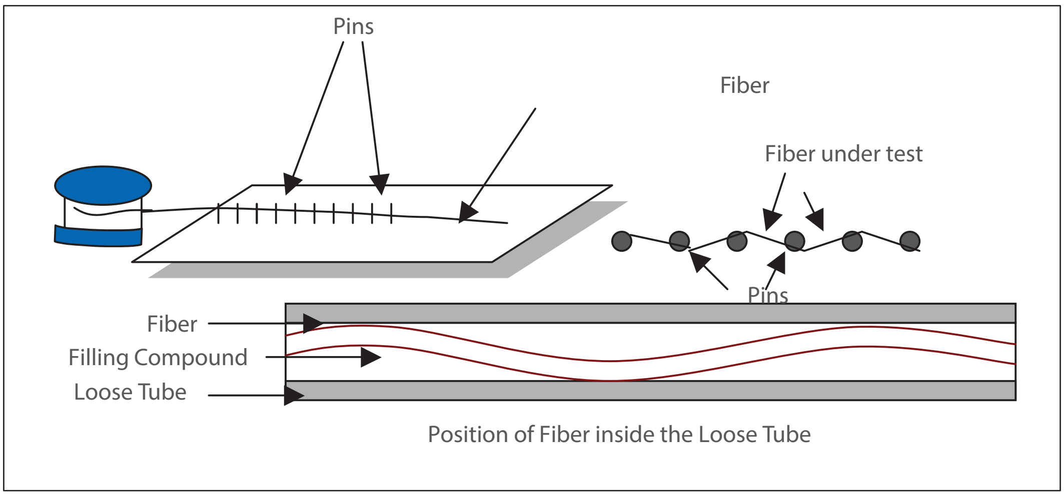


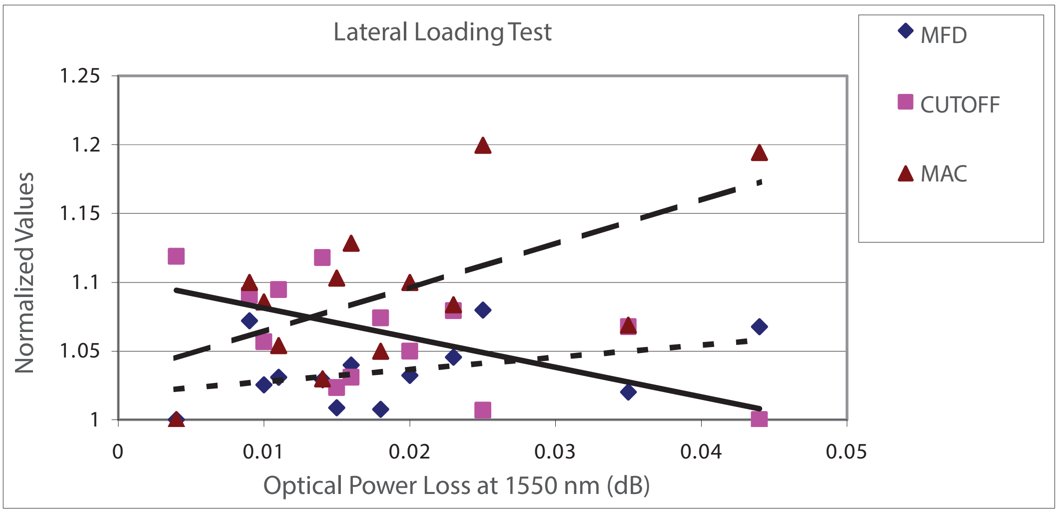
Fig. 2 Set up for Pin Array Test and Position of fiber inside the Loose Tube

Water Aging Test

This test has been carried out to evaluate the sensitivity of the fiber to micro-bending which is primarily caused by unbalanced stresses developed due to water absorption while aged under de-ionized water for 14 days at 25ºC temperature. This test has been conducted as per FOTP-74 (TIA/EIA – 455 – 74). Maximum change in attenuation at 1550 nm (in dB/km) was measured by OTDR for fibers having different MFD, Cut-off and MAC values.

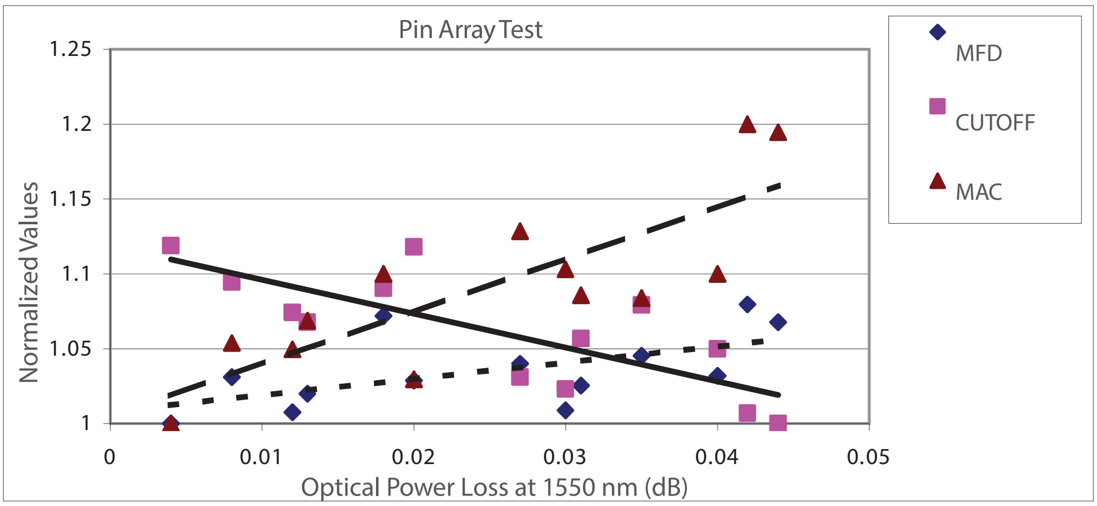
Analysis

The figures 3 to 6 show plots of macro and microbending losses vs MFD, MAC value and Cut-off using various testing techniques.



Trend line (Cut-off) — — — Trend Line (MAC) ----- Trend Line (MFD)

Fig. 3 : Plot of optical power loss at 1550 nm with MFD, Cut-off and MAC – value for Lateral Loading Test



Trend line (Cut-off) — — — Trend Line (MAC) ----- Trend Line (MFD)

Fig. 4 : Plot of optical power loss at 1550 nm with MFD, Cut-off and MAC value for Pin Array Test

Trend line (Cut-off) — — — Trend Line (MAC) ----- Trend Line (MFD)

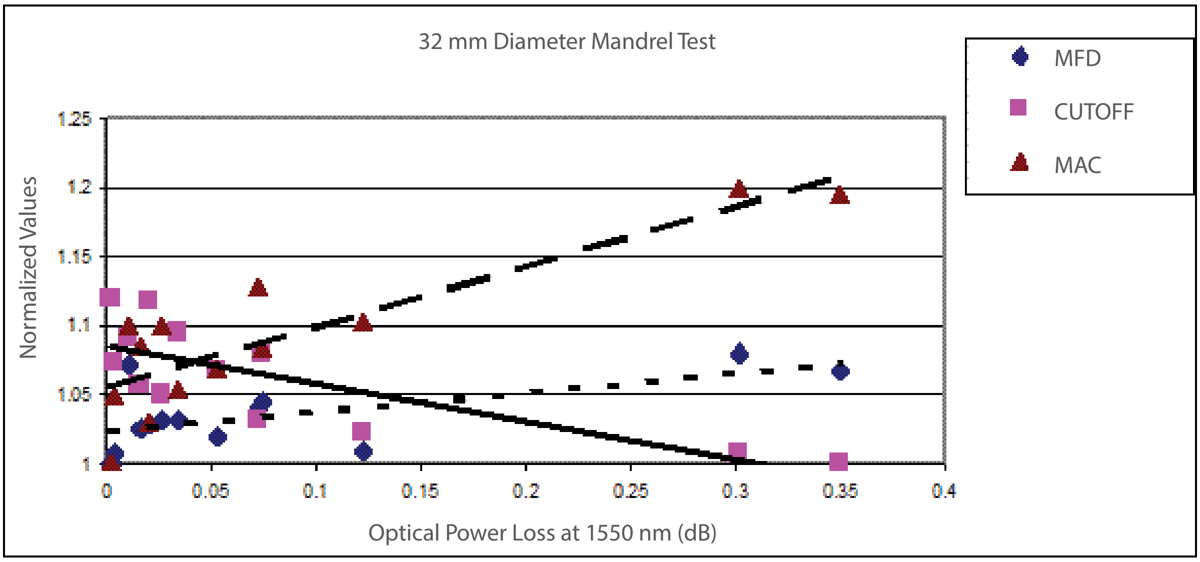


Fig. 5 : Plot of optical power loss at 1550 nm with MFD, Cut-off and MAC value for 32 mm diameter mandrel test

Trend line (Cut-off) Trend Line (MAC) Trend Line (MFD)

Trend line (Cut-off) Trend Line (MAC) Trend Line (MFD)

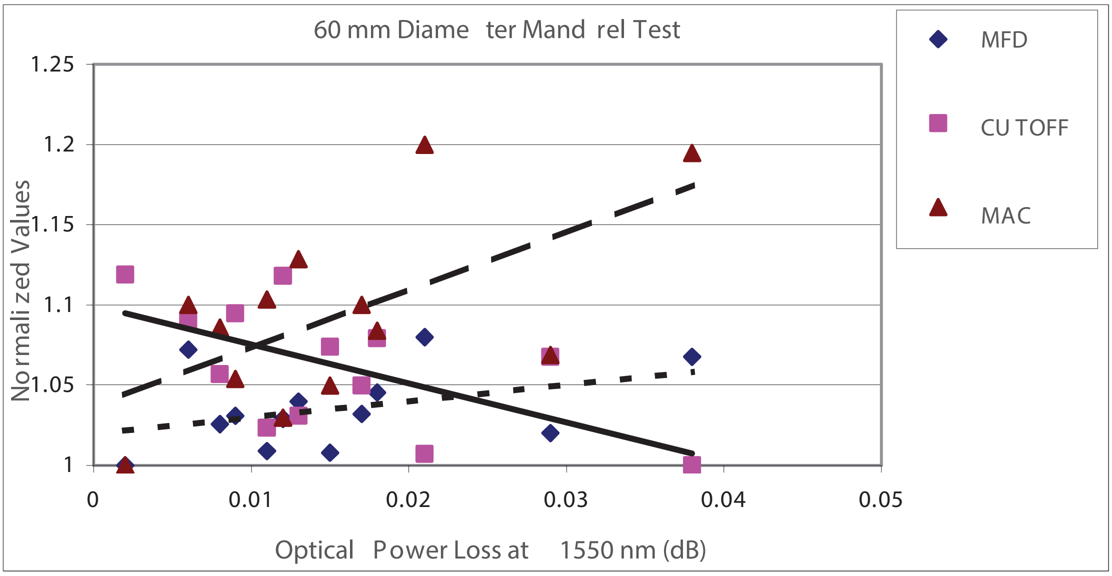


Fig. 6 : Plot of optical power loss at 1550 nm with MFD, Cut-off and MAC value for 60 mm diameter mandrel test

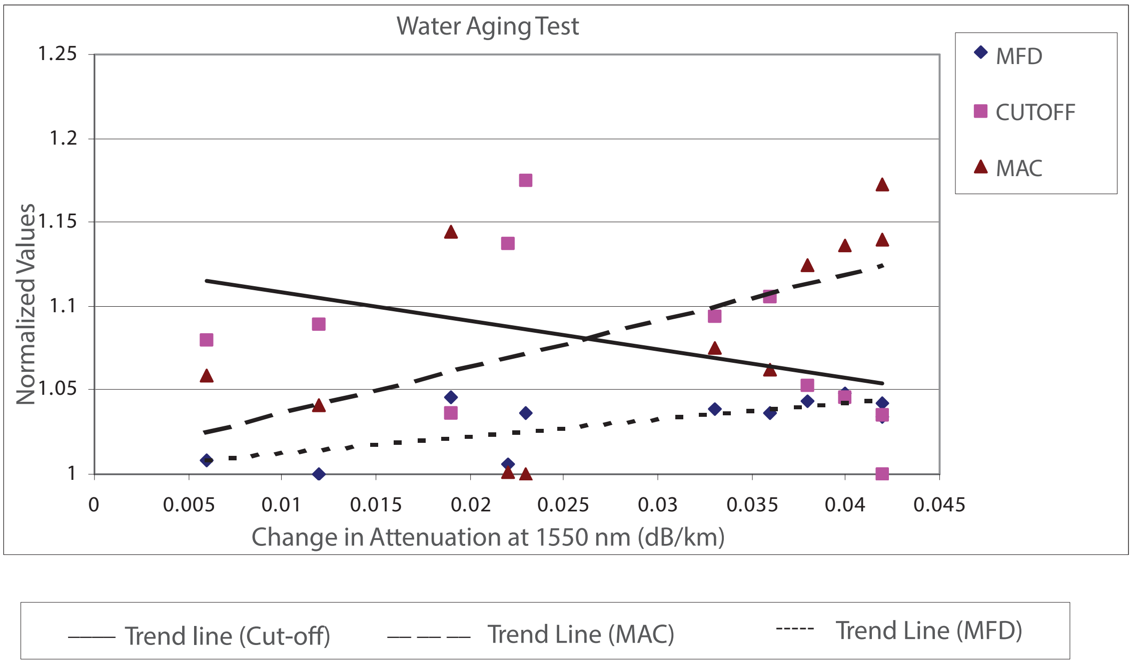


Fig. 7 : Plot of maximum change in attenuation at 1550 nm with MFD, Cut-off and MAC values for water aging test

Figure 7 shows maximum change in attenuation at 1550 nm (in dB/km) of SMF having different MFD, Cut-off and MAC value for water aging test. The values of the slope of the above trend lines represent the sensitivity of that particular parameter on bending loss. The values of the slope are given in Table 1.

Table 1: The values of the slope of different trend lines of the above figures

Parameters	Lateral Load	Pin-Array	32 mm dia	60mm dia	Water Aging
MFD	0.89	1.1	0.14	1.02	0.99
MAC-value	3.22	3.51	0.44	3.64	2.77
CUTOFF	2.15	2.26	0.27	2.43	1.7

The slope of the MAC value vs bending loss graphs are considerably higher in all cases than that of MFD and Cut-off. This indicates that, bending losses are more dependent on MAC value. We have used two different techniques for measuring micro-bending loss i.e LLT and PAT. The values of the slope of different parameters for PAT are higher than that of LLT. This indicates that, PAT is more effective than LLT to evaluate micro-bend sensitivity of SMF. Similarly, the absolute values of the slope of macro bending on 60 mm diameter mandrel are higher than that of 32 mm diameter mandrel. However, 32 mm diameter mandrel test has shown highest optical power loss amongst all testing techniques.

The minimum change in attenuation at 1550 nm for water aging test was 0.006 dB/km. Which could be due to the presence of osmotic pressure and hydrolytic phenomena caused by small absorption of water by the coating material. Change in attenuation beyond 0.006 dB/km was controlled by different bend sensitivity parameters i.e. MFD, Cut-off and MAC value. Among these three parameters MAC value has shown the highest sensitivity as highlighted by the other micro-bending tests.

beyond tomorrow

Conclusions

1. Bending sensitivity of match clad, step-index SMF depends on MFD, Cut-off and their ratio, MAC value.
2. Both micro and macro-bending losses increase with the increase in MFD & MAC value and increase with decrease in Cut-off wavelength.
3. Both micro and macro-bending losses are more sensitive to MAC value as compared to Cut-off & MFD for all testing techniques. Hence, bending sensitivity of SMF can be predicted by knowing MAC value only.
4. PAT is a better technique as compared to LLT while evaluating micro bending sensitivity of match clad, step –index SMF.
5. Similarly winding on 60 mm diameter mandrel is a better technique to evaluate macro bending sensitivity with respect to MFD, Cut-off and MAC value as compared to winding on 32 mm diameter mandrel.
6. Change in attenuation in water aging test is due to micro-bending effect that is controlled by water absorption of coating material and has shown a minimal value.
7. Change in attenuation in water aging test is also effected by MFD, Cut-off and MAC value as these parameters effect micro-bending sensitivity. Among these three parameters MAC value has shown the highest sensitivity as shown by the other micro-bending tests.

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