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Original

Lifetime modeling of silica optical fiber in static fatigue test

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Abstract

During their use, optical fibers are subject to harsh installation and environmental conditions. To evaluate more precisely the lifetime of an optical fiber, it is necessary to study the mechanical behavior of optical fibers under extreme conditions, in particular under mechanical and thermal stresses.

This paper presents the results of new silica optical fibers aged in hot water between 20 °C and 70 °C and subjected to mechanical static bending stresses from 3 GPa to 3.5 GPa. Thermal dependence of the time to failure was observed. This dependence can be described by the Arrhenius model, where the activation energy is one of the main physical characteristic. The stress corrosion parameter also seems to regularly change with temperature.

Keywords: Optical fibers; Bending stress; Hot water; Activation energy; Stress corrosion parameter; Lifetime

1. Introduction

A lot of progress has been made on the ability to produce long lengths of strong optical fibers for telecommunication networks. Thereby, some important advances have also been made in the protection of the external surface of the fiber from environment damage through the development of new coatings. Among these coatings, epoxy acrylate coatings were used in telecommunication networks; during the drawing, the application of the polymer on the fiber was easy and its polymerization was very fast. However, there is not a sufficiently detailed understanding of the influence of aging conditions on the fiber strength when these types of fibers were aged in an aqueous environment and under mechanical stress (Evanno, 1999; Gougeon, 2003). It is important to estimate the life duration of these fibers generally degraded under moisture and mechanical torsion stresses when these ones must be used in harsh environments.

Shiue and Matthewson (2002) have studied the effect of the temperature variation of water pH on the static fatigue of fused silica optical fibers and its impact on the apparent activation energy.

Sakaguchi and Hibino (1984) were interested by the fatigue in the low-strength of silica optical fibers. The fatigue behavior is mainly characterized by crack growth parameter *n* (stress corrosion parameter). The value of *n* for low-strength fibers which contain macroscopic flaws has not been sufficiently clarified, because only a few examinations have been made on low strength fibers (Donaghy & Nicol, 1983; Gulati, Helfinstine, Justice, McCartney, & Runyan, 1979), although many studies have been made on high-strength fibers which have no macroscopic flaws (Chandan & Kalish, 1982; Kalish & Tariyal, 1978; Sakaguchi & Kimura, 1981). The allowable loading condition needed to prevent any growth of the macroscopic flaw was discussed in order to assure high reliability for the fiber.

Chen and Chang (2002) have focused on the fracture mechanics of silica optical fibers to evaluate the strength and fracture characteristics of single and multi-mode fibers subjected to uniaxial tensile testing and two-point bending. The fracture strength data of both single and multi-mode under either testing were

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found to be very similar. The fracture stresses at 50% fracture probability for tensile testing and two-point bending were 4.5 and 5.1 GPa, respectively. The fracture characteristics of each tested optical fiber specimen were evaluated by using an SEM. A critical flaw on the surface of glass fiber was found to be the fracture origin for specimens under either tension or bending as expected.

Besides signal transmission for telecommunications, fibers are used in an increasing number of devices. A number of applications relate to devices exposed to severe wet environment (hot water, chemical attacks, etc.). It is the case for the sensors used in nuclear plants, high energy physics or plasmas devices.

Reliability issues must be addressed for optical fiber sensors operating under severe conditions such as harsh chemical solutions.

El Abdi, Rujinski, Poulain, and Severin (2010) have studied the mechanical behavior and aging of fibers exposed to hot water action, to hydrofluoric acid vapors (HF) and to tetramethoxysilane (TMOS) for different durations. Standard fibers tested immediately after exposure show a broader distribution of fiber strength accompanied by the drastic decrease of the failure stress. Polymer reacts with different wet environments, which induces viscosity changes.

Fiber-optic sensors are also mostly used for in situ measurements of diverse chemical composition of industrial surfactants employed in industry as detergents, emulsifying and dispersing agents, coatings, and pharmaceutical adjuvants. Another work (El Abdi, Rujinski, & Poulain, 2015) was undertaken to study the mechanical behavior of optical fibers in contact with CetylTrimethylAmmonium Chloride (cationic surfactant used as a very toxic antiseptic) in aqueous solution (CTAC) at different immersion durations and different temperatures. Result analysis demonstrates that immersion in CTAC drastically decreases the fiber strength particularly when immersed for long aging periods at high temperatures.

In our study, the used fibers were among the last qualified fibers and used in telecommunication networks. They contain very high quality silica and have an improved polymer coating.

In this work, the mechanical strength of a silica optical fiber aged in distilled water at different temperatures was studied. Optical fibers were then wound around alumina mandrels with different diameters in order to evaluate the influence of the static bending stresses on the lifetime of the fiber.

The results should be used to determine the fatigue fiber parameter changes (activation energy, stress corrosion parameter, fiber lifetime) according to water temperature (from 20 °C to 70 °C) and applied bending stresses to give a lifetime modeling of optical fibers in static fatigue.

2. Experimental

2.1. Optical fiber used

The used monomode fiber has two acrylate coatings (primary and outer coatings).

This fiber was manufactured using the Outside Vapor Deposition (OVD) process which produces a totally synthetic, ultra-pure fiber. It has high strength and low attenuation. Its dual acrylate layer (CPC6) coating provides excellent fiber protection. On the other hand, the operating temperature range was −60 °C to +70 °C. A soft, primary coating has a low module of elasticity, adheres closely to the glass fiber and forms a stable interface. It protects the fragile glass fiber against micro-bending and attenuation. The outer coating protects the primary coating against mechanical damage and acts as a barrier to lateral forces. It has a high glass temperature and Young modulus and a good chemical resistance. The combined coating diameter is 245 μm ± 5 μm, the clad diameter is 125 μm ± 1 μm and the coating thickness is equal to 62.5 μm ± 2 μm.

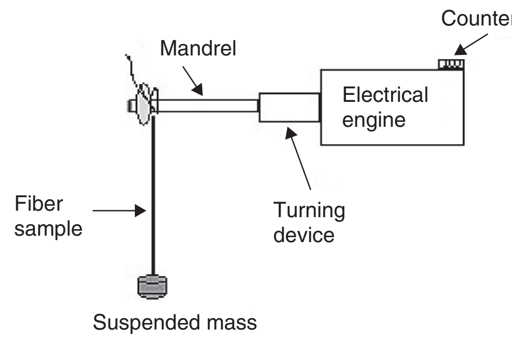

Figure 1. Electrical engine for winding of each fiber.

2.2. Test bench used

Optical fiber was wound onto an alumina mandrel of 2.6, 2.7, 2.8 or 3 mm in diameter (Fig. 1). Electrical engine helps to wound fibers around alumina mandrels. A counter gives the maximum number of circumferences around each mandrel. The winding of each fiber was automated and the same applied stress was obtained for each fiber. The real deformation for each fiber depends on the mandrel diameter; with the use of suspended mass (Fig. 1) each fiber has taken on the exact shape of the mandrel.

The extremities were clamped in two oblique cuts simple clamping rings, made of elastomer-rubber, and mounted on the extremities of the alumina mandrels. Once the fiber was wound around the mandrel, it was placed between a transmitter T and a light receiver R (Fig. 2). The light beam cannot reach the receiver and from then on the time of fiber loading is triggered. The mean time to failure is recorded, 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, the light beam can reach the receiver 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 alumina mandrels have a very low surface roughness. The friction between the fiber polymer coatings and the mandrel is negligible.