Mechanical reliability of optical fibers

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Abstract
The scientific background for the mechanical reliability of optical fibers and methodology followed at Sterlite Tech based on which the reliability of optical fiber under a constant stress has been estimated is described in this report. It should be noted that the reliability is expressed as an expected lifetime or as an expected failure rate. The results cannot be used for specifications or for the comparison of the quality of different fibers.

Keywords
Optical fibers, Mechanical Reliability, Power Law Theory, Lifetime estimation, Fatigue testing, Proof testing, Long length tensile testing

I. INTRODUCTION

With the global market for fiber optic components being projected to reach US$ 42 billion by the year 2017, the growth will be driven by continuously growing demand for bandwidth and the ensuing need for fiber-based broadband, robust growth in mobile internet and stronger FTTx related deployments [1]. This growing demand for optical fiber deployment in various application scenarios poses some serious challenges in terms of their mechanical reliability as the deployed fiber is expected to survive the in-service conditions for maximum possible time duration without compromising with its optical properties.

II. OPTICAL FIBER LIFETIME

The fiber strength distribution is a key element for the mechanical reliability models generally used to predict the optical fiber lifetime under given in-service stress conditions. Although all these models based on the theory of crack propagation in silica based glasses [2], the power law theory is the most relevant to date as it considers the influence of environment dependent crack growth parameters while modelling the crack growth and predicting lifetime of optical fibers.

According to the technical report of International Electrotechnical Commission-IEC/TR 62048 [3], the formula for calculating the in-service lifetime of an optical fiber based on power law theory is presented in equation (1).

$$t_f = \left[\left\{ \frac{\beta^{m_s}}{L} \ln \frac{1}{P} + \left(\sigma_p^n t_p \right)^{m_s} \right\}^{\frac{1}{m_s}} - \sigma_p^n t_p \right] \sigma_a^{-n}$$

(1)

Where, t_f is the lifetime (time to failure) under constant stress or static fatigue testing; m_s is the Weibull modulus under static fatigue; is the Weibull -value; σ_a is the applied stress under static fatigue and lifetime; σ_p is the proof-test stress (0.72 GPa); t_p is the effective proof time; L is the fiber effective length under uniform stress, or equivalent tensile length; n is the stress-corrosion parameter; P is the fiber survival probability.

The lifetime model proposed in IEC/TR 62048 (Equation 1) is equivalent to that proposed by Griffioen et al. [4, 5] for long-length proof-tested fiber as given in equation (2):

$$\sigma_s^n t_s = \sigma_p^n t_p \left[\left\{ 1 - \frac{\ln(1-F)}{N_P L} \right\}^{\frac{n-2}{m}} - 1 \right]$$

(2)

Where, σ_s is the in-service stress, t_s is the fiber lifetime, σ_p is the proof stress, t_p is the time during which each point of the fiber experiences proof stress, F is the failure probability, L is the fiber length, N_P is the mean number of breaks per length during proof testing, m is the Weibull parameter obtained for extrinsic flaw distribution.

In accordance with IEC/TR 62048, Sterlite Technologies Ltd. (STL) employs equation (2) to predict the lifetime of their optical fiber under in-service stress conditions. A detailed overview of the theory and practice of estimating the mechanical reliability of optical fibers has been presented in our technical report entitled, "Estimating the mechanical reliability of optical fibers". The data presented below provides an insight into the expected lifetime of STL optical fibers based on the inputs given in equation (2).

Table 1: Expected lifetime for any length of STL optical fiber with varying applied stress[1]
1 Failure Probability << 1 ppm

Expected applied stress (σ_a)	Lifetime
22 kpsi	≥ 40 years
27 kpsi	4 months
30 kpsi	24 hours
36 kpsi	5 hours
54 kpsi	3 seconds

Summary

Power law theory has been used to predict the mechanical reliability of STL optical fiber and gives the stress guidelines for its usage. For the greatest reliability, long terms stresses should not exceed one-fifth the proof stress (22 kpsi) while the short-term stresses should be limited to 1/3rd the proof stress (36 kpsi).

References

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