INFLUENCE OF ENVIRONMENT ATMOSPHERE ON OPTICAL FIBER STRENGTH

R. El Abdi[1], R. Leite Pinto[1], G. Guérard, C. Capena[2]
[1]Univ. Rennes- CNRS, Institut de Physique de Rennes. UMR 6251. F-35000 Rennes, France
[2]Entreprise Acom – Usines de Mortain, 50140 Mortain, France
Email: relabdi@univ-rennes1.fr

Abstract - The practical strength of optical fibers was controlled by flaws, usually on the surface. It was well established, furthermore, that such flaws can grow in time so that an initially intact silica optical fiber may undergo delayed fracture from the combined influence of stress levels and the chemical environment as air humidity. On the other hand, glass optical fibers were almost always coated with a polymer immediately after drawing to protect them from subsequent handling damage and from chemical environment. When studying the strength and fatigue properties of the fibers, it was useful to be able to remove this coating in order to directly observe the fatigue properties of the glass in immediate contact with the environment. Silica optical fibers with and without polymer coatings were submitted to bending tests when fibers were aged in air atmosphere and in inert atmosphere. Median fiber strength underlines the role of used atmosphere and that of the polymer coating.

Keywords: Optical fibers, Polymer coating, Bending Tests, Inert atmosphere.

1. Introduction

Optical fibers are key components in telecommunication technologies. Apart from optical specifications, optical fibers are expected to keep most of their physical properties for 10 to 20 years in current operating conditions. Fiber failure makes an irreversible accident which may occur when an external stress is applied on a defect located on fiber surface. While intrinsic defects, referred to as Griffith flaws, lead to failure only for large applied stresses, other heterogeneous defects make a far more serious concern as they lead to the fiber failure of the aged fibers under moderate stress. The fabrication process includes a proof test that eliminates the largest defects. However, the chemical action of water is likely to induce stress corrosion in the long term and to promote fiber aging.

Polymer coatings are currently applied to optical fibers to prevent the formation of surface defects through scratches and abrasion and to minimize the influence of the pre-existing defects. They also act as a diffusion barrier against the surrounding humidity reaching the glass surface. Water is known to be one major factor of the propagation of cracks at fiber glass surface because it makes much easier the breaking of the Si-O bonds which build the vitreous network [1]. Accordingly, fiber strength is closely related to the water concentration at the glass surface [2]. It is well known that flaws in glass subject to stress in humid conditions grow subcritically.

Crack velocity is related to applied stress and also to relative humidity [3]. It has also been reported that the kinetics of the reaction between silica and water changes at very low water concentration [4, 6].

In this paper, the influence of chemical environment and that of the polymer coating are analysed. Silica optical fibers were stripped using a new stripping gel to remove the optical fiber coating materials that leaves the surface of the glass cladding intact. Optical fibers with and without polymer coatings were submitted to bending tests in two atmospheres: air atmosphere and inert atmosphere to measure the humidity influence on fiber strength.

2. Fiber and Test Bench Used

The used monomode silica fiber has an acrylate coating. This fiber was manufactured using the Plasma activated Chemical Vapor Deposition (PCVD) process which produces a totally synthetic, ultra-pure fiber. The combined coating diameter is 242 ± 5 µm, the clad diameter is 125 ± 0.7µm and the coating thickness is 58.5 ± 0.5µm.

A two points bending bench made up of a displacement plate which is mounted on an aluminium plate. The first thrust block is movable and mounted on the displacement plate, while the second thrust block is fixed on a force sensor. The optical fiber is positioned between the two thrust blocks in such a way that it forms a "U". To avoid slipping, the fiber is positioned in the grooves of the thrust blocks. During the test, load and displacement are recorded, allowing the load/displacement curve to be obtained (Fig. 1).

The test bench was introduced inside a compact glove box with purification system (H_2O <1ppm, O_2 <1ppm, 95% N_2 or Ar + 5% H_2) (Fig.2). External gloves allow performing bending tests inside the box.

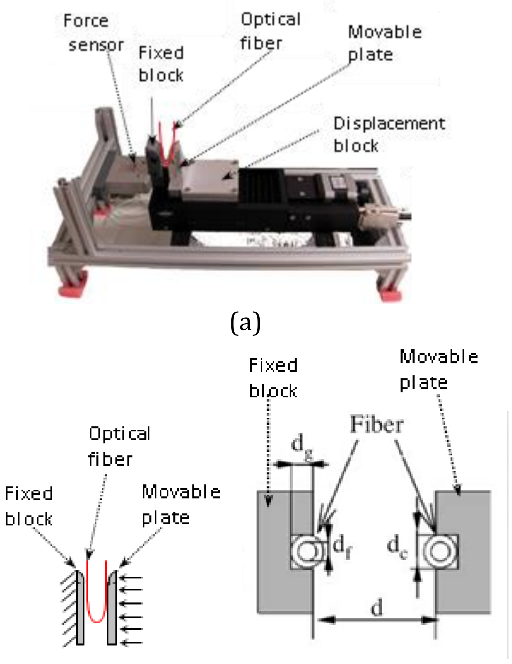

Figure 1: (a) Bending bench used; (b) and (c) fiber between thrust blocks

Figure 2: Compact glove box with purification system (Jacomex GP Campus T2)

The stripping gel used contains methylene chloride (CH_2Cl_2: > 60 %) (used as a solvent in manufacturing) and other elements such as trichloroethylene ($CHCl_3$) and heavy naphtha.

Figure 3 shows that the coating has been removed and the glass cladding surface has remained intact.

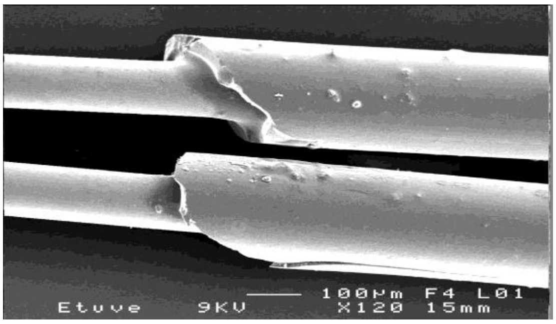

Figure 3: Stripped fibers

3. Theoretical Background

The Weibull theory is one of the most used methods to characterize the failure of optical fibers [7]. The statistical Weibull law gives a relationship between the probability *F* of fiber rupture with a length *L* and the applied stress *σ*:

$$Ln\left[\frac{1}{L}\left\{Ln\left(\frac{1}{(1-F)}\right)\right\}\right] = m\left[Ln(\sigma)-Ln(\sigma_o)\right] \quad (1)$$

where *m* is a size parameter and σ_o is a scale parameter.

The evolution of $Ln\left[\frac{1}{L}\left\{Ln\left(\frac{1}{(1-F)}\right)\right\}\right]$ according to $Ln(\sigma)$ is called Weibull diagram.

This diagram enabled us to calculate *m* and σ_o which respectively correspond to the curve slope and to the curve intersection with the stress axis.

The *m* parameter characterizes the defect size dispersion [8]. A high *m* value indicates that along the fiber the defects sizes are averaged. A low *m* value reveals that the defects found at the fiber surface have varying sizes, which results in different values of the failure stress. As to the σ_o parameter, it represents the stress for which the cumulated rupture probability of the fiber *F* is equal to 50%.

To plot the Weibull diagram, which corresponds to a fiber thus characterizing a defect population, a series of mechanical tests were carried out on a great number of samples of this fiber (in practice about thirty samples were tested). All the samples were the same length *L* (here, L being equal to 1*)*. Once the tests were carried out, by ascending order:

$$\sigma_1 \le \sigma_2 \le .... \le \sigma_i \le \sigma_{i+1} \le .... \le \sigma_N \quad (2)$$

(*N* is the total number of tested samples).

The obtained breaking stresses were classified. For each breaking stress σ_i, a rupture probability *Fi* is affected using the following estimator:

$$F_i = \frac{i - 0.5}{N} \tag{3}$$

If the rupture is characterized by a single defect category, *Ln* [(1/*L*) {*Ln* (1/(1-*F*))}] varies in a linear way with *Ln (σ)* and Weibull modulus is given by the slope of this curve. But when the tests are carried out with large fibers lengths, one observes a slope break indicating the passage of a defect distribution to another.

Figure 4 represents the rupture probability for a test of fatigue dynamic test. The observed slope break implies that the rupture is due to two defect categories. Thus, one speaks about bimodal distribution.

The defect crack propagation generally follows two modes associated with two zones: zone 1 where the parameter m has a high value ($m = m_1$) i.e. where a small failure stress distribution exists contains defects called intrinsic microcracks (Fig. 4), and zone 2 where the parameter m has a lower value m_2, we found defects called extrinsic microcracks. Those microcracks can have several origins: dust which was in the fiber drawing furnace, presence of particles in materials used for coating. These defects tend to appear when the tested sample fiber length increases.

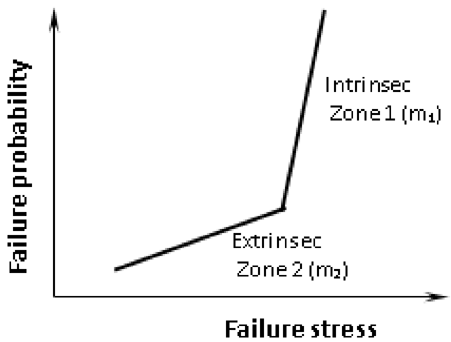

Figure 4: Failure stress bimodal distribution

4. Results and Discussion

- ***Tests under air atmosphere***

Figures 5 and 6 give Weibull curves for different faceplate velocities when the tests were undertaken in the air for coated and stripped fibers respectively. Overall, coated and uncoated fibers exhibit the same mechanical behaviour. The failure stress increases with the faceplate velocity. The failure stresses of coated and stripped fibers were similar; the coated fibers have slightly higher values than the uncoated fibers which don't benefit from the coating rigidity (Fig. 7).

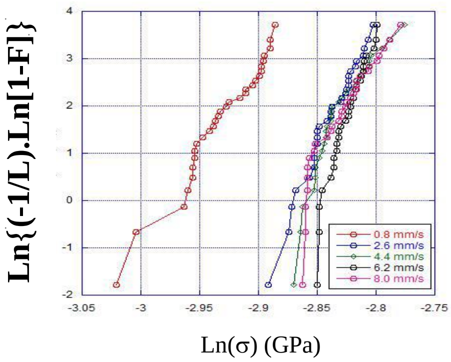

Figure 5: Weibull curves for coated fibers in the air

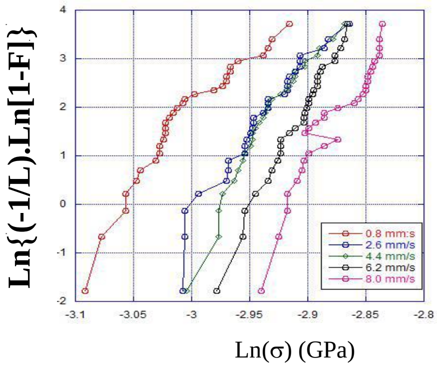

Figure 6: Weibull curves for stripped fibers in the air

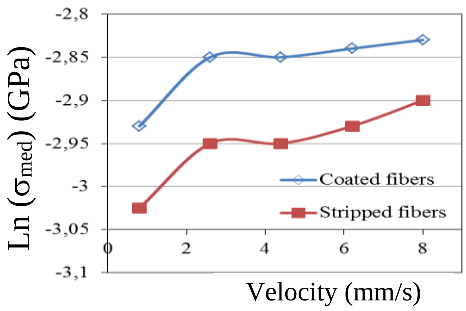

Figure 7: Median strength for coated and stripped fibers in the air versus faceplate velocity

- ***Tests under inert atmosphere***

Figures 8 and 9 give Weibull curves for different faceplate velocities when the tests were undertaken in the inert atmosphere for coated and stripped fibers respectively.

Here again, the failure stresses of coated fibers are slightly higher than those of stripped fibers (Fig. 10).

Table 1 summarizes the results for both atmospheres for coated and stripped fibers. It should be noted that the median failure strength doesn't varies significantly when the coating was removed.

On the other hand, the test environment had an important influence. Indeed, the failure fiber strength can drop by 50% due to the air humidity which weakens the silica bonds [3, 6].

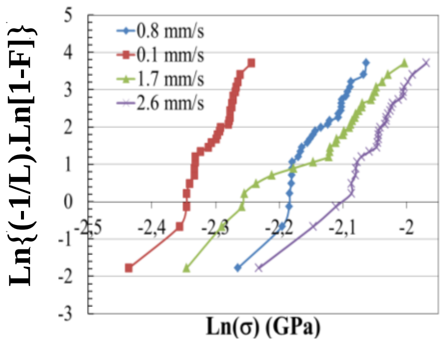

Figure 8: Weibull curves for coated fibers in inert atmosphere

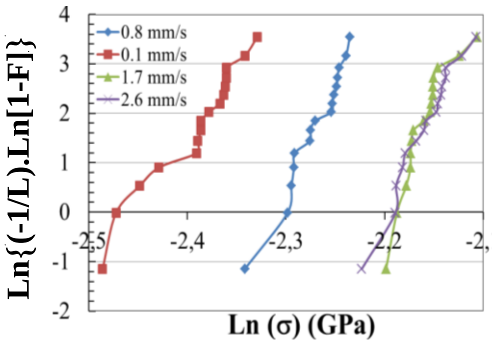

Figure 9: Weibull curves for stripped fibers in inert atmosphere

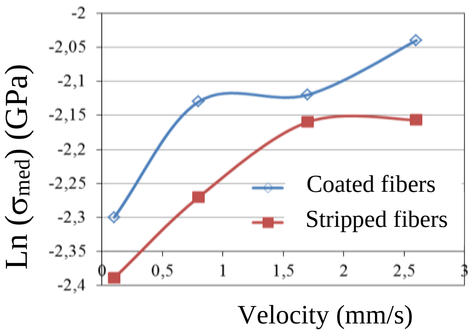

Figure 10: Median strength for coated and stripped fibers under inert atmosphere versus faceplate velocity

Table 1. Median strength for coated and stripped fibers under two atmospheres

Median fiber strength (GPa)		
	Coated fibers	Stripped fibers
Inert atmosphere	0.11 ± 0.003	0.10 ± 0.003
Air	0.058 ± 0.003	0.052 ± 0.003

Silica is a brittle material. The failure of optical fibers was brutal. The failure cross section surface was straight and perpendicular to fiber length (Fig. 11). Some glass flakes were found on the cross failure section; the fiber breaks suddenly when the failure stress was reached.

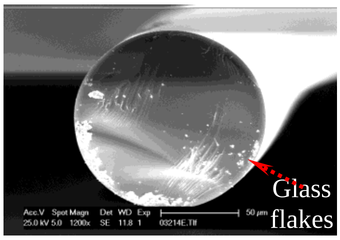

Figure 11: Cross area of stripped fiber after failure

5. Conclusions

Acrylate coatings are applied to large core optical fibers, though they are applied to nearly all telecom fiber for lower cost and ease to coating removal for termination. Acrylate coatings were currently applied to optical fibers to prevent the formation of surface defects through scratches and abrasion and to minimize the influence of the pre-existing defects. They also act as a diffusion barrier against any attack by chemical agents reaching the glass surface. They lightly increase the fiber strength and limit the water attack but they can't stop it and the molecular water diffuse in the glass and react with the glass network to form hydroxyls (Si-O-Si + H_2O ↔ 2 Si-OH). This water diffusion weakens the fiber strength as shown by the results obtained in the inert atmosphere.

In some fiber designs, a polymer jacket is extruded over initial coating for extra protection. But the choice of the fiber is conditioned by its optical and physical performances but also by its cost.

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