Report on product specifications

According to Telcordia GR–1312–CORE Generic Requirements for OFAs and Proprietary DWDM Systems Issue 3, April 1999 and TIA/EIA-455-28 (FOTP-28) "Measuring Dynamic Strength and Fatigue Parameters of Optical Fibers by Tension"

Contents:

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v1.1, July 21st, 2003

1 Product: Erbium Doped Fiber manufactured by Direct Nanoparticle Deposition (DND)

Fiber code: LF1200
Observation: Although the tests have been performed on LF1200, the results apply for LF1x00, LF2x00 and LF3x00 series because they are manufactured using the same technology.

2 Summary of test results

Under the mentioned requirements and specifications, the erbium doped fibers manufactured by DND are qualified as follows:

1. **Hydrogen contamination test according to GR-1312-CORE:**

   <0.1dB increase in absorption (1420-1430nm) of 4m of LF1200 when the fiber is exposed to H_2 at 0.01 atmosphere partial pressure over 20 years at 80°C

2. **Dynamic breaking strength test according to TIA/EIA-455-28C**:

	Unaged fiber		Aged	
Failure probability level	15%	50%	15%	50%
Failure strain (GPa)	4.54	4.68	4.88	5.03

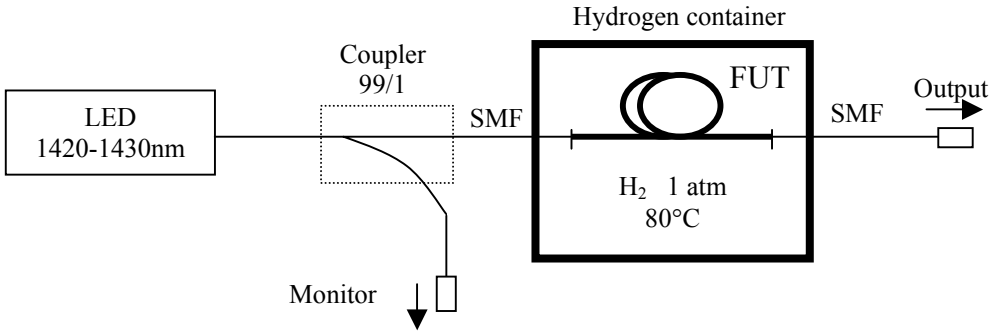
Strain rate=5%, Gage length=0.5m, Sample size=15

3. **Stress corrosion test:**
   - $n_d \geq 18.6$
   - 95% confidence interval: 16.9 – 20.7

3 Hydrogen contamination test

This test determines the increase of attenuation between 1420-1430nm when the fiber is exposed to hydrogen-contaminated environment.

3.1 Test set-up



FUT: LF1200

- Fiber length: 4m
- Total fiber absorption at 1530nm: 80dB

3.2 Environmental test conditions

- Hydrogen pressure: 1atm
- Hydrogen temperature: 80°C

3.3 Test preparation

- The fiber under test is spliced in between 99% coupler's pigtail and output connectorized pigtail. The splices are sleeved.
- The FUT is arranged inside the container on a loose loop of 20cm diameter and do not touch any metal part of the container. The sleeved splices are fixed inside the container. Less than 1m of SMF are inside the container.
- The container is sealed and then vacuum is created inside the container.
- The container is filled with hydrogen.
- The gas temperature is raised to 80°C
- The hydrogen pressure is tuned to 1 atmosphere
- The pressure and temperature inside the container is monitored throughout the test

3.4 Measurements

- LED source is switched on
- The monitor pigtail is connected to optical spectrum analyser (OSA) and the spectrum between 1420 and 1430nm is recorded
- The output pigtail is connected to OSA and the spectrum is recorded
- The absorption is calculated using the formula:

$$Abs(\lambda) = P_{out}(\lambda) - \left[P_{mon}(\lambda) + 20\right] \qquad dB$$

where $P_{out}(\lambda)$ is the output power in dBm/nm, $P_{mon}(\lambda)$ is the monitor power in dBm/nm, λ is the wavelength between 1420-1430nm in 1nm steps.

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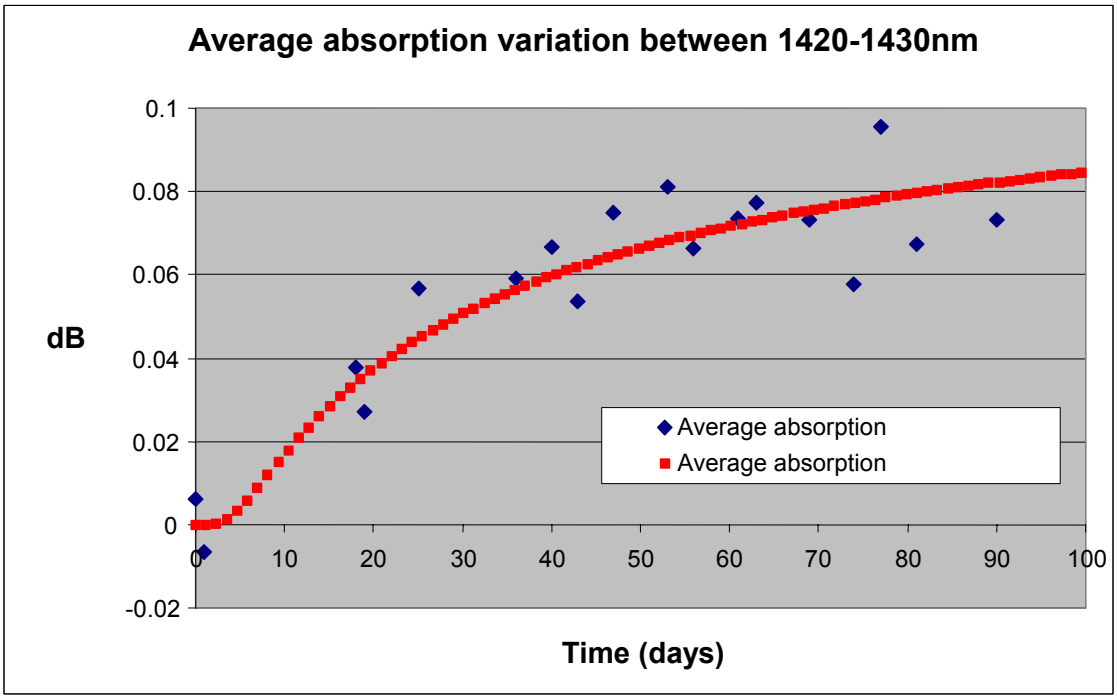
- The measurements have been made for 90 days, about twice a week: total 18 measurements.

3.5 Results

For each measurement, the average power is calculated over the spectral range 1420-1430nm. Considering the average absorption measured at the beginning of the test as a reference, the average variation in time is presented below (blue dots):



The red dots represent the following approximation function:

$$\Delta Abs = k_0 \cdot erfc\left(\frac{k_1}{\sqrt{C_{H2} \cdot t}}\right)$$

where k_0 and k_1 are constants, C_{H2} is the hydrogen concentration in the container, t is time and erfc(x) is the following function:

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-y^2} dy$$

The 0.09dB increase in absorption induced by 90 days of exposure to H_2 at 1 atmosphere is equivalent to 0.09dB increase in absorption induced by

$$\frac{90 \cdot 1}{0.01} = 9000 days = 24.6 years$$

of exposure to 0.01 atmosphere partial pressure.

To allow a generous margin we can conclude that a maximum 0.1dB increase in the absorption between 1420-1430nm is obtained when 4m of LF1200 fiber is exposed to hydrogen at 0.01 atmosphere partial pressure over 20 years at 80°C.

4 Dynamic breaking strength test

The test was performed for five unaged and aged fibres. Sample size was 15 breakings per fibre.

4.1 Test set-up

as described in TIA/EIA-455-28 (FOTP-28) Figure A1, page 16

- Gage length: 0.5 m
- Stress rate: 5 %/min

4.2 Testing environment

- Temperature: 21C
- Humidity: 48 % R.H.

4.3 Aging environment

- Temperature: 85C
- Humidity: 85 % R.H.
- Duration: 2000 hours

Tested fibres were preconditioned at the testing environment more than two weeks.

4.4 Results

Breaking strengths were calculated with the following formula:

$$\sigma = \frac{T}{A}$$

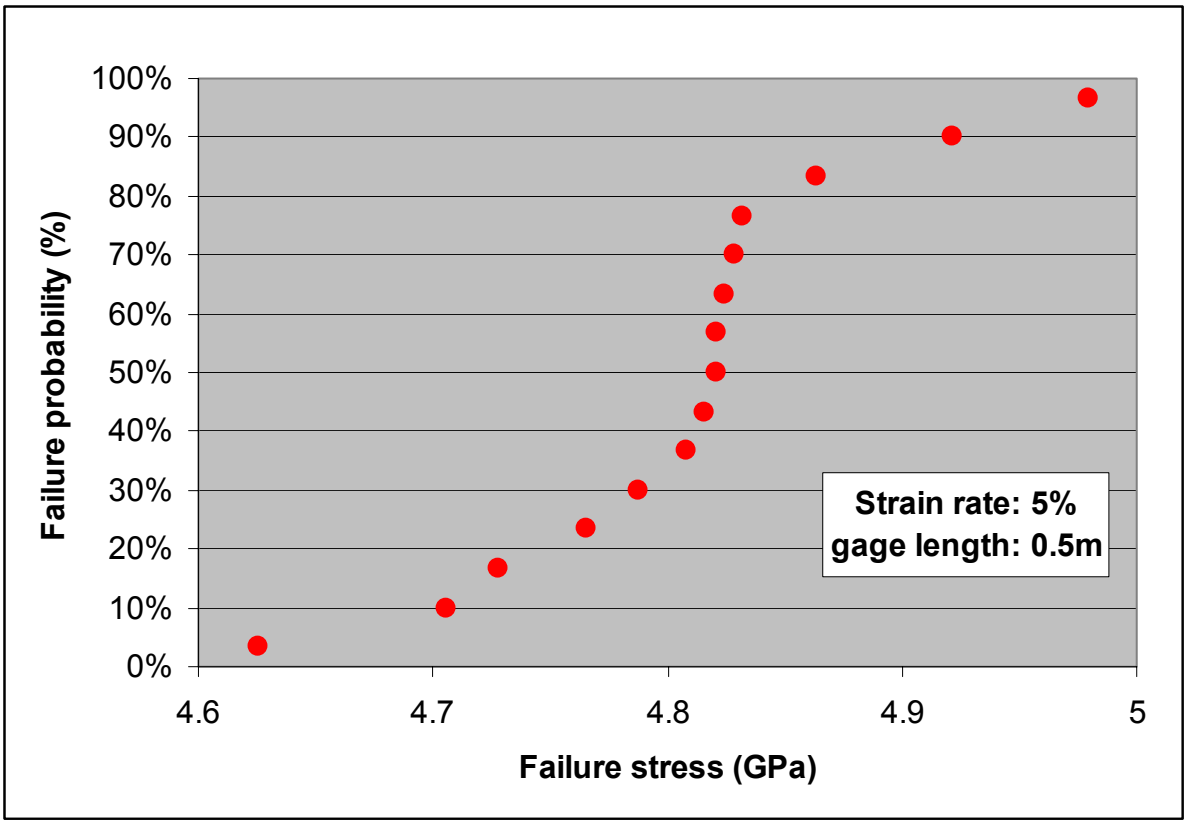
where T is force needed to break the fibre and A is the cross sectional area of the glass portion of the fibre.

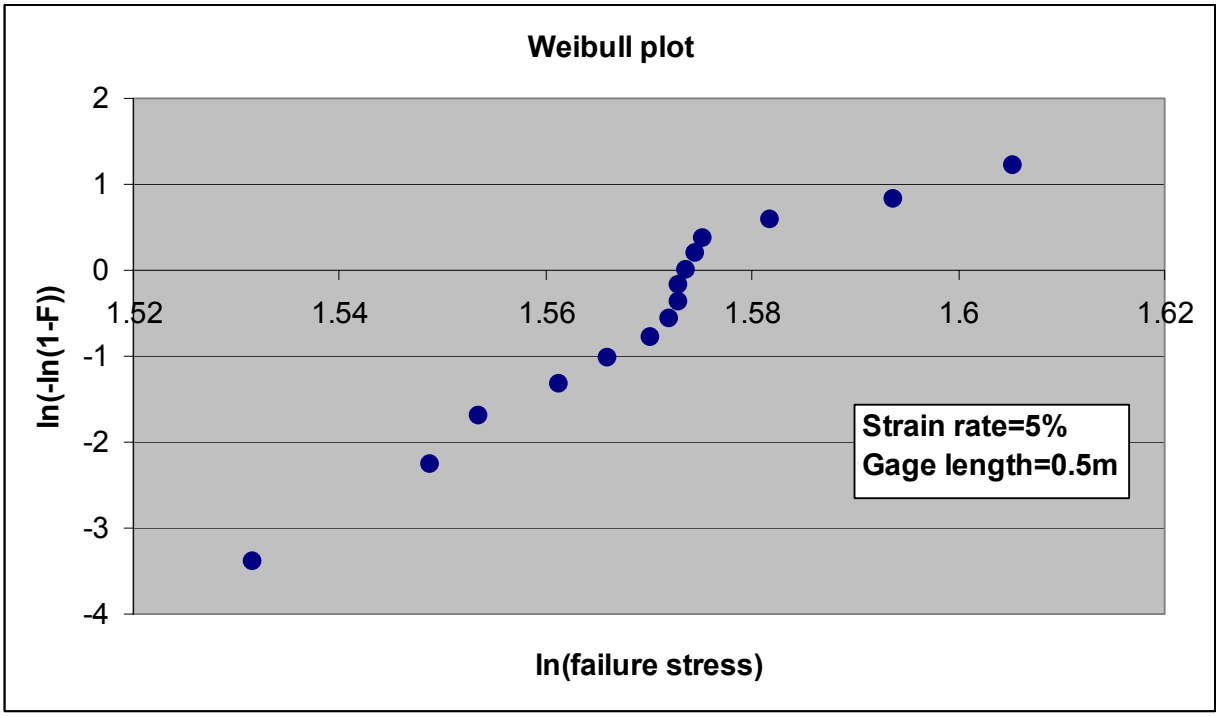
Failure probability is calculated with the following formula:

$$F = \frac{k - 0.5}{N}$$

where k is the rank of the given failure stress (from 1 to 15) and N is total number of samples (15)

4.4.1 Typical failure probability and Weibull plots





4.4.2 Calculated results

	Stress for unaged fiber (GPa)		Stress for aged (GPa)	
Failure probability	15%	50%	15%	50%

Sample 1	4.6	4.7	5.1	5.3
Sample 2	4.7	4.8	4.85	5
Sample 3	4.4	4.6	4.5	4.7
Sample 4	4.6	4.7	4.95	5
Sample 5	4.4	4.6	5	5.15

Minimum	4.4	4.6	4.5	4.7
Median	4.6	4.7	4.95	5

Observation:

Aging the fibres increases the breaking strength. Conditions of 85C and 85 % R.H. seemed to affect on acrylate coating by making it stronger.

5 Stress corrosion test

5.1 *Test set-up*

as described in TIA/EIA-455-28 (FOTP-28) Figure A1, page 16

- Gage length: 0.5 m
- Stress rate: 0.2 %/min, 1%/min, 5%/min, 16%/min

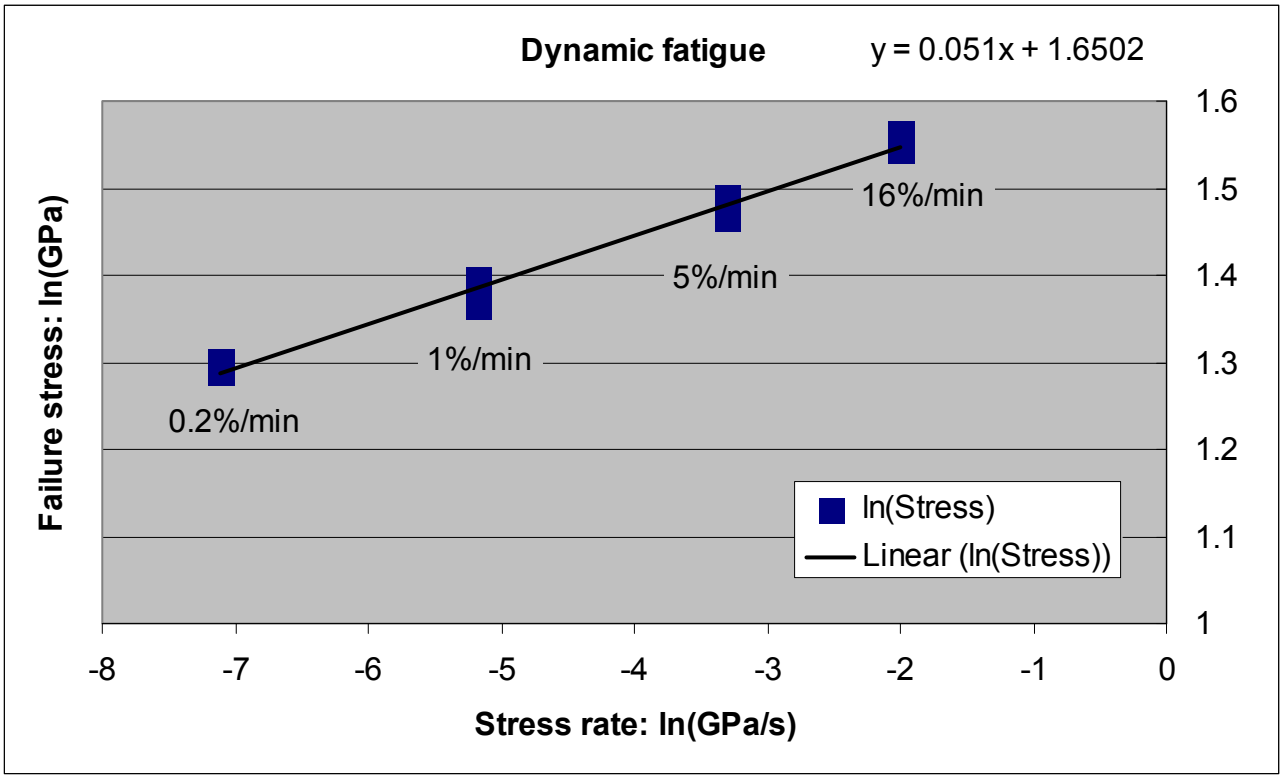
5.2 Testing environment

- Temperature: 24C
- Humidity: 67 % R.H.

5.3 Sample size

- 15, unaged fibers for each stress rate

5.4 Dynamic fatigue diagram (failure stress versus stress rate)



5.5 Results

Failure stress slope:

s=0.051

Stress corrosion parameters:

$$n_d = \frac{1}{s} - 1$$

n_d=18.6

Standard error of the estimate:

SEE= 0.01248

95% confidence interval

$$n_{d\max} = \frac{1}{s - \frac{SEE}{\Delta x}} - 1 \qquad n_{d\min} = \frac{1}{s + \frac{SEE}{\Delta x}} - 1$$

where Δx is the stress rate interval of the test: Δx =7.1-2=5.1

$n_{d\max}$=20.7 $n_{d\min}$=16.9