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Measurements in New Optical Cables

Pre-Construction and Post-Construction Measurements

Author

Sudipta Bhaumik

Abstract

Dynamic fatigue behavior of high strength silica optical fiber was studied as a function of relative humidity of draw environment. Fibers were drawn with graphite induction heating furnace and controlled temperature, relative humidity and particle count of the draw environment i.e. drawing furnace to coating application point. Dynamic fatigue of the drawn fibers were measured with two different modes of loading, tensile & two-point bending. Draw humidity was found to have a decided impact on dynamic fatigue measured by tensile loading.

Introduction

Dynamic fatigue behavior of silica optical fiber has been studied for many years. As lifetime of optical fiber used in long-haul telecommunication network can be predicted by dynamic fatigue parameter1,2, this has been a topic of research and interest for optical fiber manufacturers. Dynamic fatigue or stress corrosion, which influences rate of crack growth and delayed failure of silica optical fiber, is known to happen in presence of external stress, flaw/micro-crack and moisture on the surface of fiber. All of these three conditions are to be present together for fatigue to occur. So to prevent fatigue, removal of any of these three conditions is necessary. The first condition i.e. presence of external stress, can not be avoided completely with existing different types of cable designs like loose tubes, tight buffers and ribbons. In tight buffer and ribbon, fiber can face complex array of external stresses. Even GR-20 (Telcordia) allows fibers to carry 60% of proof-test load (i.e. almost 550gm) inside the cable 3.

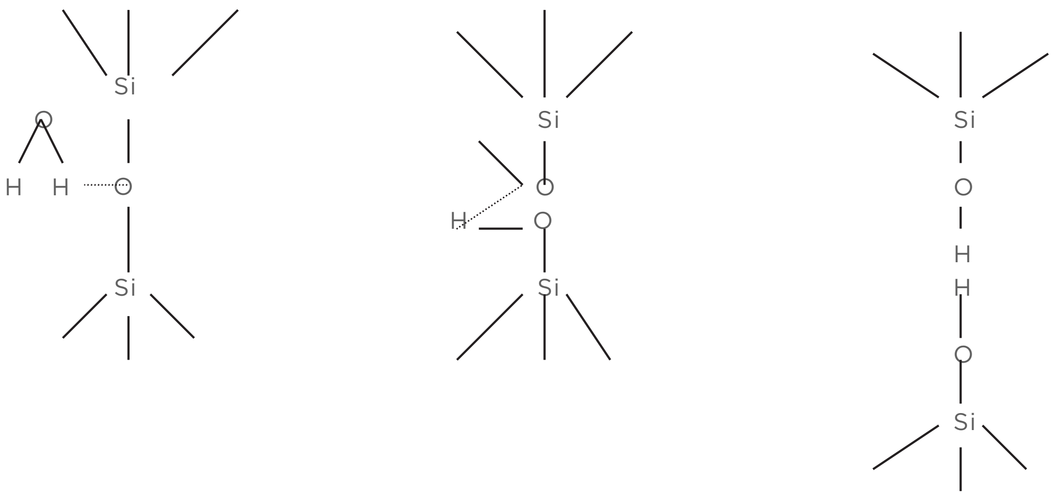
The second condition i.e presence of surface flaw/micro-crack , is of great interest to optical fiber manufacturers. Advancement in quality of raw materials for optical fiber manufacturing and understanding of manufacturing process and controlling instrumentation, made significant improvement in reduction of surface flaws and increase of strength value. Now commercially available fibers are having minimum tensile strength value of 4.4 GPa4 and typical value of 4.8 GPa measured with 5% strain rate against minimum requirement of 3.8 GPa as per GR-20 (Telcordia). But the tensile strength value is still much lesser than the theoretical value of 20GPa. That means surface flaws/micro-cracks have been reduced but not eliminated completely. Previous studies reveal that mechanisms of fatigue, or absence of fatigue, apparently do not depend on the size of surface flaws and initial strength of fiber 5,6,7. It was also concluded that the fatigue behavior of flaws in optical fiber is relatively independent of origin like abrasion, particle contamination and indentation 7. That's mean reduction of size of surface flaws does not guarantee improvement of dynamic fatigue of silica optical fiber unless until flaws are eliminated completely.

Thus the third condition, i.e. presence of moisture, becomes most important criteria and research interest. Stress corrosion in silica glass by water is well known. The reaction between water and strained Si-O-Si bond at surface crack tip of optical fiber involve three steps 8.

1. Adsorption of water to Si-O bond at the crack tip

2.Concerted reaction involving simultaneous proton and electron transfer

3.Rupture of hydrogen bond and formation of surface hydroxyl groups



Duncan et al.9 have studied the behavior of strength and fatigue as a function of both humidity and temperature of test environment and suggested the following equations which can be used to predict the failure strain   (or stress) and fatigue parameter (n) as a function of relative humidity (Z) and absolute temperature (T):

  = 2.28 Z-0.093 exp(2400/RT) -------------------------------------(1)
n-1 = -10 / [-0.9 –0.093logZ + (2400/2.3RT)]---------------------(2)

Later these results was reconfirmed by Mrotek J.L. et al. 10 who found the reaction order for fatigue of high strength fused silica fiber to be ~2 at high humidity (20-95% RH) and ~1 in low humidity (0.025-13% RH). After understanding of detrimental effect of moisture on fatigue, several studies have been done to prevent moisture to come in contact with glass surface and to improve fatigue value. The result was development of "hermetic" coating, which isolate the fiber surface from environment. Application of various hermetic coating, metal (Aluminum, Nickel, Zirconia), inorganic (SiON, SiC, TiC etc) and carbon , on the surface of glass showed substantial improvement of fatigue value. Dynamic fatigue values ranging from 23 to 500 were noted .[11,12,13,14,15] But substantial lowering of the measured strength values- levels of 2.5-3.5 GPa was noted for hermetically coated fibers. Tomozawa et al [16,17,18] determined that the strength and fatigue behavior of optical fiber is dependent on fictive temperature of glass. Lower fictive temperature allows more water vapor to enter the glass and thus lowers fatigue resistance parameter. As most of the commercially available fibers are polymer coated fibers, studies have been done on diffusion of moisture through optical fiber coatings and it has been found that moisture penetrates on a time scale of ~10^2 to 10^3 seconds [19]. Armstrong J.L. et al.[20] had studied dynamic fatigue behavior of silica fibers as a function of humidity of test environment for acrylate, polyamide and silicone coated fibers and compared with bare fiber. All coated and bare fibers had shown reduction in dynamic fatigue value with increase in relative humidity of test environment. The polymer coatings had shown negligible effect on the kinetics of the fatigue as long as the fibers were properly equilibrated in the test environment before testing. Inniss D. et al. [21] showed addition of particulate materials (Silica, Alumina, Zirconia, Titania), which are partially soluble in water in the coating increase moisture resistance and thus fatigue life of optical fiber.

It is clear from the literature that moisture from test environment is playing an important role to control dynamic fatigue value. Particularly the strength value at slower stress rate where moisture from test environment gets sufficient time to diffuse through coating and corrode glass surface. But the previous studies have ignored the influence of relative humidity of draw environment which may be because of little exposure time of bare glass before coating application for high speed drawing. But direct adsorption of water molecule on glass surface and cover up by coating during drawing should have more impact compared to water molecule diffused through coating from test environment. This paper is intended to describe effect of relative humidity of draw environment on dynamic fatigue of high strength polymer coated silica optical fiber.

Experimental

Sample

Dual polymer coated high strength silica optical fibers for standard telecommunication networks were used in this study. Silica optical fibers with glass diameter of 125µm and coating diameter of 245µm were drawn with controlled drawing atmosphere in terms of temperature, relative humidity and particle count. The space where bare fiber exposed to surrounding atmosphere during drawing, that means space between draw furnace and coating applicator, was maintained to pre-determined environment. A total of eight samples were drawn with constant temperature of 24±2ºC, class-100 (i.e. less than 100 particles of size ≥0.5µm per ft^3 volume of air) particle count and varying relative humidity from 40% to 80%. The drawn fibers were prooftested with 1% strain and then proof-tested fibers were tested for dynamic fatigue by different methods. All the samples were aged in laboratory environment (55±5% relative humidity and 23±2ºC temperature) for minimum 12 hours prior to testing. Tensile strength of all eight fibers are above 4.4 GPa (Sample length: 0.5 meter and extension rate: 25 mm/min).

Dynamic fatigue by tensile loading

Dynamic fatigue by tensile loading of coated fibers after proof testing was measured as per FOTP-455- 28C (EIA/TIA)[22]. We had chosen four different extension rates between 0.09, 0.6, 4 & 30 %/min so that the extension rates are apart by a factor of 7 from each other. The gauge length was 0.58 meter. A sample size of 15 per extension rate for each fiber sample was used. Dynamic fatigue or stress corrosion parameter (N_d) had been calculated from the slope of linear plot of log of failure stress vs. log of the stress rate. As N_d is inversely proportional to the slope, lesser slope of the linear plot will result higher N_d. Lesser slope means lesser difference between tensile strength measured at four different extension rates.

Dynamic fatigue by two-point bending

Dynamic fatigue of proof-tested coated optical fibers were measured according to the procedure written in Telecommunications System Bulletin no. TSB62-13. In two-point bend apparatus, the fibers are bent between two faceplates that are brought together until fiber breaks. An acoustic transducer detects the break. Grooved faceplates are used to locate the fiber accurately. Bending stress developed at the tip of the fiber sample placed in between two faceplates. The length of the region under bending stress is approximately 2 mm. The two-point bend strength of the fiber samples were measured at four different faceplate velocities (1, 10, 100 and 1000 μ m/sec). Nd was calculated by the method described earlier.

Result and Discussion

The dynamic fatigue values both with two-point bending and tensile loading of each fiber along with corresponding draw humidity are shown in Table.1. There is a clear trend of decrease in N_d measured by tensile loading with increase in draw humidity. But no such trend exists for Nd measured by two-point bending. Fig.1 shows dynamic fatigue plot of Fiber#1 (highest N_d by tensile loading) and Fiber#8 (lowest N_d by tensile loading). It can be seen that the variation of tensile strength at lowest extension rate (0.09%/min) is much higher in Fiber#8 compare to Fiber#1. The variation in tensile strength resulted lower N_d value. For clarity, weibull plot of tensile and two-point bend strength values measured at four different speeds of one fiber each from four draw humidity range were shown in Fig.2 & 3 respectively. From Fig.2, it is clear that as draw humidity increases, tensile strength measured at lowest extension rate decreases but no significant change in values measured at higher extension rates. Fig.3 suggests no such change in strength values measured by two-point bending at different speeds for different fibers except fiber#8, which was drawn in maximum humid environment.

The effective 'tested' length of fiber under load during strength testing is much higher in case of tensile loading (580 mm) compared to two-point bending (~2 mm). Breuls A. [23] & Mattheson MJ. et al [24] showed difference in effective 'tested' glass area (i.e. length & geometry-bending or tensile) can give different strength value and also derived way to predict bending strength from tensile strength. But while comparing predicted & experimental strength values they found good agreement only for low strength (<0.72GPa) & high Weibullmodulus fiber. As in this study high strength fiber used and at lower extension rate bi-modal strength distribution found (see fig.2), the way to predict bending strength from tensile strength cannot be applied.

As written in IEC 60793-1-33 (Annex H), both the test methods used in this study are measured stress corrosion data of the intrinsic strength distribution. But different values of N_d measured by two different methods particularly for the fibers drawn in higher humid environment (or moisture corroded) were found. The findings suggest that two-point bend strength method where effective test length is approximately 2 mm , is measured intrinsic strength distribution and remain unchanged when extrinsic strength distribution changed. For the fibers drawn with drier environment (like fiber #1 to 4), N_d measured with two different methods are closer, compare to those drawn with humid environment (like Fiber# 5 to 8). That means for the fibers #1 to 4, there were no big difference between extrinsic & intrinsic strength distribution but for the fibers #5 to 8 extrinsic strength distribution differed by moisture corrosion due to humid draw environment. In the previous studies, stress corrosion parameter of mechanical & particle abraded fibers were found higher than those of the intrinsic strength distribution [25,26]. But in this study we have found lower value of stress corrosion parameter of moisture-corroded fibers.

Conclusion

Relative humidity of fiber drawing environment effects dynamic fatigue (or stress corrosion parameter, N_d) of high strength polymer coated silica optical fiber. Higher draw humidity decreases strength at lowest extension rate and subsequently dynamic fatigue parameter measured by tensile loading but N_d measured by two-point bending has little impact except extremely high relative humidity. Two-point bending measures N_d of intrinsic strength distribution which is unaffected by moisture corrosion due to humid draw environment. Closer values of N_d obtained for two different mode of loading (tensile & bending) when intrinsic & extrinsic strength distributions are same for the fibers drawn with drier draw environment. Moisture corrosion by humid draw environment changes extrinsic flaw distribution and decreases Nd measured by tensile loading.

Table.1 Dynamic fatigue values of various fibers drawn with different relative humidity

	Draw Relative Humidity (%)	Two-Point bending	Tensile Loading
Fiber#1	40-50	25	25
Fiber#2	40-50	28	25
Fiber#3	50-60	24	25
Fiber#4	50-60	25	22
Fiber#5	60-70	29	21
Fiber#6	60-70	27	22
Fiber#7	70-75	27	19
Fiber#8	75-80	20	16

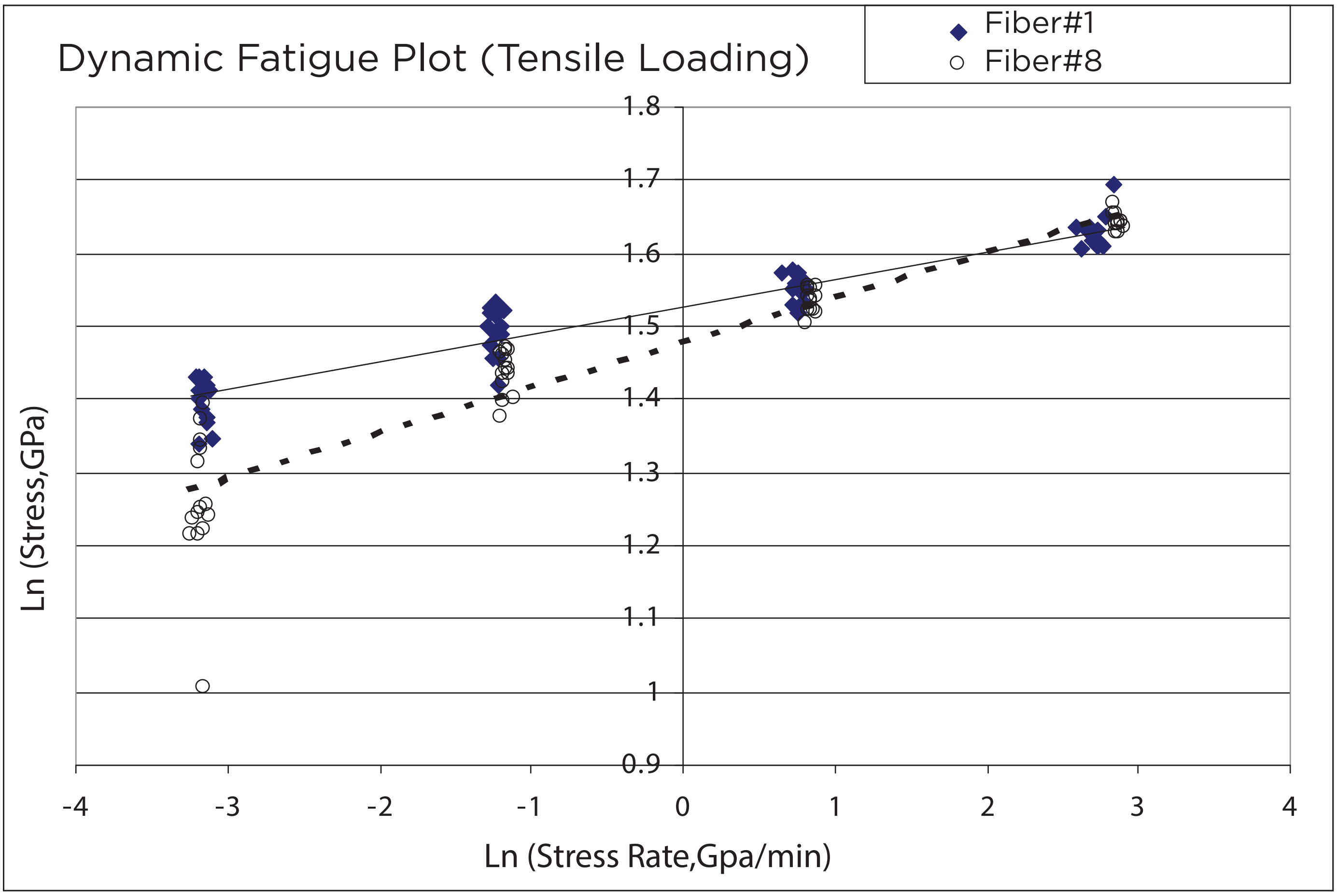


Fig.1 Dynamic Fatigue (tensile loading) plot of Fiber#1 & 8

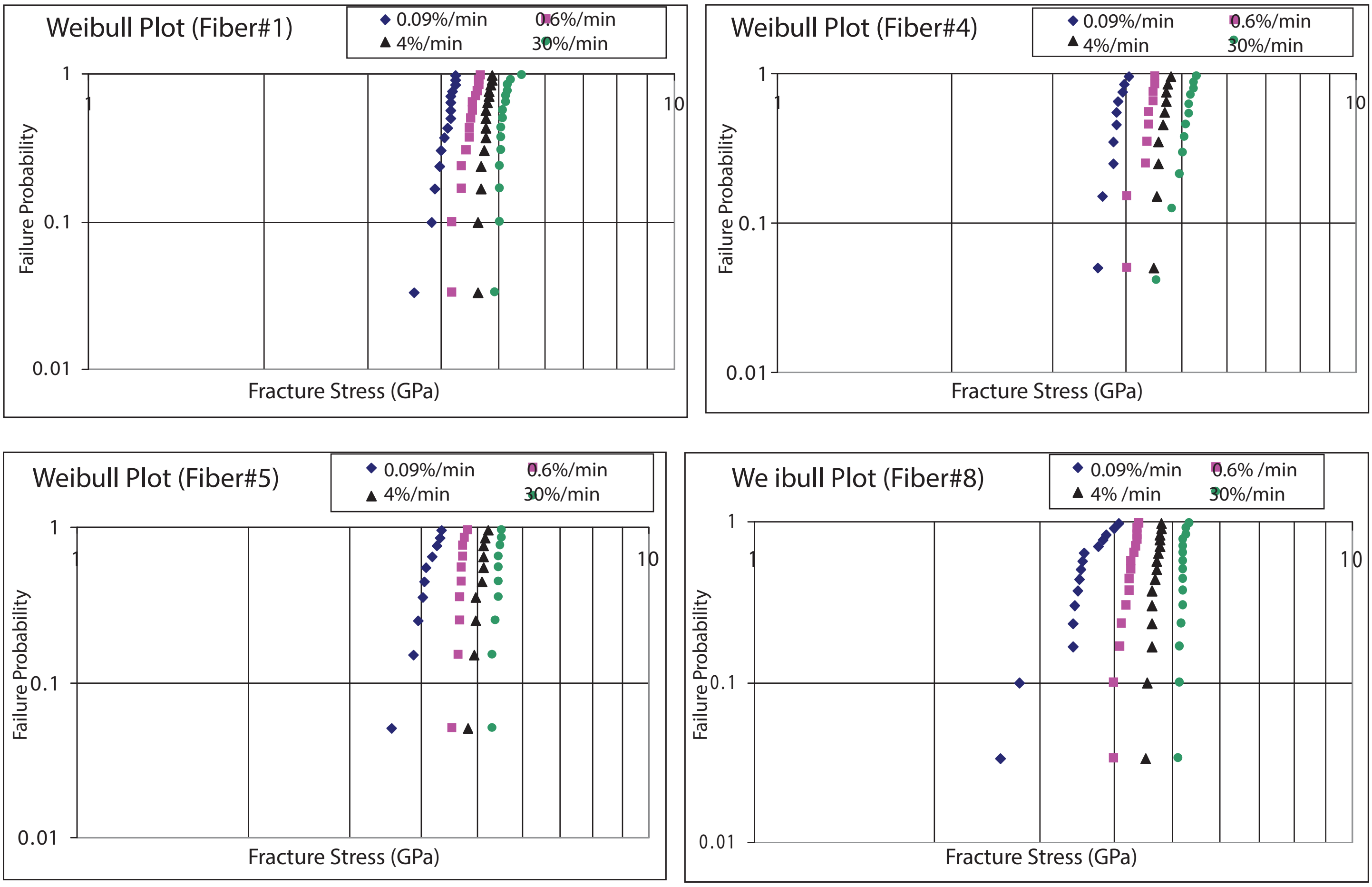


Fig.2 Weibull plot of tensile strength values at four extension rates of Fiber# 1,4,5 & 8

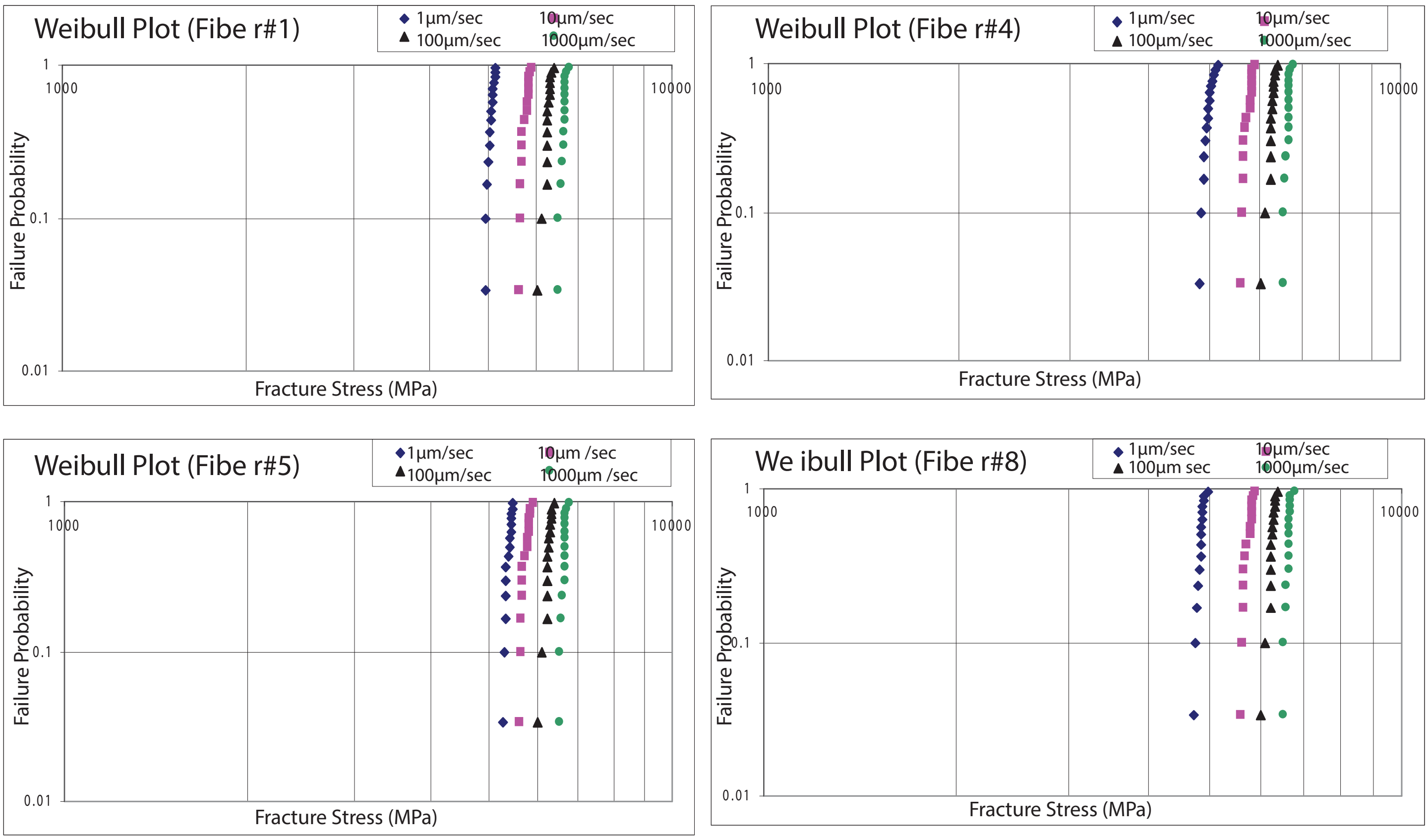


Fig.3 Weibull plot of two-point bend strength values at four extension rates of Fiber# 1,4,5 & 8

beyond tomorrow

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We design and integrate these digital networks for our customers. With core capabilities in Optical Interconnect, Virtualized Access Solutions, Network Software and System Integration, we are the industry's leading end-to-end solutions provider for global digital networks. We partner with global telecom companies, cloud companies, citizen networks and large enterprises to deliver solutions for their fixed and wireless networks for current and future needs.We believe in harnessing technology to create a world with next generation connected experiences that transform everyday living. With intense focus on end-to-end network solutions development, we conduct fundamental research in next-generation network applications at our Centre of Excellence. STL has a strong global presence with next-gen optical preform, fibre and cable manufacturing facilities in India, Italy, China and Brazil, optical interconnect capabilities in Italy, along with two software-development centres across India and one data centre design facility in the UK

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Sudipta Bhaumik is an Associate Manager in Sterlite Optical Technologies Limited, Aurangabad, India. He joined Sterlite in 1998 as process development engineer. He received his bachelor's degree in ceramic engineering from Calcutta University, India and master's degree in ceramic engineering from Banaras Hindu University, India. He has been engaged with quality and reliability issues of optical fiber and development of analytical techniques. He has received Urbain J.H.Malo medal award for best technical paper in Electrical/Fiber Optics division in 2002 and 2003.