FATIGUE TESTING OF SILICA OPTICAL FIBRES

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ABSTRACT

Manufacturing technologies of silica optical fibers are reviewed and the role of different external coatings underlined. Mechanical properties of optical fibers have been investigated and fatigue testing procedures were described. Different commercial silica optical fibers were tested. Dynamic fatigue testing using two point bending bench at four different stress rates were carried out. Fiber strength was determined using Weibull statistical treatment and Weibull plots were traced. The n-corrosion parameter was calculated. Static fatigue testing were carried on winding sample fiber around alumina mandrel. Fiber time to failure was measured and n-corrosion factor was calculated.

KEYWORDS: optical fibres, manufacturing, static and dynamic fatigue testing, corrosion parameter

1. INTRODUCTION

Optical fibers are now key components of high capacity telecommunication networks. The concept of an optical fiber is probably very old and the transmission of light through glass rods and filaments was known by glass makers of the antique Mediterranean civilizations. Due to the use of the vapor phase deposition technology, the milestone of glass fiber attenuation, lowered down to 20 dB/km, comparable to the damping undergone by an electric current in a copper wire, was reached in 1980, resulting in the spectacular decrease of the fiber loss [1].

Even if drawing a fiber from a glass rod might be a simple exercise, manufacturing an optical fiber requires the rigorous control of any contamination factor. Silica fibers are made by drawing at 2000 °C high purity preforms with a set-up which is described schematically in fig. 1. Preforms are rods in which the central part consists in core glass of higher index of refraction while the external part is made from cladding glass. These preforms are prepared by vapor phase process in which silicon chloride reacts with gaseous oxygen. This results in a very high purity material which contains extremely low levels of metal impurities and hydroxyl. Variation of refractive index is achieved by the modification of the vapor composition: germanium, phosphorous and fluorine can be incorporated in this way. High quality preforms can be made using other chemical processing, for example sol-gel.

Optical fibers may also be drawn directly from the melt using the double crucible method. Both core and cladding glasses are heated in two concentric crucibles at a temperature for which melt viscosity of large enough. Then a step index fiber may be drawn from the bottom of the double crucible, as exemplified by fig. 2.

Special glasses mare sometimes difficult to draw into fiber because of their tendency to devitrification. These problems are solved by adjustment of glass composition and processing optimization.

An external polymeric coating is applied to protect fiber from scratches, to limit chemical attack of water and to increase mechanical strength. Usual coatings are epoxyacrylate resins, but other polymers such as silicones and polyimide may be used.

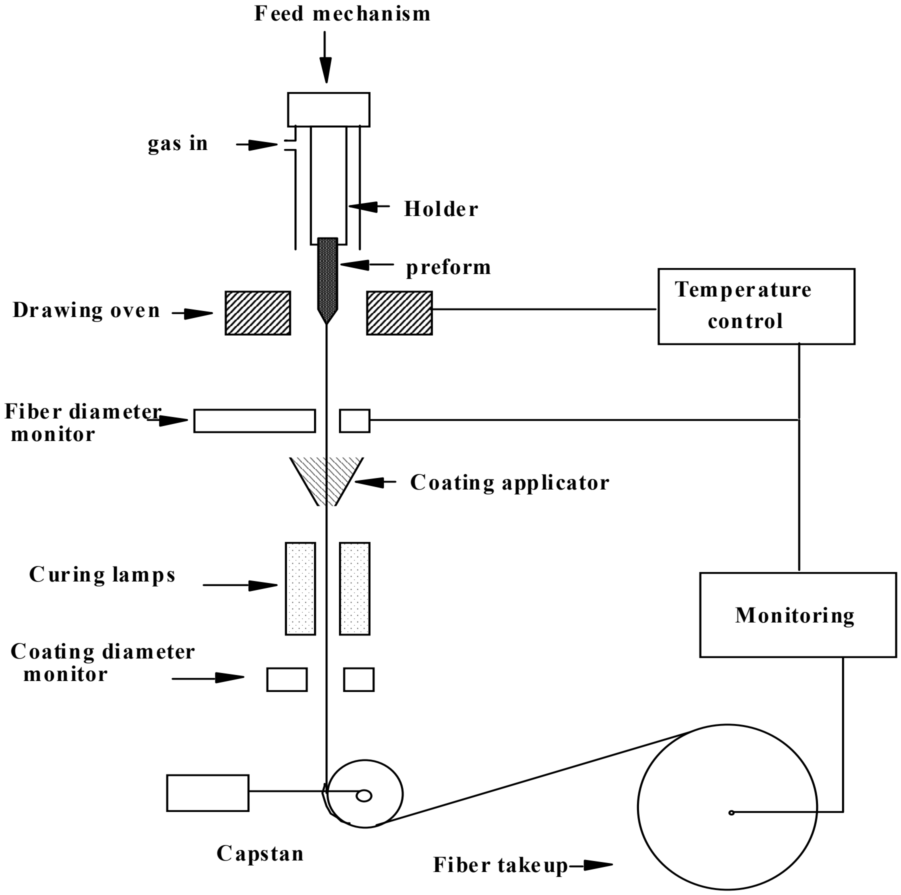

Fig. 1. Schematic representation of a draw tower for silica glass preforms

2. FATIGUE TESTING - EXPERIMENTAL

The reliability of the optical fibers depends on various parameters that have been identified: time, temperature, applied stress, initial fiber strength and environmental corrosion. The major – and usually unique – corrosion reagent is water, either in the liquid state or as atmospheric moisture. Glass surface contains numerous defects, either intrinsic – the so-called “Griffith’s flaws – and extrinsic, in relation to fabrication process. Under permanent or transient stress, microcracks grow from these defects, and growth kinetics depend on temperature and humidity. Although polymeric coating efficiently protects glass surface from scratches, it does not prevent water to reach glass fiber.

Tests have been implemented using commercial single mode silica fibers of 125 µm in diameter with a 62.5 µm thick epoxy-acrylate polymer coating (Alcatel and Verrillon).

2.1 Dynamic fatigue measurement using a two-point bending testing apparatus

As-received fibers were subjected to dynamic fatigue tests using a two-point bending testing device. The samples of 10 cm in length are bent and placed between the grooved faceplates of the testing apparatus, in order to avoid the fiber slipping during the faceplates displacement and to maintain the fiber ends in the same vertical plan. A series of 30 samples were tested for each faceplate constant velocity of 80, 150, 500 and 800 µm/s, respectively. The measurements were performed in the normal ambient environment, the temperature and the relative humidity being noted for each of the testing series. The stress to fracture applied to the fiber was calculated from the distance separating the faceplates, using the Proctor and Mallinder relation, improved by Griffioen [2]. So for each tested sample one determined the stress to fracture, then the results were treated through a statistical approach using the Weibull theory. The classical Weibull plots of the logarithm function of the cumulative failure probability related to the logarithm of the stress to fracture (***σ***) has allowed to calculate the statistical parameters and the ***n***-stress corrosion parameter [3,4].

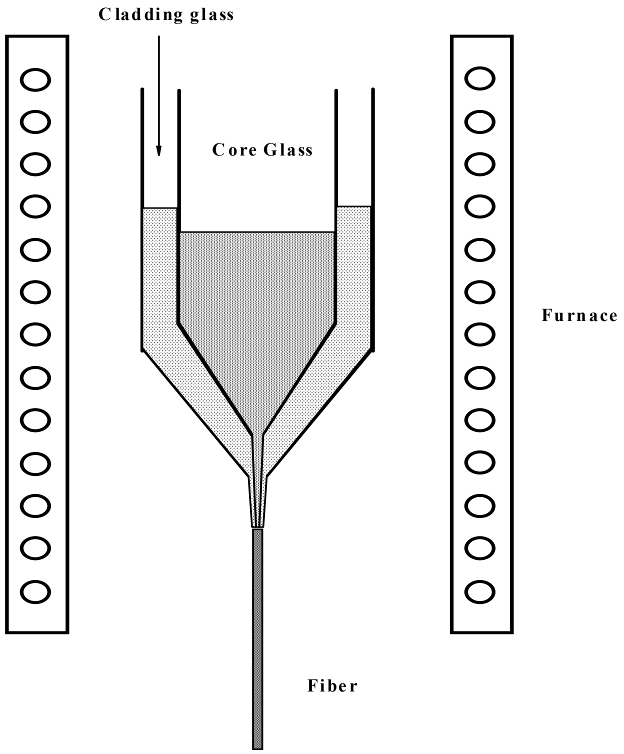

Fig. 2. Double crucible for drawing fibers from glass melt

2.2 Static fatigue measurement

The static fatigue parameters were measured by a static bending test accordingly to the international standard IEC 793 [5]. As received fibers, one meter in length, were subjected to bending stresses by winding around alumina mandrel with calibrated diameter sizes. The constant level of the applied stress can be adjusted by the proper choice of the mandrel size. The time to failure is measured, and this corresponds to the time required for the fiber strength to degrade until it equals the stress applied through winding round the mandrel. The time to failure is measured by optical detection when the ceramic mandrel moves out of the special holder. When fiber breaks, the mandrel rocks from its vertical static position and the time to failure is directly recorded with an accuracy of ±1 s. The testing setup consists of a large number of vats containing 16 holders each.

The applied stress on the fiber depends on the mandrel diameter accordingly to the Mallinder and Proctor relation [4], as follows:

$$\sigma = E_0 . \varepsilon \left(1 + \frac{\alpha' . \varepsilon}{2} \right) \qquad (1)$$

where: σ : applied stress (GPa); E_0 : Young modulus (= 72 GPa for the silica) ; ε : relative deformation of the fiber ; $\alpha' = \frac{3}{4}\alpha$; with α : constant of elasticity non-linearity (=6).

The relative deformation of the fiber depends on the mandrel calibrated diameter, as follows:

$$\varepsilon = \frac{d_{core}}{\phi + d_{fibre}} \qquad (2)$$

with ϕ the mandrel diameter (in µm); d_{core} = 125 µm, the glass fiber diameter; d_{fibre} = 250 µm, the fiber diameter, including polymer coating.

This leads to the corresponding stress of 3.92, 3.76, 3.34 and 3.22 GPa for the calibrated diameter mandrel of 2.3, 2.4, 2.7 and 2.8 mm, respectively. The testing environmental conditions during static fatigue measurements has slightly ranged between 18.5-20.5°C, in temperature and 30 to 45%, in relative humidity. The ***n***-stress corrosion parameter of fibers was determined as the reverse of the slope of the linear function relating logarithm (failure time, in hours) to logarithm (applied stress, in GPa), directly related to the mandrel diameter.

3. RESULTS

The stress to fracture, σ, of the as-received fibers were determined and the correspondent Weibull plots are given in Fig. 3 for four different testing faceplates velocities chosen for the two-point bending testing. The cumulative failure probability *(ln(-ln(1-*F_k*))* in function of the logarithm stress σ, *(ln(stress, MPa))*, has allowed to evidence the influence of testing parameters on fibers subjected to permanent deformation. The corrosion stress parameter was calculated on the basis of the linear interpolation of the dynamic plot, respectively the stress at 40% fiber fracture, *ln (stress, MPa)*, in function of velocity gradient, *ln (velocity, µm/s)*, are given in fig. 4. The n-corrosion parameter for the Alcatel (F1) fiber has a value of 13.16 with rather a good interpolation (0.98).

The comparison of the as-received fibers, tested in static conditions, shows increasingly initial strength values in the order F1 (Alcatel), F2 (Verrillon) and finally F3 (Verrillon, an other preform), as reported in table 1. Moreover, the F3 noted fiber has a three times higher failure time. Note that the applied stress (through the mandrel diameter) was higher for the Verrillon fiber.

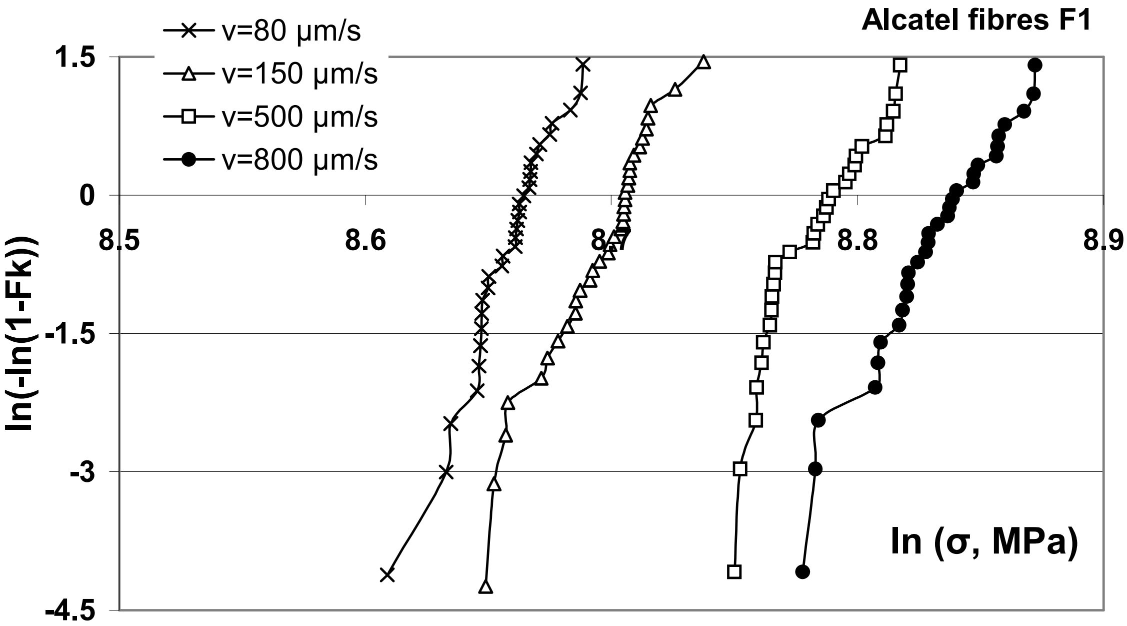

Fig. 3. Results of two point bending testing for different faceplates velocities v, in µm/s (in axes: Fk cumulative failure probability, in % and σ stress, in MPa)

Table 1. Failure time of as-received fibers (static fatique testing)

Fiber reference (as-received)	F1 Alcatel fiber	F2 Verrillon fiber	F3 Verrillon fiber
Failure time, hours	2.1	10.7	33.4
Correspondent applied stress, GPa	3.223	3.757	3.757

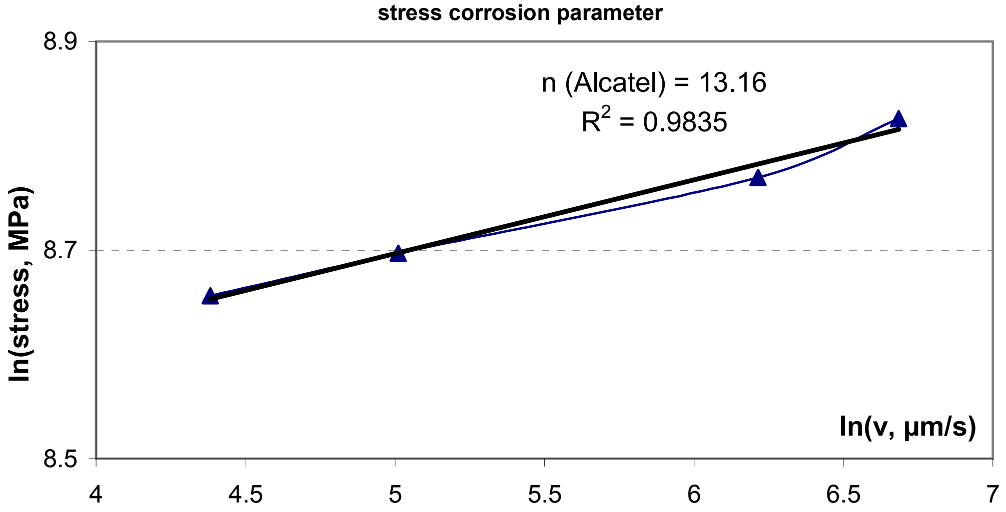

Fig. 4. Stress corrosion parameter of Alcatel fiber (F1) – static fatigue testing

In order to calculate the stress corrosion parameter, ***n***-factor, four different mandrel diameters were used ranging between 2.3 and 2.8 mm. The n-stress corrosion parameter is given by the linear interpolation of the failure time median values (noted ***Ft*** in figures legend) in a logarithm representation of the fiber failure time *(ln(failure time, hours)* in function of the uniform bending stress *σ (ln(stress, GPa).* The experimental results are seen in fig. 5. For the F2 noted fibre (Verrillon), a 26.3 value of ***n***-stress corrosion parameter was found, with a regression coefficient of 0.99.

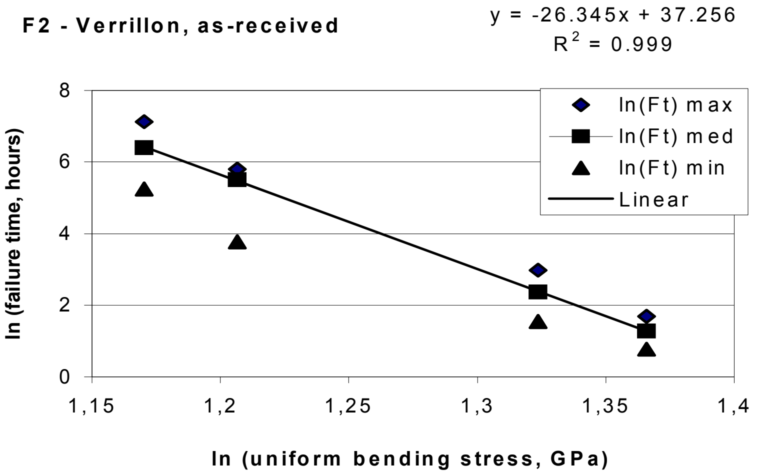

Fig.5. The n-factor calculus of Verrillon fibre noted F2 – dynamic fatigue testing

4. CONCLUSION

Taking into account, on one hand, the huge fiber applications emerging in other fields than telecommunications and, on the other hand, the complexity of phenomena and mechanisms related to the optical fibers reliability and overall characterization, a lot of testing are still required in current and harsh conditions.

Once the methodology established, the dynamic and static fatigue testing has to be implemented and the experimental results statistically treated in order to compare the statistical parameters and the fibre's strength values. So, the fibres in as-received state or aged in different aging conditions (more or less drastic) have to be tested using a two point bending bench at a given stress rate.

If the interest is to compare different types of fibres or different aging conditions, with a fixed stress rate, a series of at least 30 testing in dynamic fatigue testing conditions have to be implemented. The Weibull plots allow to find the statistical parameters and to compare the strength and the curve's slopes indicating the defects distribution along the fibre.

For the n-corrosion parameter, the testing at four different stress rates are required so the four series of at least 30 testing are necessary in order to find the n-factor.

Similar procedure is required for the static fatigue testing. A series of mandrel sized diameter has allowed compare different fibres or different aging treatment previously applied. In order to find the n-corrosion parameter, four different mandrel sized diameter have to be used, so for each series the minimum number for the statistical treatment is necessary.

The merit of the paper is to describe the experimental procedure to test optical fibres in dynamic and static fatigue conditions.

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