FIBERCORE Limited, Chilworth, SO16 7NS	REPORT
Reliability Programme – HBT Optical Fibre	Page 1 of 19
	March 2002

ABSTRACT

Fibercore Singlemode Polarisation Maintaining Fibre HBT has been subjected to a rigorous Qualification and Reliability Program – as defined in document Q&R 010.

Interim results are presented here against the following sections:

1. Fibre strength

    - Weibull plot for Tensile Strength unaged and aged
    - Dynamic Tensile Strength unaged and aged
    - Stress Corrosion Parameter unaged and aged
    - Static Fatigue unaged

2. Coating strip force – unaged and aged

3. Geometrical characterisation: fibre diameter, core concentricity and fibre ovality

4. Discussion of lifetime model

RESULTS OF THE QUALIFICATION OF FIBERCORE HBT FIBRE TYPE

ABSTRACT

Fibercore singlemode polarisation maintaining optical fibre has been subjected to a rigorous Qualification and Reliability Program – as defined in document Q&R 010. This fibre type is a singlemode polarisation maintaining fibre with variants designed for use at 980, 1310 or 1550 nm. The principal uses of this fibre include pigtailing of optical components, pump diodes, couplers, splitters, filters etc. or for use in poliarmetric sensors.

OBJECTIVE

To subject the fibre type HBT to a comprehensive set of tests, consistent with documented industry standards. A further objective is to provide the data necessary to predict lifetime in deployed environments.

Where relevant and appropriate, tests are based on Telcordia (Bellcore) documents or international standards, FOTP's, IEC, OFMeC etc.

SUMMARY OF RESULTS

The results are summarised below with test descriptions and results deferred to later sections in the report.

Test No	Test Detail	Results
1.1	Coating strip force	
1.1.1	Ambient	Av = 4.85 n, SD = 0.72 N 40 samples
1.1.2	Temperature extremes	
1.1.3	Temp/humidity-aged 250µm coating	Av = 3.16 N, SD = 0.28 N 10 samples
	Water-aged	Av = 4.80 N, SD = 0.74 N 20 samples
1.2	Tensile strength	
1.2.1	Unaged	50% point 4.40 GPa, 15% point 4.34 GPa
1.2.2	Temperature & Humidity-aged	50% point 4.60 GPa, 15% point 4.25 GPa
1.3	Dynamic Fatigue	Nd = 20.6 unaged, 21.9 aged
1.4	Static Fatigue	Ns = 31.4 unaged
1.5	Geometry	
1.5.1	Fibre diameter125 µm (all types)	Av = 124.86 µm, SD = 0.27 µm
1.5.2	Cladding non-circularity (all types)	Av = 0.65%, SD = 0.34%
1.5.3	Core eccentricity (all types)	Av = 0.217 µm, SD = 0.139 µm
1.6	Fibre Cleavability	< 0.5 degrees, no hackle
1.7	Splice Performance	< 0.1 dB loss, > 30dB extinction ratio

FIBRE TYPES TO BE INCORPORATED INTO THE TESTS

Fibercore Ltd. manufactures a large range of fibres for a diverse range of applications. This report summarises the results with the fibre type HBT, a singlemode polarisation maintaining fibre for operation at 980, 1300 or 1550 nm.

Two types of coating are offered within this range, a 400 µm or 245 µm dual acrylate package.

Fibre types incorporated in these tests:

A 125µm HB1250T or HB1500T fibre with a 400 µm (nominal) dual acrylate coating which has been proof tested to 1% shown as HBT 400 in the following table.
A 125 µm HB980T with a 245 µm dual acrylate coating shown as HBT 400 in the following table.

SUMMARY OF QUALIFICATION PLAN

Test description	Fibre type	Reference
1.1 Coating strip force 1.1.1 Unaged fibre at termination temp. 1.1.2 Temp and humidity aged fibre 1.1.3 Water aged fibre	HBT 245	Bellcore GR-20-CORE Issue 2, section 4.4.2
1.2 Tensile strength of coated fibre (dynamic) 1.2.1 Unaged 1.2.2 Temperature and humidity aged	HBT 245 & 400	Bellcore GR-20-CORE Issue 2, section 4.4.3
1.3 Dynamic fatigue	HBT 245 & 400	Bellcore GR-20-CORE Issue 2, section 4.4.3
1.4 Static fatigue	HBT 245 & 400	GR-20-CORE Issue 1; September 1994, R4.41.
1.5 Geometry		
1.5.1 Fibre diameter	All fibres	Bellcore GR-20-CORE Issue 2, section 4.3
1.5.2 Cladding non-circularity	All fibres	Bellcore GR-20-CORE Issue 2; section 4.3
1.5.3 Core eccentricity	All fibres	Bellcore GR-20-CORE Issue 2, section 4.3

Additional tests outside Bellcore requirements

Test description	Fibre type	Objective and Reference
1.6 UV acrylate temperature performance	HBT 400	To determine the suitability of the UV acrylate coating packages over appropriate temperature ranges.
1.7 Fibre cleavability	HBT 245	Bellcore TR-TSY-000264, Optical Fiber Cleaving Tools, section 4.1.2.1
1.8 Splice performance	HBT 245 & 400	To determine the loss associated with incorporating Fibercore fibres into existing fibre networks. Bellcore TR-NWT-000765, generic requirements for Single-Mode Splicing Systems.

TEST RESULTS

1.1 Coating Strip Force

1.1.1 Reference: Bellcore GR-20-CORE Issue 2; R4-29
The force required to remove 30 ± 3 mm (1.2 in ± 0.1 in) of the unaged fibre's protective coating at the fibre termination temperature extremes [0° C and 45° C (32° F and 113° F)] shall not exceed 9.0 N (2.0 lbf) and shall be equal to or greater than 1.0 N (0.2 lbf).

1.1.2 Reference: Bellcore GR-20-CORE Issue 2; R4-30
The force required to remove 30 ± 3 mm (1.2 in ± 0.1 in) of the unaged fibre's protective coating for the temperature/humidity-aged fibres shall not exceed 9.0 N (2.0 lbf) and shall be equal to or greater than 1.0 N (0.2 lbf).

1.1.3 Reference: Bellcore GR-20-CORE Issue 2; R4-31
The force required to remove 30 ± 3 mm (1.2 in ± 0.1 in) of the unaged fibre's protective coating for the water-aged fibres shall not exceed 9.0 N (2.0 lbf) and shall be equal to or greater than 1.0 N (0.2 lbf).

Test procedure

Fibre strip force shall be tested in accordance with the procedure specified in FOTP-178. The following exceptions and additions shall apply to FOTP-178.

The tool(s) used to determine the conformance of the fibre coating to the strip force requirements in this document shall conform to the requirements of TR-NWT-000955, *Generic Requirements for Optical Fiber Stripping (Coating Removal) Tools.*

Samples
Ten fibres from each type of coating package shall be tested for conformance to the requirements at each test condition.

Preconditioning

Type of sample	Preconditioning Environment
Termination Temperature Samples	Fibres shall be preconditioned for a minimum of five minutes at each of the fibre termination temperature extremes: 0° C (32° F) and 45° C (113° F). Humidity need not be controlled
Temperature/humidity-Aged samples	The humidity-aged fibres shall be soaked at a temperature of 85 ± 2 ° C (185 ± 3.6 ° F) and a noncondensing humidity of 85 ± 5 % for a period of 30 days
Water-Aged Samples	The water-aged fibres shall be soaked in tap water at a temperature of 23 ± 5 ° C (73 ± 9 ° F) for a period of 14 days.

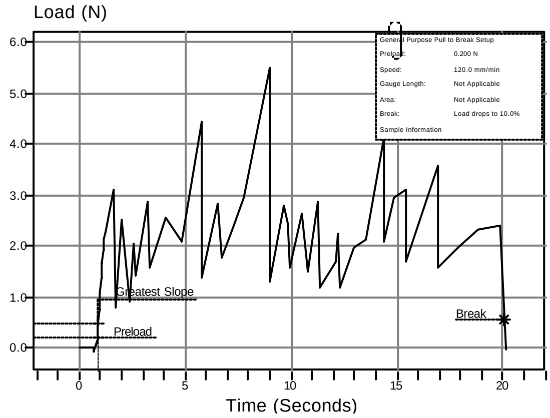
Results

A set of Miller Strippers were mounted onto a tensometer and the force required to remove a 30mm length of coating as a function of time determined.

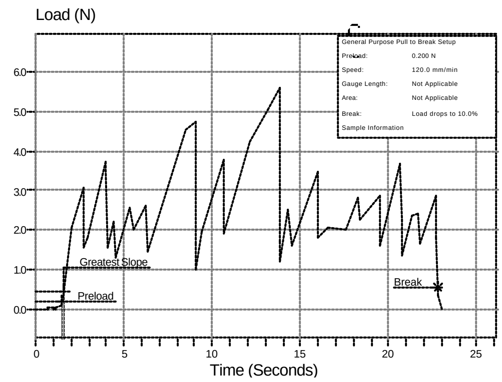
A 125 µm HBT fibre coated with a generic dual acrylate package to 245 µm was used. This acrylate package is one which is common with other telecomms fibre types.

Test Details	No of samples	Mean (N) of maximum force during strip	Standard Deviation (N)
Termination temperature extremes 0 °C (32° F) 20 °C (68°F) 45 °C (113° F)	40	4.85	0.72
Temp/humidity-aged	10	3.15	0.28
Water-aged	20	4.80	0.74

Typical plot of force required to strip 40 mm coating from unaged fibre at 20°C. The maximum and minimum values are between the Bellcore defined limits of 9.0 and 1.0 N.



Typical plot of force required to strip coating from 40 mm length of fibre after water aged for 30 days at 20°C.



These plots are consistent with the removal of a semi-rigid material which is adhered to the glass surface. The test verifies that the adhesion of the inner coating to the glass strand is good and that the mechanical properties of the coating are suitable. The saw tooth response is consistent with the coating puckering and then splitting and being stripped from the glass strand. The coating is not removed as a continuous tube.

The Bellcore requirements were satisfied for both unaged, humidity aged and water aged samples. In all the tests no values were recorded outside the requirement.

1.2 Dynamic Tensile Strength of a Fibre

Requirements: Reference Bellcore GR-20-CORE Issue 2; R4-32.

The minimum tensile strength GPa (kpsi) of unaged fibre shall be as listed in the following table.

	Weibull probability level	
Fibre gauge length	15 %	50 %
0.5 m (19.6 inches)	3.14 (455)	3.8 (550)

Reference Bellcore GR-20-CORE Issue 2; R4-33
The minimum tensile strength GPa (kpsi) of aged fibre shall be as listed below

	Weibull probability level	
Fibre gauge length	15 %	50 %
0.5 m (19.6 inches)	2.76 (400)	3.03 (440)

Test procedure

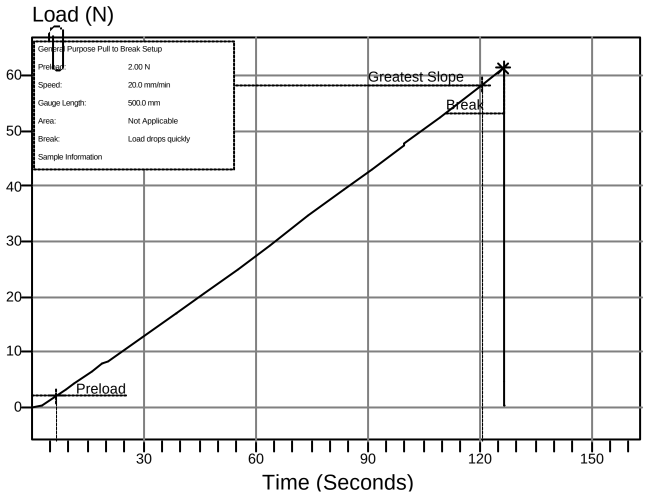
The samples shall be aged at a temperature soak of 85 ± 1° C (185 ± 1.8° F) with a noncondensing atmosphere of 85 ± 5 % for a period of 30 days.

The tensile (dynamic strength) testing shall be in accordance with FOTP-28, at a temperature of 23 ± 2° C (73 ± 3.6° F) and a relative humidity shall be 50 ± 5% during testing.

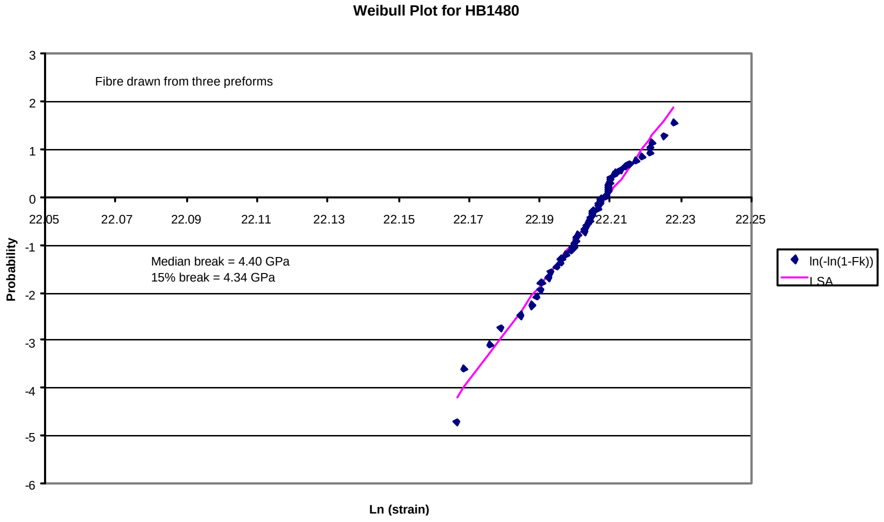
Results

Fibre type 1 was a 125 µm HBT fibre coated with a generic dual acrylate package to 245 µm. This had been proof tested at 1% (0.69 GPa).

A typical plot of load against time is shown below for an unaged sample.



The data is interpreted by ranking each failure according to breaking load, then generating a Weibull curve from the data set. Regression analysis is used to fit a straight line to the results to generate the slope and intercept. These values are then used to calculate the probability level at the 50% and 15% point.

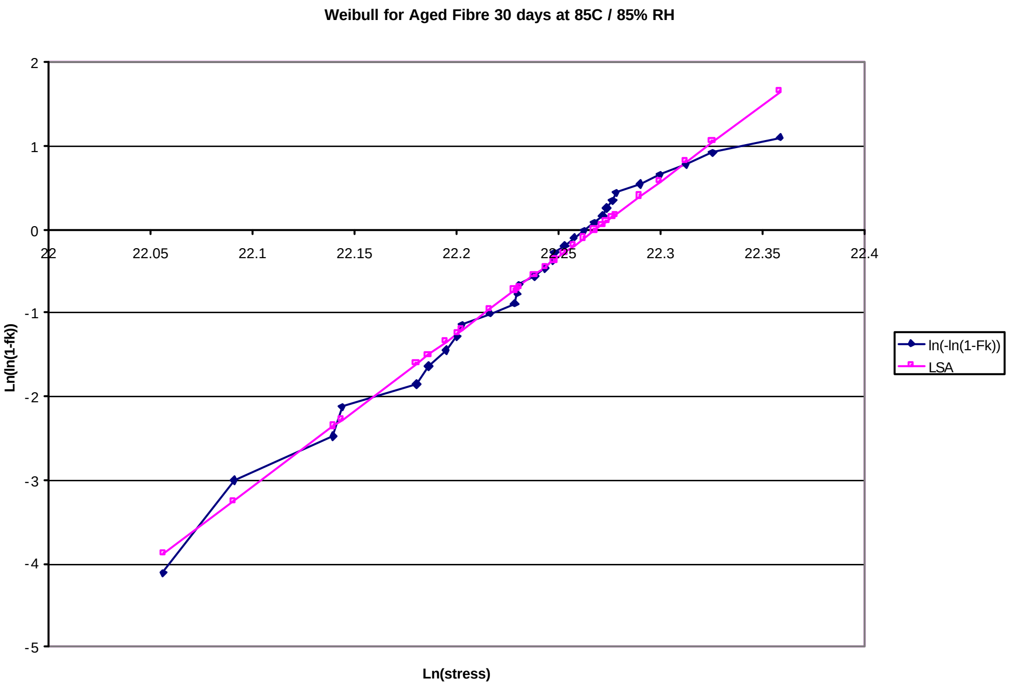


A PM 125 micron diameter fibre with a 400 micron dual acrylate coating was characterised.

The median break was calculated to be 4.40 GPa and the 15% break was 4.34 GPa. These values exceed the requirement of 3.8 GPa and 3.14 GPa respectively for unaged fibre.

Aged fibre

The following Weibull curve shows the results from temperature / humidity aged fibre.



The median value for this distribution with the fibre aged for 30 days at 85C / 85 % is 4.60 GPa, which is well in excess of the requirement of 3.03 GPa. The 15% point is 4.25 GPa, which exceeds the requirement of 2.76 GPa.

1.3 Dynamic Fatigue

Requirements: Reference Bellcore GR-20-CORE Issue 2; R4-34.
The dynamic stress corrosion parameter, n_d, of unaged and aged fibres shall be equal to or greater than 18.

Rationale

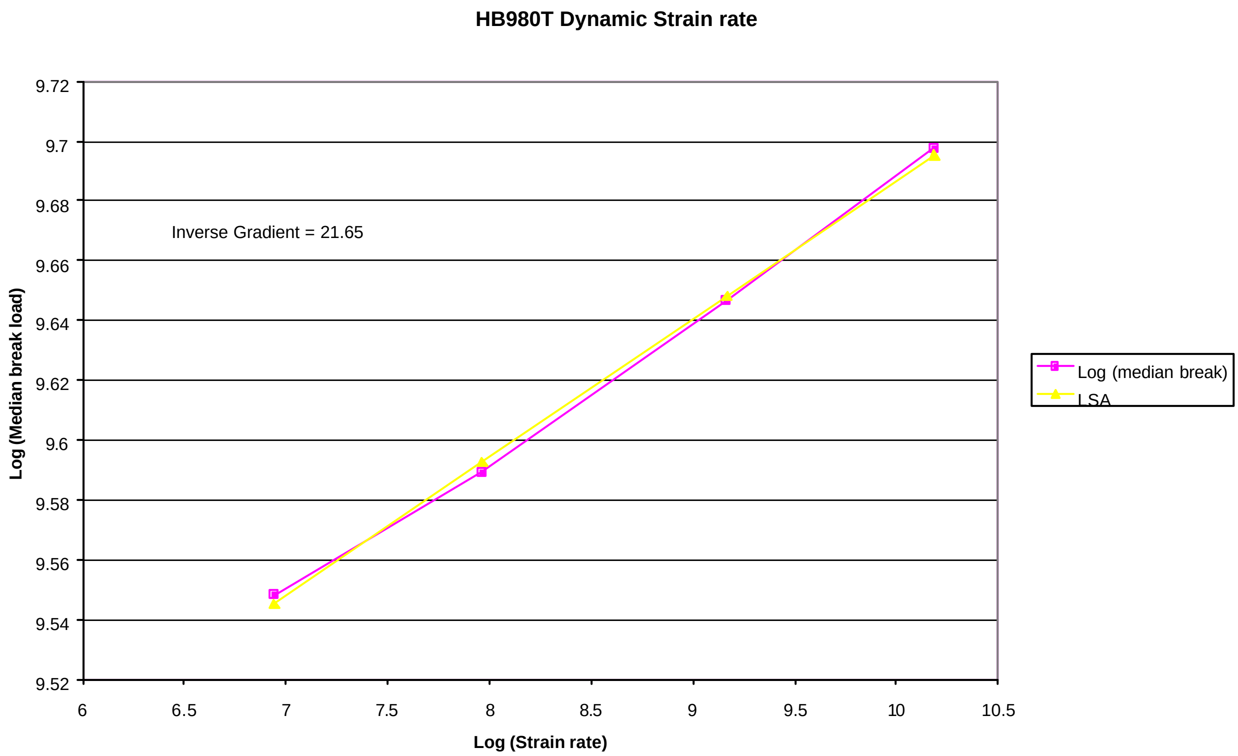
Interlaboratory testing has demonstrated that fibres whose mechanical behaviour is consistent with an n_d value of 20 may be found by some laboratories to have much lower measured values when tested in accordance with the procedure of FOTP-28. To accommodate this reproducibility concern, values of n_d equal to or greater than 18 are deemed to be consistent with the requirement of 20 previously specified in GR-20-CORE, Issue 1.

Test Procedure

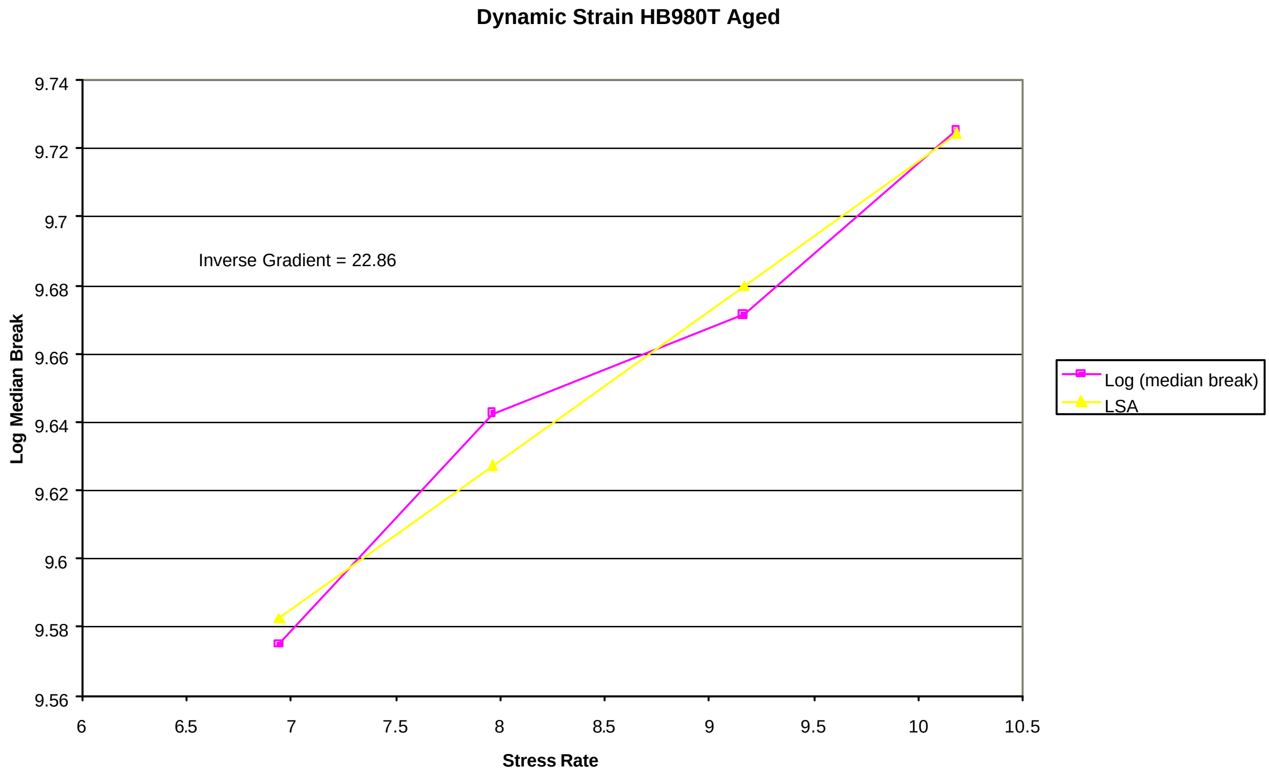
Fibre samples shall be tested both before and after aging. The dynamic (tension) stress corrosion parameter n_d, shall be determined in accordance with FOTP-28.

The samples shall be aged at a temperature soak of 85 ± 1° C (185 ± 1.8° F) with a non-condensing atmosphere of 85 ± 5 % for a period of 30 days.

Results



The value for n_d is found from the equation gradient = 1 / (n_d - 1) which is 20.6 for unaged samples. This exceeds the requirement of 18.



Aged Samples

For aged samples the value for n_d is found to be 21.8. The range of failures at each strain rate is higher for the aged samples and the degree of fit of the least squares curve is less. More measurement points at each strain rate would improve the quality of fit.

1.4 Static Fatigue

Reference Bellcore GR-20-CORE Issue 1; September 1994, R4-41.
The static stress corrosion parameter, n_s,of unaged and aged fibres shall be greater than or equal to 20.

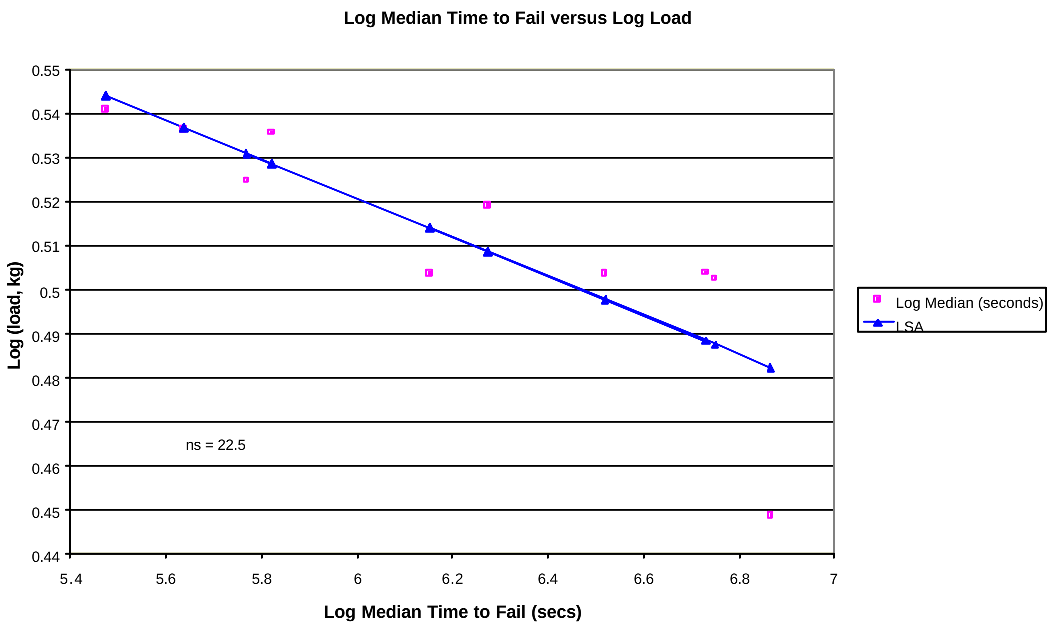
Test Procedure

Fibre samples shall be tested both before and after aging. The test method is as per recommendations in document M70C.

The samples shall be aged at a temperature soak of 85 ± 1° C (185 ± 1.8° F) with a non-condensing atmosphere of 85 ± 5 % for a period of 30 days.

Interim Results

The results for static fatigue are for a 125 µm non PM fibre coated with a generic dual acrylate package to 245 µm. This had been proof tested at 1% (0.69 GPa). Dynamic test results do not indicate significant mechanical variation.



The least squares fit to the static fatigue data has a gradient which is equal to $-1/n_s$ Consequently n_s is calculated to be 22.5. This test is ongoing.

1. 5 SUMMARY OF GEOMETRICAL CHARACTERISTICS

1.5.1 Histogram of glass diameter – all fibres
A histogram of the glass diameter from a cross-section of fibres manufactured at 125 µm. Reference Bellcore GR-20-CORE Issue 2; R4-22.

The cladding outside diameter shall be 125.0 µm ± 1.0 µm

1.5.2 Histogram of cladding non-circularity – all fibres
A histogram of the cladding non-circularity from a cross-section of fibre types manufactured at 125 µm.

Reference Bellcore GR-20-CORE Issue 2; R4-23.

The cladding non-circularity ≤ 1.0%

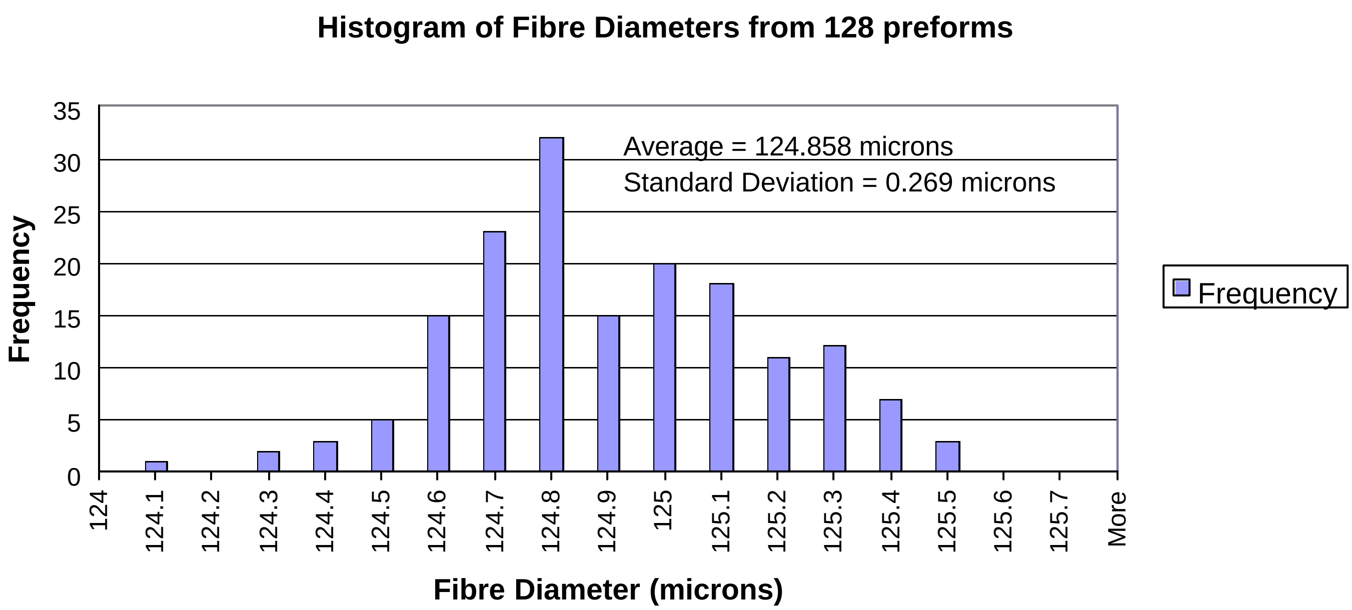
1.5.3 Histogram of core/cladding concentricity error – all fibres
A histogram of the core concentricity from a cross-section of fibre types manufactured at 125 µm.
Reference Bellcore GR-20-CORE Issue 2; R4-24.

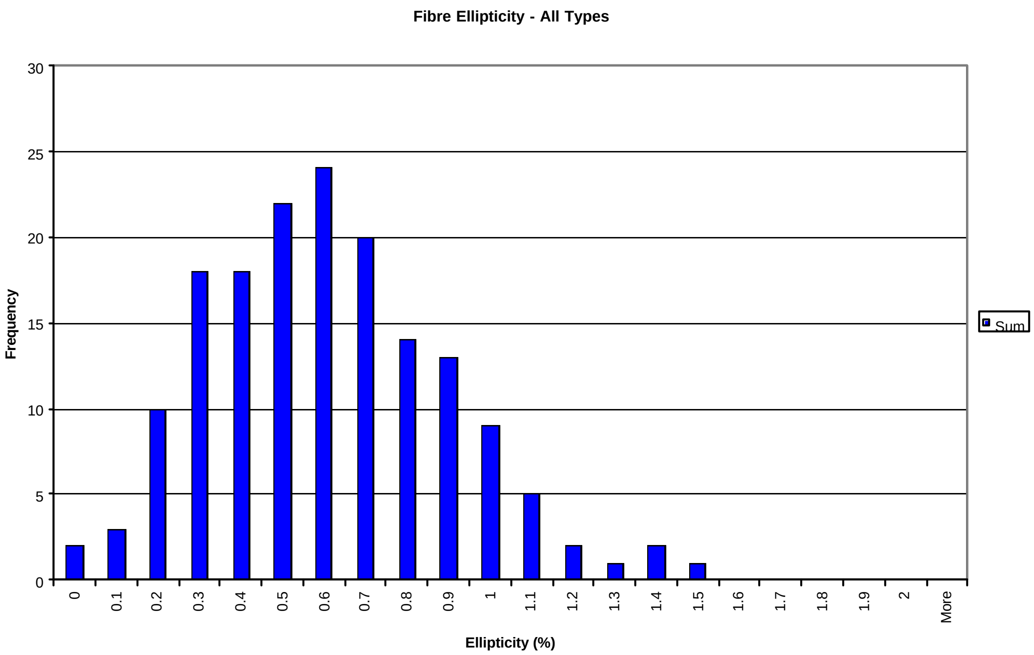
The offset between the centre of the core and the centre of the cladding shall be ≤ 0.8 µm.

Results

The histogram of glass diameter attached for 125 µm is shown below. The measurements were made on a York S20 instrument.

1.5.1 Histogram of glass diameter – all fibres





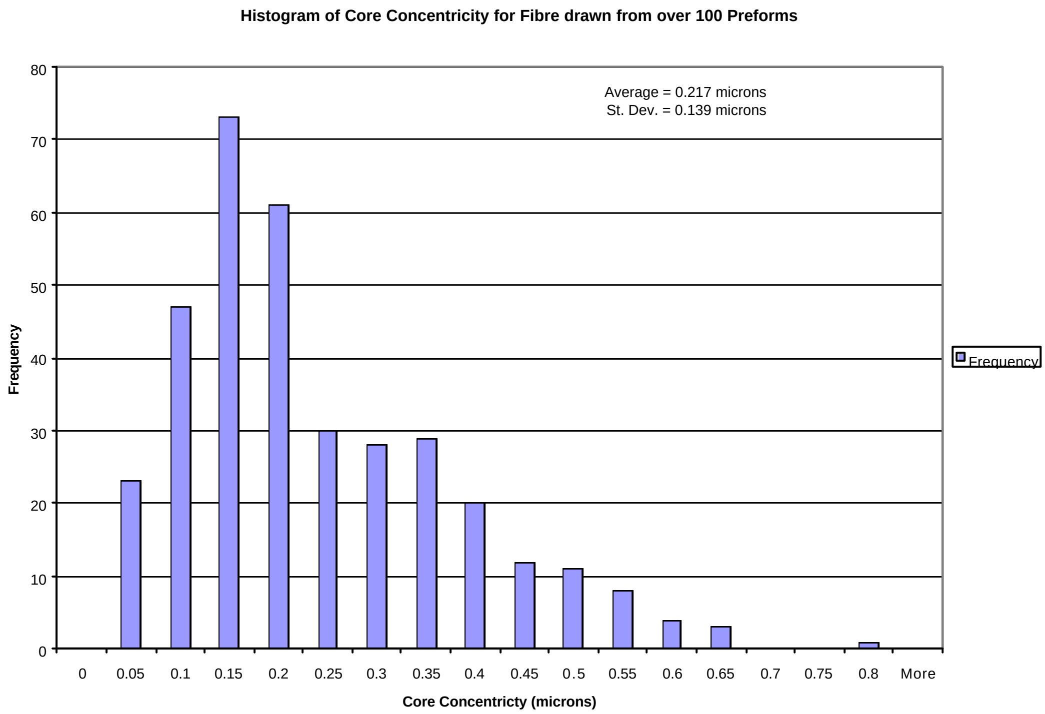
The distribution for 125 µm fibre has a mean of 124.86 µ m and a standard deviation of 0.27 µm. The sample size was fibre drawn from 128 preforms.

1.5.2 Histogram of cladding non-circularity – all fibres

A histogram of the cladding non-circularity from a cross-section of fibres manufactured at both 80 and 125 µm is shown for fibre drawn from over 100 preforms. The average is 0.65 % and the standard deviation is 0.34 %.

1.5.3 Histogram of core eccentricity – all fibres

A histogram of the core concentricity from a cross-section of fibres manufactured at both 80 and 125 µm is shown for fibre drawn from over 100 preforms. The average value is 0.217 µm and the standard deviation is 0.139 µm.



1.6 Fibre Cleavibility

Reference Bellcore TR-TSY-000264, *Optical Fiber Cleaving Tools*, section 4.1.2.1

Cleaver Qualification

The cleaver used in determining fibre cleavability shall meet the requirements for a high precision perpendicular cleaver in section 4.1.2.2 of TR-TSY-000264, *Optical Fiber Cleaving Tools*.

Test Procedure

Fibre Cleavability Qualification

1. The person performing the fibre cleaving shall be someone who performs stripping and cleaving on a regular basis.

2. The cleaver shall be baselined using a total of 10 previously qualified fibres from one or more manufacturers. The fibres shall meet the cleave quality criteria contained within the requirements of section 4.1.2.1 of TR-TSY-000264.
3. A minimum of ten fibres shall be used to qualify the new fibre design. Cleave each fibre three times to generate a total of 30 cleaved ends.
4. The fibre ends shall meet the cleave quality criteria contained within the requirements of Section 4.1.2.1 of TR-TSY-000264.

Results

The cleaver used was a York FK11 fibre cleaver. The ends were inspected using a splice machine with end face analysis.
The end angle was consistently less than 0.5 degrees with no hackle.

1.7 Splice performance

A number of fibres were selected and spliced in the following combinations. The splice loss was optically measured at the wavelength indicated.

Fibre combinations

Fibre type 1	Fibre type 2	Condition
HB1500T	HB1500T	On-axis PM splice, measured at 1550 nm
HB1500T	HB1500T	45° PM spice, measured at 1550 nm

Silica fibres shall be fusible with commercially available fusion splicer(s) that are commonly used for this operation by the BCCs. The fusion splicer used in determining the fusibility of the fibres to the requirements in this section shall conform to the requirements in TR-NWT-000765, *Generic Requirements for Single-Mode Splicing Systems.*

Test Procedure

A generic fibre from a minimum of two preforms shall be identified for fusion compatibility testing. Provide five fibre ends from each preform of the new fibre to meet a 1° cleave requirement with no protruding ends. The fibres that were used for the cleavability testing may be used for fusibility testing.

The five fibres from each preform shall be spliced to each other and between fibre types as indicated. The conformance testing shall be conducted in accordance with the test procedures specified in TR-NWT-000765, to the following requirements,

Mean splice loss
Reflectance
Splice Strength

A separate report is available on this aspect and should be requested from Fibercore Ltd.

2.0 Long term reliability

2.1 Lifetime Model
An appropriate model to predict lifetime under deployed conditions has been identified. The COST 218 model to be used for this work is defined in 'Mechanical Lifetime Model for Optical Fibers in Harsh Environments' authored by W. Griffeon (SPIE Vol. 1973 pp150 – 160). The load at break has been measured on a large population of 125 micron fibres which have previously undergone a proof test at 1% strain (0.69GPa). The static fatigue constant is 31.4.

Lifetime Estimate

The equation or model used to generate a lifetime estimate, as part of this programme of testing, is the COST-218 lifetime model. This model is based on the use the power law to relate crack distribution and propagation to applied stress. The COST 218 model is shown below:

$$\frac{\sigma_a}{\sigma_p} = \left(\frac{t_p}{t_a}\right)^{1/n} \left[\left\{ 1 - \frac{L_0}{L} \ln(1-F) \left(\frac{B S_0^{n-2}}{\sigma_p^n t_p} \right)^{\frac{m}{n-2}} \right\}^{\frac{n-2}{m}} - 1 \right]^{1/n}$$

Where:

σ_a = applied (in-service) stress / GPa
σ_p = proof test stress / GPa
t_a = time for which in-service stress is applied / s
t_p = proof test dwell time / s
n_s = static stress corrosion constant
L_0 = gauge length for which Weibull probability constants are defined /m (this is the gauge length in the dynamic strength measurement)
L = fibre length to apply in the model /m
F = failure probability
m = Weibull shape constant for extrinsic (low strength) failures.

Parameters of particular interest are m, n_s, and BS_o, which are taken from Dynamic Tensile Strength, Static Fatigue and Dynamic Fatigue tests respectively.

For illustration for a 1% proof stress, n_s = 22.5, L_o = 500mm, L = 1000m, F = 1 in 10,000, m = 3.8 and BS_o = $6.1x10^{16}$Gpa.

Using the COST-218 lifetime model we can make the following lifetime estimations. The maximum residual stress should be less than indicated for the appropriate lifetimes.

Lifetime (yrs)	Under a residual stress of; (% of proof stress)
10	29.1
25	26.0
30	25.8

Referenced Documents

Bellcore GR-20-CORE Issue 1, September 1994, Generic Requirements for Optical Fiber and Fiber Optic Cable
Bellcore GR-20-CORE Issue 2, July 1998, Generic Requirements for Optical Fiber and Fiber Optic Cable
Bellcore TR-TSY-000264, Optical Fiber Cleaving Tools
Bellcore TR-NWT-000765, Generic Requirements for Single-Mode Splicing Systems.

Bellcore TR-NWT-000955, Generic Requirements for Optical Fiber Stripping (Coating Removal) Tools
FOTP-28B, Method for measuring dynamic tensile strength of optical fibre.
FOTP-76, Method for measuring dynamic fatigue of optical fibres by tension.
FOTP-97, Procedure for measuring static fatigue of optical fibres in two point bending.
FOTP-178, Measurements of strip force required for mechanically removing coatings from optical fibres.
British Telecommunications plc, Specification M70C for both Singlemode and Multimode Fibres
British Telecommunications plc, Specification CW1505H for Step Index Single-mode Optical Fibres
Mechanical Lifetime Model for Optical Fibers in Harsh Environments. W. Griffeon SPIE Vol. 1973 pp150 –160.

Report prepared by: Fibercore Limited
Epsilon House
Enterprise Road
Chilworth Science Park
Southampton
SO16 7NS

Tel: 44 (0)23 8076 9893
Fax: 44 (0)23 8076 9895

Email: Fibercore@interalpha.co.uk
Website: www.fibercore.com