MECHANICAL RELIABILITY ASSESSMENT OF OPTICAL FIBRES IN RADIATION ENVIRONMENTS

Background

After more than two decades of intensive research and even some pioneering applications in space, optical fibres are now finding their way in various radiation environments, including both fission and future fusion nuclear-power plants, and high-energy physics experiments. For example, next to distributed monitoring applications of large nuclear infrastructures, fibre-optics can also be used for data communications during maintenance operations in the reactor vessel of the future ITER (International Thermonuclear Experimental Reactor), or for plasma diagnostics applications during operation of the reactor. These maintenance and diagnostics tasks require the optical fibres to withstand extremely high doses of radiation, up to MGy dose levels and temperatures above 150°C.

Objectives

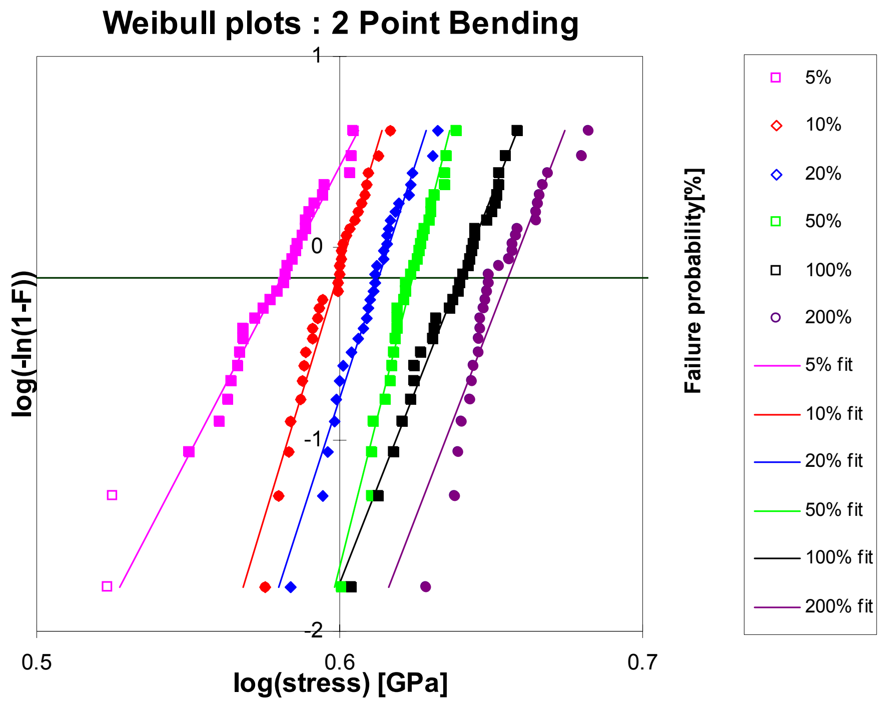
The reliability assessment of fibre-optic systems for their qualification in nuclear environments often requires to meet stringent radiation tolerance levels. The majority of (usually accelerated) radiation assessments have so far focused on optical properties, such as wavelength-dependent radiation induced attenuation and radio-luminescence. The relation of these radiation effects with the fabrication methods and other environmental parameters has been the subject of years of research. Only a few results are available on the long-term evolution of mechanical properties of irradiated optical fibres. As a first step towards understanding the long-term reliability of fibre-optic composite cables in hostile radiation environments, we therefore performed dynamic fatigue tests with different commercial-grade optical fibres, both multi-mode and single-mode types.

Principal results

We selected for testing four standard telecom acrylate-coated Ge-doped single-mode fibres from three different manufacturers, and one acrylate-coated Ge-doped multi-mode fibre. Fibre samples of 50 m were loosely coiled with a diameter of 60 mm and exposed during a first experiment with a dose rate of 27 kGy/h up to a total dose of 15 MGy at an ambient temperature of approximately 55 °C.

In collaboration with both Draka Comteq Optical Fibre in Eindhoven and with the School of Engineering (Metallurgy and Materials Department) at the University of Birmingham, we performed several mechanical tests before and after irradiation, including the two-point bend test. These destructive two-point bend tests allow to determine the fibres' strength (50 % failure stress) and the dynamic fatigue factor. Both physical quantities are estimated from the measurement of the failure stress as a function of the applied stress rate [GPa/sec], resulting in typical Weibull plots as presented in the picture hereunder, which presents the probability of failure versus the applied stress with logarithmic scales.

Our Weibull analysis reveals a strength reduction of about 50 % at these MGy dose levels. SEM (scanning electronic microscope) images of the fibres samples, which were uncoated after irradiation, further suggest that roughening of the outer glass surface can explain this degradation. These first results indicate that the long-term mechanical strength of optical fibres could be seriously affected when exposed to MGy dose levels.



Evolution of the mechanical strength as a function of the applied stress rate, after irradiation up to MGy dose levels. (Courtesy of Draka Comteq Optical Fibre, Eindhoven)

Future work

During a second irradiation, we exposed three pristine samples from one single-mode fibre at 55 °C with a dose rate of 1.7 kGy/h, 3.4 kGy/h and 17 kGy/h up to total doses of respectively 1.0 MGy, 2.0 MGy and 10.1 MGy. In parallel, we thermally aged an identical pristine fibre sample in a climate chamber at 55 °C with a relative humidity of 50 %. This complementary experiment was conducted in order to distinguish between thermal ageing and combined radiation-thermal ageing effects, while we also look for mechanical degradation mechanisms at intermediate dose levels.

We also intend to evaluate the potential impact of different protective coating materials on the mechanical reliability of optical fibres in radiation environments, including hermetic amorphous carbon and polyimide coatings.

Main contact person

Marco Van Uffelen, marco.van.uffelen@sckcen.be

Main reference

M. Van Uffelen, S. Kukureka, Y. El Shazly, P. Matthijsse, G. Kuyt, F. Berghmans, *Mechanical reliability studies of optical fibres under high-dose gamma radiation, accepted for presentation at the conference on "Reliability of Optical Fiber Components, Devices, Systems, and Networks III,"* part of the SPIE Photonics Europe Symposium, 3-7 April 2006 in Strasbourg, France.