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ABSTRACT

A programme of testing was completed in order to characterise the mechanical properties of Fibercore Limited's 80 μm optical fibre. Dynamic Tensile Strength, Dynamic Fatigue and Static Fatigue tests were undertaken. The results were incorporated in the COST-218 lifetime model. All tests were carried out in accordance with the Fibercore Qualification Plan Q&R 010, which is based on the Telcordia document GR-20-CORE.

Results are presented in the following sections:

1. Dynamic Tensile Strength

- Weibull plot, aged and un-aged.
- Extrinsic (low strength) failure Weibull plot, aged and un-aged
- Tensile strength aged and un-aged

2. Dynamic Fatigue

Dynamic stress corrosion constant (n_d) aged and un-aged

3. Static Fatigue

Static stress corrosion constant (n_s) un-aged.

4. Lifetime estimation for un-aged fibre using COST-218 model

The fibre met or exceeded the requirements in all aspects.

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INTRODUCTION

Optical fibre strength is determined by the size and frequency of flaws in the glass surface. All optical fibre has a distribution of flaws. The smaller and less frequent the occurrence then the stronger the fibre. These flaws, or cracks, propagate under service conditions weakening the fibre. Mechanical characterisation tests provide data on crack size and crack distribution. It is possible to use these results to estimate or predict lifetime in service for the fibre.

The tests covered in this report were performed in accordance with the following Bellcore (Telcordia) publications:

- Dynamic Tensile Strength: Bellcore GR-20-CORE Issue 2; July 1998, R4-32 and R4-33 for un-aged and aged fibres respectively.
- Dynamic Fatigue: Bellcore GR-20-CORE Issue 2; July 1998, R4-34
- Static Fatigue: Bellcore GR-20-CORE Issue 1; September 1994, R4-41

Fibres were tested both before, and after ageing. Samples were aged at a temperature soak of $85\pm 2^{\circ}\text{C}$ with a non-condensing atmosphere of $85\pm 5\%$ RH for 30 days.

OBJECTIVE

To characterise the mechanical properties of 80 μm diameter optical fibre manufactured by Fibercore Ltd. This will be achieved through rigorous mechanical testing and application of the results to the COST-218 lifetime model.

REQUIREMENTS

Dynamic Tensile Strength

The minimum tensile strength of 0.5m fibres must be;

	Weibull Probability	
Fibre	50% (Median)	15%
Un-aged	3.80 GPa	3.14 GPa
Aged	3.03 GPa	2.76 GPa

The Weibull shape constant for extrinsic failures (m) is a requirement for the COST-218 lifetime model.

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Dynamic Fatigue

The dynamic stress corrosion constant (n_d) for aged and un-aged fibre must be greater than or equal to 18.

Static Fatigue

The static stress corrosion constant (n_s) for aged and un-aged fibre must be greater than or equal to 20.

Lifetime Estimate

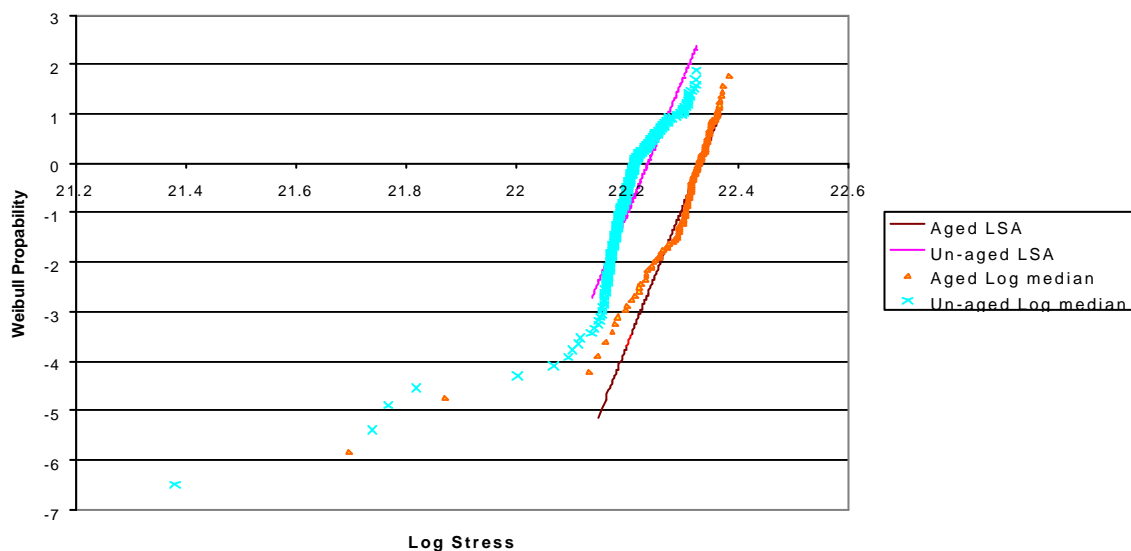
Fibre is required to last 25 years under an in-service stress expressed as a percentage of the proof stress.

TEST RESULTS

Dynamic Tensile Strength

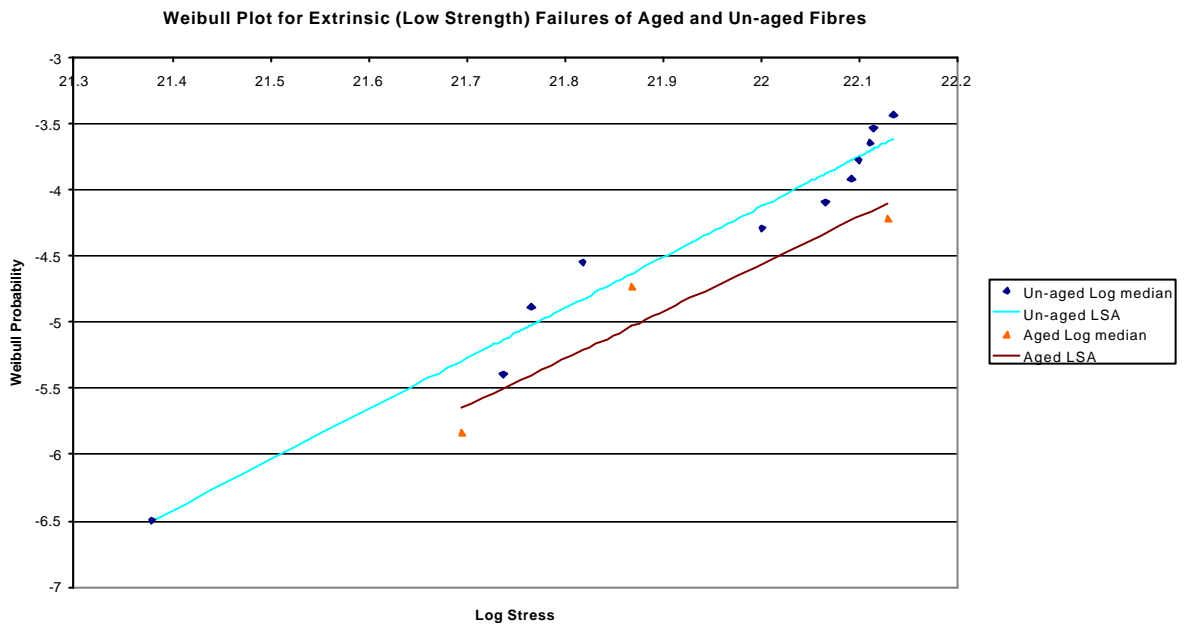
Five types of polarisation maintaining fibre and two types of singlemode (non PM) fibre, all of 80 μm glass diameter, were used in testing for dynamic tensile strength. A Weibull plot of breaking load against probability was determined and a best fit line using a least squares fit was applied. The results represent the entire population of 80 μm fibre tested.

Weibull Plot for Un-aged and Aged 80 Micron Diameter Fibre.



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The extrinsic (low strength) failures were plotted to determine the best fit line.



Summary of gradients (m).

Gradient of Weibull plots

Gradient (m)	Un-aged	Aged
Intrinsic (High Strength)	26.8	27.7
Extrinsic (Low Strength)	3.8	3.6

Summary of gradients against targets in Telcordia GR-20-CORE.

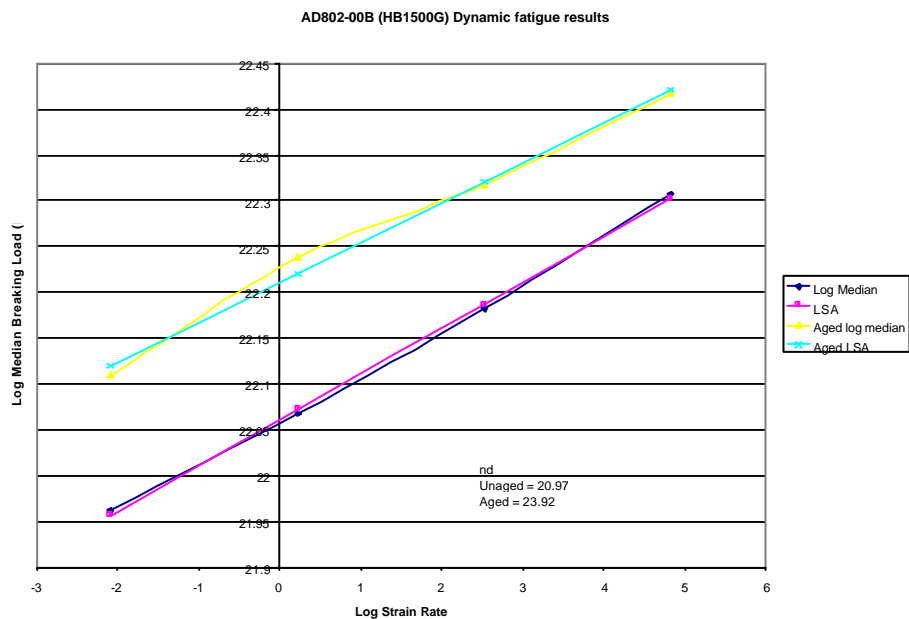
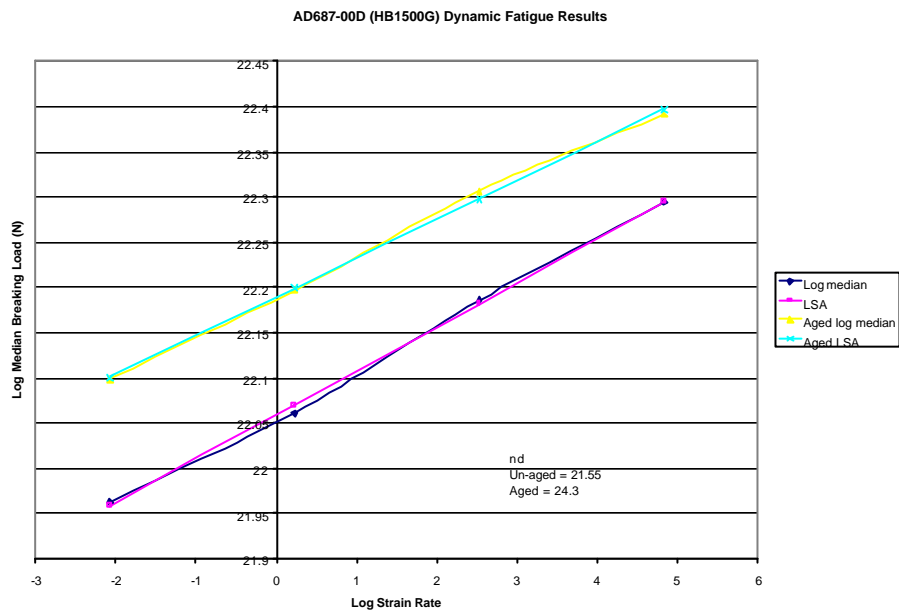
Tensile Strength of Fibres

Weibull Probability	Un-aged		Aged	
	Measured	Required	Measured	Required
Median (50%)	4.46 GPa	3.80 GPa	4.92 GPa	3.03 GPa
15 %	4.02 GPa	3.14 GPa	4.47 GPa	2.76 GPa

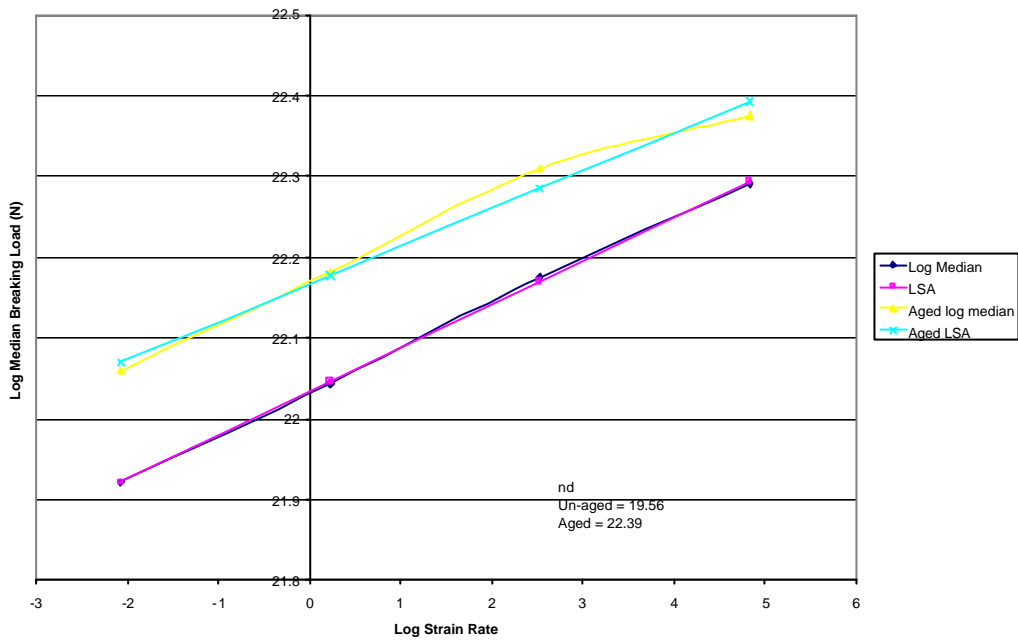
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Dynamic Fatigue

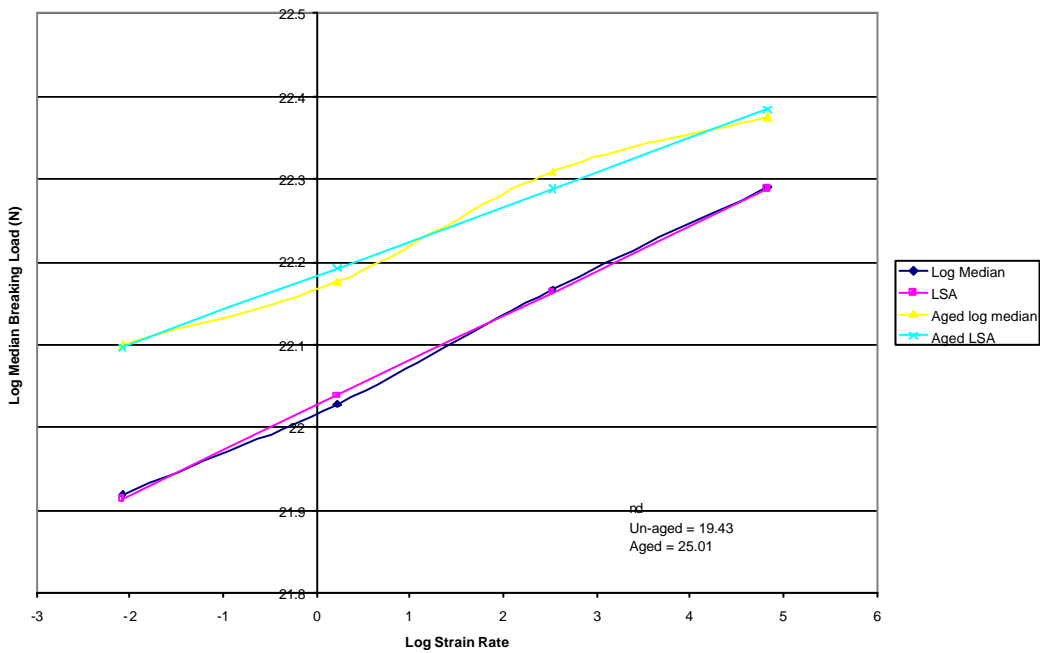
The same seven fibre types as used for dynamic tensile strength testing were used both before and after ageing in dynamic fatigue tests. The results for individual fibre types are presented below.



AD816-00A (HB1500G) Dynamic Fatigue Results

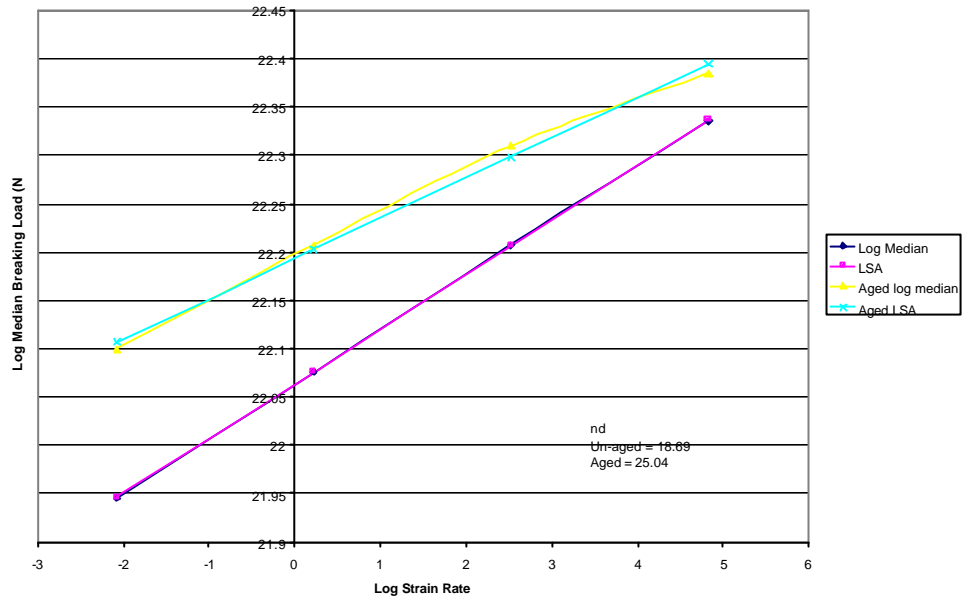


SD417-00A (HB800G) Dynamic Fatigue Results

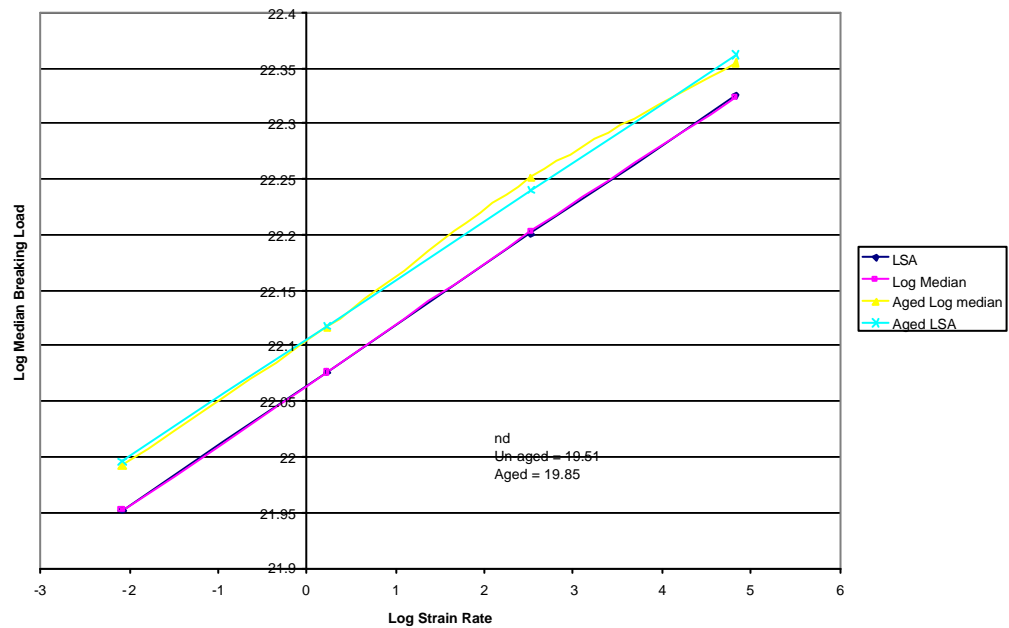


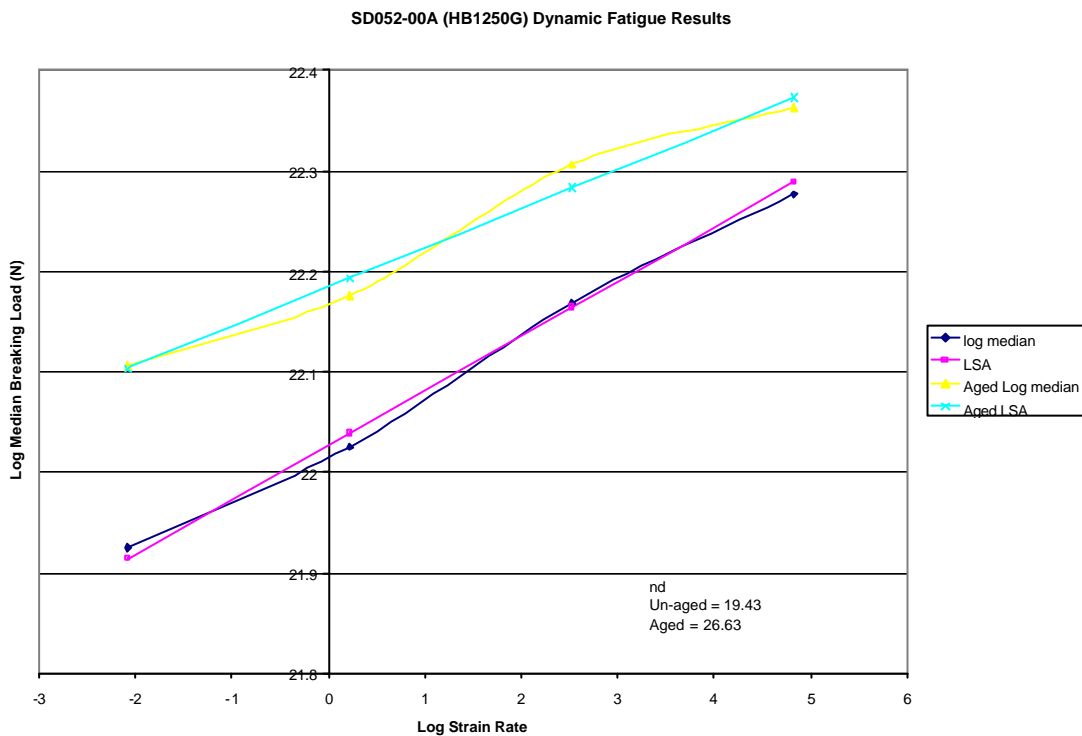
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SD372-00A (SM1500 6.4/80) Dynamic Fatigue Results



SD405-01A (SM1500 5.3/80) Dynamic Fatigue Results





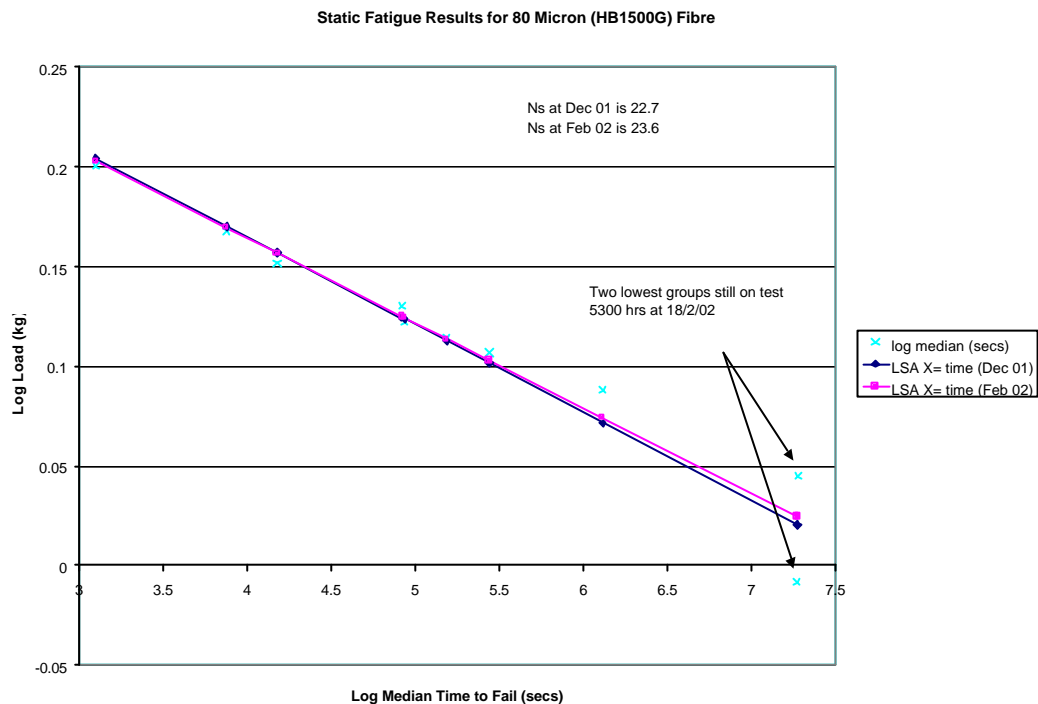
The value of n_d was calculated from the equation; $\text{Gradient} = 1/(n_d - 1)$. In all cases the dynamic stress corrosion constant (n_d) was above the required value of 18 for both aged and un-aged fibre. A summary of dynamic stress corrosion constants for each fibre is given below.

Fibre Type	Sample Number	Dynamic Stress Corrosion Constant (n_d)	
		Un-aged	Aged
HB1500G	AD687-00D	21.55	22.30
HB1500G	AD802-00B	20.97	22.53
HB1500G	AD816-00A	19.56	22.39
HB800G	SD417-00A	19.43	25.01
SM1500 6.4/80	SD372-00A	18.69	25.04
SM1500 5.3/80	SD405-01A	19.51	19.85
HB1250G	SD052-00A	19.43	26.63

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Static fatigue

A different sample of fibre was used for the static fatigue tests. This fibre was AD811-00B, HB1500G an 80 µm fibre.



The gradient of the LSA best-fit line is equal to $-1/n_s$. Hence the static stress corrosion constant, n_s has been found to be in the region of 23, comfortably above the requirement of 20.

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 a power law to relate crack distribution and propagation to applied stress. The COST 218 model is shown below:

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$$\frac{s_a}{s_p} = \left(\frac{t_p}{t_a}\right)^{1/n} \left[\left\{ 1 - \frac{L_0}{L} \ln(1-F) \left(\frac{BS_0^{n-2}}{s_p^n t_p} \right)^{\frac{m}{n-2}} \right\}^{\frac{n-2}{m}} - 1 \right]^{1/n}$$

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_0 , which are taken from Dynamic Tensile Strength, Static Fatigue and Dynamic Fatigue tests respectively.

For illustration for a 1% proof stress, $n_s = 23.0$, $L_0 = 500$ mm, $L = 1000$ m, $F = 1$ in 10,000, $m = 3.8$ and $BS_0 = 6.1 \times 10^{16}$ 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	27.7
25	26.7
30	26.4

Ongoing work

Increasing the population of fibres tested will increase the accuracy and the confidence level of these results. Tests are continuing for Static fatigue to accumulate extra points. Further testing should be carried out in accordance with the testing schedule of Q & R 010.

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Referenced documents

- Q & R 010 – Qualification program for Fibercore optical fibre; Fibercore Ltd, 4th December 1999
- Report on Reliability Program Q & R 010 for Fibercore HBT Optical Fibre; Fibercore Ltd, March 2001.
- Bellcore GR-20-CORE Issue 2, *Generic Requirements for Optical Fiber and Fiber Optic Cable*; July 1998.
- FOTP-28, *Method for measuring dynamic tensile strength of optical fibre*; October 1991, EIA/TIA-455-28B
- FOTP-76, *Method for measuring dynamic fatigue of optical fibres by tension*; 14/05/1993, EIA/TIA-455-76
- COST 218, *Evaluation of optical fibre lifetime models*; Optical Materials Reliability and Testing, 1992, SPIE vol. 1791 pg190-201.
- W. Griffioen, *Mechanical lifetime model for optical fibres in harsh environments*; SPIE vol. 1973 pg150-160.

Report prepared by: Fibercore Ltd.
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