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The degradation in tensile strength of polymer-coated glass optical fibres under γ-irradiation

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The tensile strength of glass optical fibres when coated with various polymers has been measured as a function of γ-ray dose. Fibres protected with acrylate, silicone + acrylate or polyimide coatings showed little degradation after receiving a total dose of 1 MGy (they retained > 95% of their preirradiated strength). For a fibre with an extruded nylon overcoat the nylon became very brittle after 0.5 MGy, but as far as could be assessed, the strength of the central glass fibre was little affected. Two other types of fibre, both protected with fluorinated polymers, were severely weakened after 0.1 MGy (their tensile strength being reduced to < 40% of their pre-irradiated strength). Experimental results are given supporting the hypothesis that the degradation results from gaseous fluorine-containing species chemically attacking the surface of the glass fibre.

1. Introduction

Scientists and engineers are turning increasingly to the new technology of optical fibres for communications and sensing applications in a wide range of adverse environments, particularly where freedom from electromagnetic interference, light weight or high bandwidth are important. The influence of ionizing radiations is an important consideration for space, military, medical and nuclear applications. Whilst there is a considerable body of literature on how ionizing radiation affects the optical properties of fibres, there is virtually none on how their mechanical properties are affected. This is an important consideration because the optical transmission characteristics of a fibre are critically dependent on its structural integrity. Many potential application areas within the nuclear industry would require optical fibres to remain flexible, e.g. for use on robotic limbs, or to be used in confined spaces. In the latter case, although dynamic stresses may be small, the fibre may well experience high static stresses caused by small bend radii. In such applications, although the attenuation per metre for the irradiated fibre may be large (exceeding 1 $dB\,m^{-1}$ for some wavelengths) the length irradiated can frequently be designed to be quite small, a few metres, enabling the optical system to operate successfully after exposure to high doses of radiation. For these applications, the limiting factor can be the ability of the fibre to retain its structural integrity.

The intrinsic strength of silica fibres is very high: maximum tensile strengths of 14 GPa have been reported for short gauge lengths [1]. However, defects located either on the surface or internally act as stress intensifiers and cause fracture to occur at much lower levels of applied stress. In order to minimize mechanical abrasion and chemical degradation of the fibres' surface, glass fibres are given protective polymeric coatings when drawn. It is also well known that radiation adversely affects the properties of polymers [2]. This paper reports an experimental investigation aimed at quantifying how γ radiation affects the mechanical strength of optical fibres coated with different polymers.

2. Experimental procedure

2.1. Determination of tensile strength

The six fibres detailed in Table I were investigated. The tensile failure point of the optical fibres was measured using a modified version of the ANSI standard [3]. Several turns of double-sided adhesive tape were wound around knurled, 3 cm diameter capstans prior to winding several centimetres of fibre (between 50 and 90 cm on each capstan), care being taken that none of the turns crossed. The capstans were attached to an Instron TT-CM-L tensile testing instrument, and pulled vertically. The crosshead speed (rate of elongation) was 10, 20 or 50 $mm\,min^{-1}$, and the gauge length used was 150 mm. Disadvantages of this technique were that the fibre was wound on a capstan rather than being stressed linearly, each test required 1.2–2.0 m fibre, and that the gauge length is not accurately known as a certain amount of fibre creep occurred during the test (but this can be taken as 20 > gauge length > 15 cm).

An alternative technique, frequently employed to test the tensile strength of fibres used for reinforcing composites, is to bond them on to triangular tabs and to apply a tensile load to the tab [4]. The length of

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TABLE I Details of fibres used for this investigation

Fibre manufacturer	Fibre type	Glass diameter (μm)	Polymeric coatings			
			Type	Diameter (μm)	Type	Diameter (μm)
STC Technology	Monomode	125	Acrylate, DSM Desoto 950 131	250		
STC Technology	Plastic clad silica	100	Silicone, Dow Corning Sylgardd 182	250	Acrylate, DSM Desoto 950 101	470
STC Technology	Plastic clad silica	125	Silicone, Dow Corning Sylgardd 182	250	Nylon	1000
STC Technology	Experimental	125	Polyimide	160		
Quartz et Silice	PCS 200A	200	Silicone	380	Proprietory ETFE	600
Ensign Bickford	HCP M0 200 T06	200	Proprietory coating-bonded hard polymer optical cladding	230	Tefzel (Dupont)	500

optical fibre to be tested was glued, using Araldite, to a tapered cardboard mount and pulled axially via accurately located pins at each end. The method was adapted to suit an existing Hounsfield Tensometer W which has a horizontal test bed and had been modified to pull directly on to a Schlumberger D95 series load transducer of 500 N maximum load capacity. The gauge length of fibre used was 40 mm.

Whilst this technique only uses a short (10 cm) length of optical fibre and provides a known gauge length, it is unsuitable for many fibres because adhesion at the glass/polymer interface fails before the glass component reaches its tensile failure point. In principal this can be overcome by increasing the area of the glass/polymer interface, but in practice the length of the tensometer test bed constrains the additional length available. Only the polyimide-coated fibre was suitable for testing by this technique. However, this was used in preference to winding the fibre around capstans because of the relatively short length of polyimide fibre available and the improved accuracy obtained from replicating experiments.

Fibre sufficient to provide lengths for four tests was wound round 25 or 40 mm diameter mandrels for fibres 1–4, and 5–6, respectively. This produces approximately constant static stress for the different types of fibre. Around seven such lengths, chosen at random from the whole, were irradiated to a predetermined total dose with γ-rays from ^{60}Co, at ambient temperature and at a dose rate of approximately 25 kGy/day. The dose rate was measured using red 4034 poly(methylmethacrylate) dosimeters, manufactured by the UKAEA, and was known to ± 5%. For a given position, the dose rate is time dependent, the half-life of ^{60}Co being 5.272 years, and the appropriate allowance for this was made in calculating the total dose received. The fibres were tested wthin a week following the irradiation.

2.2. Data analysis

The data from this investigation are presented as Weibull plots [5, 6], of $\ln\ln[1/(1-G)]$ against $\ln S$, where G is the fraction of samples that had failed at a particular value of stress, S. The stress was calculated from the applied load divided by the cross-sectional area of the glass; no allowance was made for any small contribution from the polymers although this can be estimated as being < 5% that of the glass for all but one of the fibres studied. It was also assumed that the diameter of the glass component of fibres was exactly that specified, see Table I. Figs 1 to 5 are plotted using the same ordinates and abscissa to enable comparison between the different fibres.

If the flaw distribution follows some simple power law, i.e. number of flaws of size $x \propto (1/x)^n$, then a linear Weibull plot results. The stress required to break 50% of the samples tested (corresponding to when $G = 0.5$, i.e. $\ln\ln[1/(1-G)] = -0.37$) gives a quantitative measure of the mean strength of the fibre. The principal errors in determining this stress, apart from the assumptions discussed above, come from measuring the breaking force (typically ± 0.2 N in 45 N) and from the statistical scatter of data comprising the Weibull plot. The gradient of the line quantifies the exponent of the power law, larger values result from fibres breaking over a narrow range of stress, and imply a narrower statistical distribution of the largest flaw in the test length.

3. Results

Fig. 1 shows the results obtained from a fibre coated with only acrylate (Desoto 950 131) before and after irradiation. The Weibull plots are approximately linear in all cases, and the strength of the fibre was not found to deteriorate appreciably even after receiving 1 MGy total dose, as is evident from the lower half of the figure.

Fig. 2 shows analogous data from a fibre coated with a silicone buffer layer overcoated with a harder acrylate (Desoto 950 101). The tensile strength of the fibre initially increased slightly on irradiation. The exact cause of this is unknown, but it probably arises from changes in Young's modulus of the protective polymers. After 1.8 MGy the strength of this fibre, 4.88 ± 0.056 GPa, is still slightly higher than for the unirradiated samples, 4.67 ± 0.054 GPa, although the gradient of the Weibull plot is significantly smaller.

The fibre having a silicone buffer layer and an extruded nylon overcoat is unique among those investigated in that the ratio of the polymer cross-

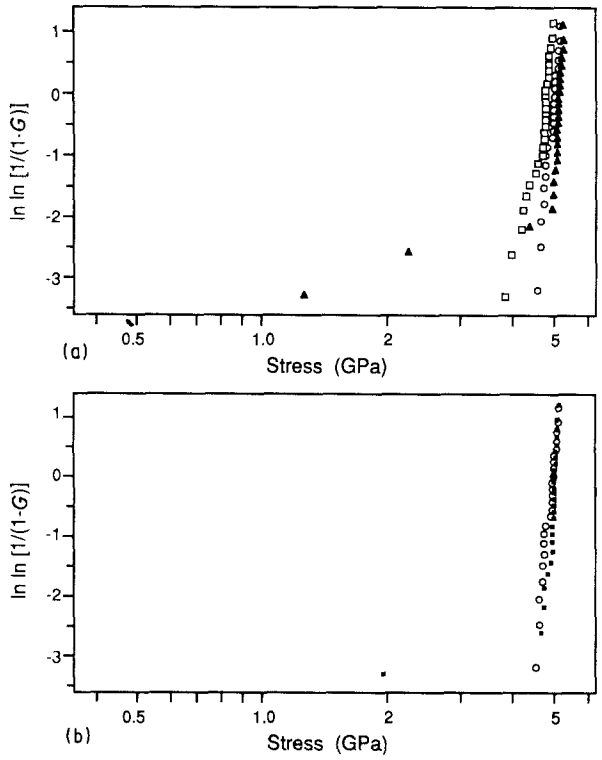

Figure 1 Weibull plot for the cumulative failure of an acrylate-only-coated glass fibre after exposure to various γ-ray doses. (a) (○) Unirradiated, (□) 0.25 MGy, (▲) 0.5 MGy. (b) (○) Unirradiated, (■) 1 MGy.

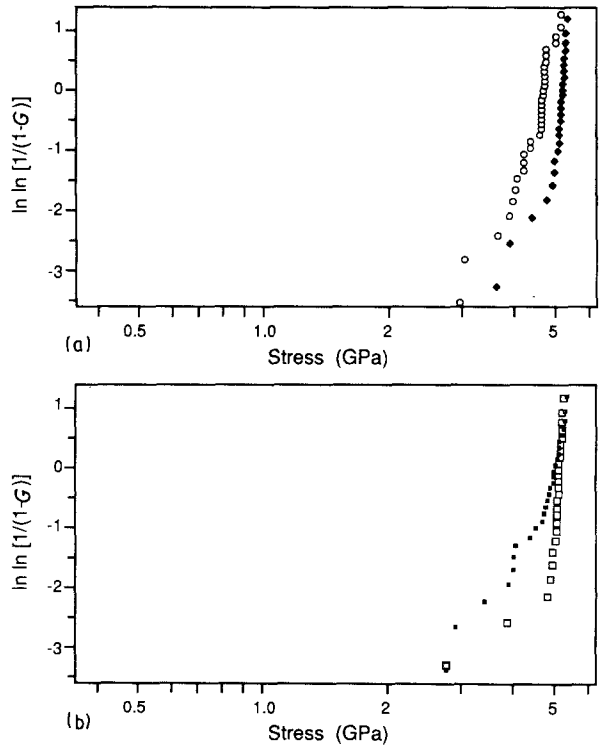

Figure 2 Weibull plot for the cumulative failure of a silicone + acrylate-coated glass fibre after exposure to various γ-ray doses. (a) (○) Unirradiated, (◆) 0.25 MGy. (b) (□) 1.0 MGy, (■) 1.8 MGy.

sectional area to that of the glass is significantly larger (64:1), and Young's modulus for nylon is several times larger than for silicone or the softer acrylate. Consequently, a significant proportion of the force required to break this fibre is used to elastically stretch the nylon. Young's modulus for the nylon coating was experimentally determined as 0.9 ± 0.1 GPa, relative to around 72 GPa for silica. Consequently, the nylon contributed around 42% to the strength of the whole fibre during elastic deformation. After 0.25 MGy the strength of the fibre had not changed significantly. However, after 0.5 MGy the nylon had become so brittle that it was not possible to uncoil it from the 4 cm diameter mandrel on which it had been irradiated. Therefore, the strength of this fibre could not be assessed after being irradiated with more than 0.25 MGy.

The data for the experimental, polyimide-coated fibre, are shown in Fig. 3. After 1 MGy, negligible deterioration had occurred. This fibre was exposed to total doses up to 10 MGy, by which time quite serious degradation had occurred, the stress at which 50% of the fibres broke having been reduced from 5.0 GPa for the unirradiated fibre, to 2.7 GPa and 2.0 GPa after 5 and 10 MGy, respectively. The gradient of the Weibull plots was independent of the dose received, within experimental error.

Fig. 4 shows the data for the plastic clad silica fibre manufactured by Quartz et Silice. This exhibits a quite different behaviour from that seen for the previous four types of fibre. Whilst a γ-ray dose of 0.025 MGy produced some slight deterioration in mechanical strength, the tensile stress required to break 50% of the fibres was reduced by some 47% after receiving a total dose of 0.05 MGy, and after 0.1 MGy the fibre's strength was $< 30\%$ that of unirradiated fibre. Therefore, both in strength relative to the unirradiated fibre, and in absolute strength, this type of fibre was weaker after 0.1 MGy than the polyimide-coated fibre was after a hundred times higher γ-ray dose.

The equivalent data for the hard-clad silica fibre manufactured by Ensign Bickford is shown in Fig. 5. For this fibre the proprietary cladding, chemically bonded to the glass does increase its tensile strength relative to the other PCS fibre studied to 4.9 GPa. The data measured for the unirradiated fibre are in close agreement with that previously reported [7]. However, after only 0.025 MGy a $> 60\%$ reduction in strength, had occurred, making it the weakest of all the fibres studied after receiving 0.025 MGy. Further irradiation caused additional weakening to a lesser

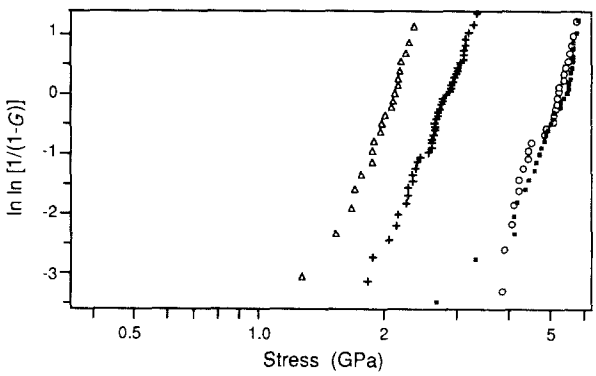

Figure 3 Weibull plot for the cumulative failure of a polyimide-coated glass fibre after exposure to various γ-ray doses. (○) Unirradiated, (■) 1.0 MGy, (+) 5.0 MGy, (△) 10.0 MGy.

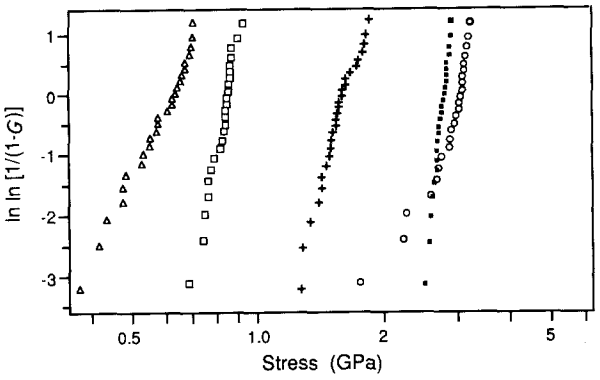

Figure 4 Weibull plot for the cumulative failure of a plastic clad silica glass fibre after exposure to various γ-ray doses. (○) Unirradiated, (■) 0.025 MGy, (+) 0.05 MGy, (□) 0.10 MGy, (△) 0.20 MGy.

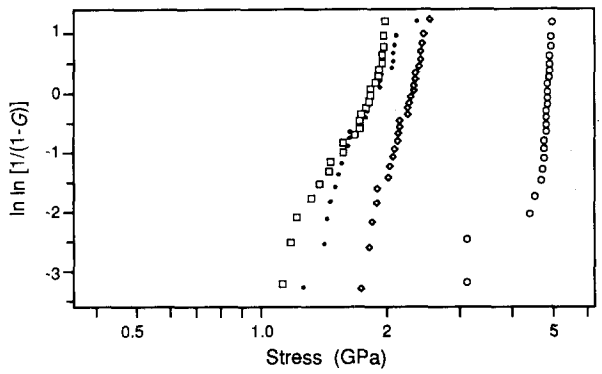

Figure 5 Weibull plot for the cumulative failure of a hard clad silica glass fibre after exposure to various γ-ray doses. (○) Unirradiated, (◆) 0.026 MGy, (□) 0.11 MGy, (◇) 0.25 MGy.

degree. For both this and the PCS fibre the gradient of the Weibull plot decreased with decreasing fibre strength.

4. Resumé of results and discussion

4.1. Resumé of results

Table II summarizes the mean strains at failure of all six fibres investigated, as determined by applying a tensile stress, prior to irradiation and after various total doses of γ radiation. The gradient of the Weibull plot is also given, as calculated using a least squares fit to put a straight line through the data after omitting any points deviating significantly (i.e. 0 and 1 points were omitted from the 0.0 and 1.0 MGy shown in Fig. 1). The error quoted is ± (2 × standard deviation) in the gradient. The data are also shown graphically in Fig. 6. From this a general trend of radiation tolerance is seen:

hard clad silica < silicone + ETFE < silicone + nylon < polyimide, acrylate and silicone + acrylate.

For the unirradiated fibres, the stress for 50% failure ranged from 3.0–5.1 GPa (after making allowance for the thick nylon overcoat on one type of fibre). The gradients of the Weibull plots varied between 8 and 50. On irradiating the two fibres having fluorine-containing protective polymers, the marked reduction

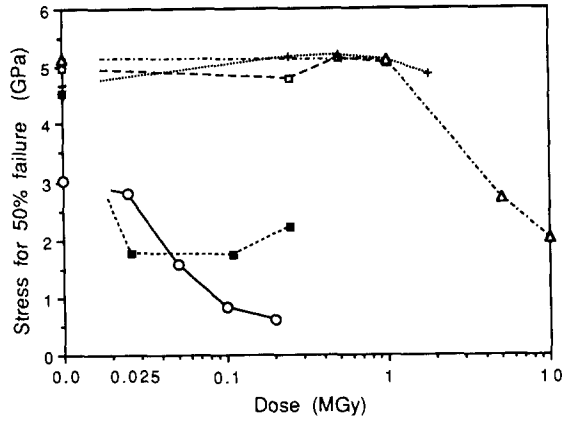

Figure 6 Graph showing the tensile strength for 50% failure against the γ-ray dose received for the fibres investigated. (– –□– –) Acrylate only, (... + ...) silicone + acrylate, (—.—△—.—) polyimide, (——○——) PCS, (– –■– –) HCP.

in strength was accompanied by a reduction in the gradient of the Weibull plot.

The above data are in agreement with previously published data on the tensile strength of fibres, although none have reported the effect of ionizing radiation on strength. Typical values for the strength at 50% failure of "as-supplied" fibres are 5 GPa (for 0.04 cm gauge length) [6], 4.1 GPa [8], and 3.5–6.6 GPa for specially coated fibres [6, 9]. The gradient of the Weibull plots ranged from around 13 [8] to 32–92 for the fibres with special coatings [9]. The work reported by Ritter *et al.* [9] is of further interest because it reports how immersing optical fibres in distilled water degraded the strength of four fibres with special coatings. The characteristics of the resulting Weibull plots are generally similar to those obtained for this work, with longer immersion times causing a reduction in fibre strength and a decrease in the gradient of the Weibull plot.

4.2. Degradation mechanism and discussion

Questions posed by these results include: why does radiation weaken optical fibres and why are specific fibres particularly weakened?

The theoretical strength of glass is determined by the bond strength of its components. Its actual strength always falls significantly below this value. The accepted model used to explain the discrepancy is the Griffith microcrack hypothesis, which postulates that there are very small cracks on the surface of the glass. When a uniform strain is applied it becomes concentrated around the tips of microcracks, and fracture is initiated at a strain much below the mean strain required to break the chemical bonds in the bulk of this brittle material. The deeper and more angular the initiating microcrack the smaller the strain required to cause fracture.

Microcracks can be formed by mechanical abrasion, e.g. handling or dust particles in the air, or by chemical etching. Chemicals which attack silica include hydroxides, hydrogen fluoride and water. The etching process is anisotropic and rates are greater

TABLE II Summary of data on the tensile strength of various irradiated fibres from their Weibull plots

STC monomode – acrylate-only coating			STC plastic-clad silica – silicone + acrylate coatings		
Dose ± 5% (MGy)	Stress for 50% failure (GPa)	Gradient of Weibull plot	Dose ± 5% (MGy)	Stress for 50% failure (GPa)	Gradient of Weibull plot
0.0	4.97 ± 0.044	28.7 ± 3.0	0.0	4.67 ± 0.054	38.2 ± 5.0
0.25	4.78 ± 0.030	29.5 ± 4.0	0.25	5.18 ± 0.030	41.1 ± 2.3
0.5	5.14 ± 0.019	48.8 ± 4.0	0.5	5.19 ± 0.030	39.6 ± 3.3
1.0	5.06 ± 0.018	54.9 ± 7.0	1.0	5.12 ± 0.030	56.3 ± 4.6
			1.8	4.88 ± 0.056	14.6 ± 1.1
STC experimental fibre – polyimide only coating			STC plastic-clad silica – silicone + nylon coatings		
Dose ± 5% (MGy)	Stress for 50% failure (GPa)	Gradient of Weibull plot	Dose ± 5% (MGy)	Stress for 50% failure‡ (GPa)	Gradient of Weibull plot
0.0	5.14 ± 0.09	8.0 ± 0.7	0.0	6.7 ± 0.3	} insufficient
1.0	5.11 ± 0.03	8.3 ± 0.6	0.25	6.1 ± 0.4	} data
5.0	2.71 ± 0.012	7.3 ± 0.2	0.5	nylon was too brittle to wind around capstans	
10.0	2.01 ± 0.013	8.5 ± 0.6		‡Nylon overcoat contributes significantly	
Quartz et Silice PCS200A – silicone + ETFE coatings			Ensign Bickford HCP M0 200 T06 – proprietary coating + tefzel		
Dose ± 5% (MGy)	Stress for failure (GPa)	Gradient of Weibull plot	Dose ± 5% (MGy)	Stress for failure (GPa)	Gradient of Weibull plot
0.0	3.01 ± 0.026	17.0 ± 1.8	0.0	4.54 ± 0.020	49.2 ± 3.7
0.025	2.79 ± 0.016	26.9 ± 1.2	0.026	1.77 ± 0.020	6.9 ± 0.5
0.05	1.58 ± 0.018	10.2 ± 0.8	0.11	1.75 ± 0.041	5.6 ± 0.4
0.10	0.84 ± 0.005	15.7 ± 1.4	0.25	2.22 ± 0.026	10.7 ± 0.6
0.20	0.60 ± 0.008	6.2 ± 0.3			

under tensile strain and around already existing microcracks. Consequently, the strain at which fracture occurs is time dependent, and also varies according to the past history of the fibre. The static fatigue behaviour of fibres was not studied as part of this investigation.

A role of the polymeric coatings is to provide the optical fibre with protection against mechanical abrasion and chemical corrosion. They are usually semi-permeable, restricting the rate of diffusion of water vapour to and from the glass surface, without hermetically sealing it. Also they do not provide any significant mechanical strength: that is usually afforded by the inner glass core and by surrounding the optical fibre with strengtheners incorporated into the cable.

The effects of radiation on polymers has attracted considerable research, and general trends are well understood [2]. Irradiation usually causes polymer chain scission and the resulting cross-linking converts the polymer from a flexible to brittle material. The other important reaction of the radiation produced radicals is gas evolution, in particular HCl and HF from chloro- and fluoro-polymers, respectively.

For the polymer-coated glass fibres studied, the strength of the whole is dominated by the strength of the glass, and consequently is somewhat independent of the mechanical characteristics of the coating. Therefore provided that a radiation embrittled coating affords the same protection from mechanical and chemical degradation as the unirradiated coating, an irradiated fibre might be expected to have a similar tensile strength to its unirradiated counterpart. However, flexing a fibre with a brittle coating will cause the coating to crack and possibly flake from the fibre. The resulting exposed areas would be particularly susceptible to weakening. The expected effect on the Weibull plot would be both to lower the mean stress at failure, and to alter the statistical distribution of cracks. The latter might either be seen as a change in the gradient of the line, or in the addition of a second line denoting a double mechanism failure process [6] if the number of exposed portions of the fibre was less than 1 per gauge length. Examination of the irradiated fibres under a microscope does not show any cracking or flaking of the coating. Also all the results shown in Figs 1–5 suggest that this mechanism is not of primary importance in determining the strength of irradiated fibres.

Generally what is observed is a lowering of the mean stress at failure with increasing total dose but no abrupt change in the gradient of the Weibull plot. The most likely cause is a general deterioration of the whole glass surface. This could arise from

(i) the irradiated coating providing reduced protection from atmospheric degradation (e.g. due to water vapour),

(ii) the coating producing corrosive species that attack the glass surface when irradiated, or

(iii) the γ-rays producing corrosive species by their action on the ambient atmosphere (e.g. through the formation of ozone or hydrogen peroxide).

The experiments described here do not differentiate between these possible mechanisms.

The two fibres whose strength is severely diminished by relatively small doses of radiation differ from the other fibres studied in that both are coated with fluorine-containing polymers: the ethylene/tetrafluoro-

ethylene overcoat for the PCS 200A, and both the proprietary cladding and the tefzel, an ethylene/tetrafluoroethylene polymer, outer coating for the HCP M200T06 fibre. It is well known that fluorinated polymers degrade rapidly on irradiation. PTFE, for example, does not cross-link but liberates fluorine atoms, which in turn react to break the carbon backbone of the polymer, or liberate HF or F_2 gas. Consequently, PTFE becomes brittle after 0.01 MGy γ-rays. Other fluorine-containing polymers degrade similarly, although often not as rapidly as PTFE. However, as previously discussed, this embrittlement alone is not likely to be responsible for the large reduction in strength of the whole fibre. The most likely mechanism for the reduction in tensile strength is that reactive, gaseous, fluorine-containing species formed by the γ-rays chemically etch the surface of the fibre. The Weibull plots indicate that weakening occurs within each gauge length, whilst visual and scanning electron microscope examination show no sign of individual defects. These observations are consistent with the hypothesis that a general degradation of the whole length occurs rather than a small number of corrosion pits.

Further evidence supporting chemical attack by fluorine-containing gaseous species comes from some semiquantitative chemical analysis. Some lengths of PCS 200A fibre, bare silica fibre and some small pieces of PTFE were placed in three different polyethylene tubes, each containing approximately 2 ml milli-Q demineralized water, resistance $> 10\ G\Omega\,cm^{-1}$. Ion-exchange chromatography, calibrated with various appropriate standards, was used to analyse the solutions following irradiation with 0.1 MGy γ-rays. The data, shown in Table III, indicate that the solution surrounding the PCS 200A contained fluoride ions after irradiation, whereas the control experiment with the bare fibre did not.

An additional experiment studying the strength of the acrylate-coated STL fibre, after exposure to 0.5 MGy, is shown in Fig. 7. Relative to the analogous data in Fig. 1, significant degradation has occurred for some of the lengths tested. The only difference between the two sets of data is that for Fig. 7 some PCS fibres were interspersed with the acrylate, being simultaneously irradiated, for some of the time. Fig. 7 identifies the polythene reel from which the test length originated, and shows that particular reels were significantly more affected than others, presumed closer/adjacent to the PCS fibre. The importance of this observation is that it further supports the hypothesis that a volatile species is involved in the mechanism for the degradation of fluorine-containing polymers, and it clearly shows that the fibre need not be coated with a fluorine-containing polymer, but need only be in its vicinity to suffer severe degradation.

Finally, it should also be appreciated that the exact mechanical properties versus γ-dose behaviour of a fibre will depend on

(i) the exact chemical composition of the polymer, the coating method and the coating thicknesses,

(ii) the dimensions of the fibre,

(iii) the presence of any static stresses,

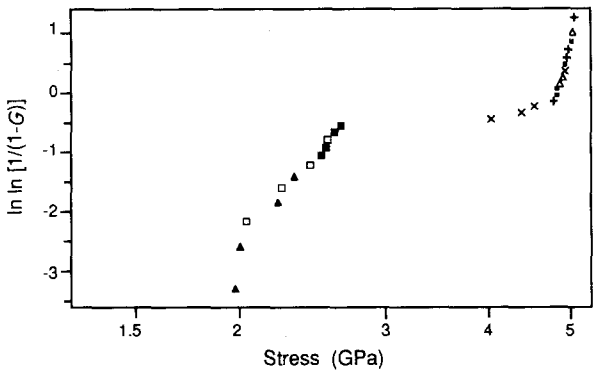

Figure 7 Weibull plot for the cumulative failure of an acrylate-coated glass fibre after exposure to 0.5 MGy γ-rays, when irradiated with some fibres coated with a fluorine-containing polymer, showing the reel from which each test length originated. Reel no.: (△) 1, (+) 2, (■) 3, (×) 4, (■) 5, (□) 6, (▲) 7.

(iv) the γ-dose rate,

(v) the ambient temperature and atmosphere (e.g. humidity, etc.),

(vi) time after irradiation.

This somewhat preliminary study provides a broad framework suggesting some coatings that can be used in high radiation environments, some coatings that should be avoided, and a mechanism by which the degradation occurs. In order to obtain detailed information for a specific application it would be necessary to test samples of the intended optical fibre in a manner that simulates the conditions under which they would be expected to operate.

A practical illustration of an application where this information is of value occurs within nuclear fuel reprocessing plants. There is a general need for chemical analysis of the actinide species and concentrations in the various streams of the plant, and the distinctive absorption spectra of actinide species means that remote absorption spectroscopy is a potentially useful technique. However, radiation levels within such a plant can be 0.1 MGy/week. The data presented here show that fibres coated with fluorine-containing polymers would require replacing within a week, whereas a fibre protected with acrylate, silicone + acrylate or polyimide coatings would survive for longer than 10 weeks. This difference in replacement frequency is sufficient to make the difference between optical fibres providing a cost effective technique for monitoring the plant, and their being impractical for this.

5. Conclusions

The experimental data presented here indicate that silica glass optical fibres coated with silicone, acrylate and/or polyimide show little reduction in their mechanical properties after being irradiated with a total dose of 1 MGy. When the polyimide-coated fibre was irradiated to higher total doses, e.g. 5 MGy, some degradation was evident. A fibre with a nylon overcoat became very brittle after a dose of 0.5 MGy. However, the strength of the central glass fibre did not appear to be too severely weakened (after 0.25 MGy the fibre as a whole still had > 90% of its pre-irradiated strength from the limited data obtained) although

TABLE III Chemical analysis of anions in the surrounding water

Tube contents	Fluoride conc. (ppm)	Chloride conc. (ppm)	Nitrate conc. (ppm)	Sulphate conc. (ppm)
Bare fibre	0	0.5	0.7	0.8
PTEE	15	0.8	0.6	1.0
PCS 200A fibre	46 ± 5	2	0.6	0.9

assessing this was difficult. This implies that such fibres would be of limited use where flexibility was required in an environment where the fibre would receive a total dose approaching 0.5 MGy.

In contrast, the glass component of fibres coated with fluorine-containing polymers was very severely weakened by 0.1 MGy ^{60}Co γ-rays. This significantly restricts the areas of application within the nuclear industry where these types of fibre may be used. A similar degradation was also noted for fibres when irradiated in the vicinity of a fluorine-containing polymer, indicating that for a fibre to retain its mechanical strength when irradiated with 1 MGy γ-rays, none of its coatings nor any component of the cabling materials should contain fluorine.

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