RESULTS OF RADIATION TESTS AT CRYOGENIC TEMPERATURE ON SOME SELECTED ORGANIC MATERIALS FOR THE LHC

M. TAVLET, H. SCHÖNBACHER
European Organization for Particle Physics Research,
Geneva

Abstract

In the near future, particle accelerators and detectors as well as fusion reactors will operate at cryogenic temperatures. At temperatures as low as 2 K, the organic materials used for the insulation of the *superconducting magnets and cables will be exposed to high radiation levels. In this work, a representative* selection of organic materials comprising insulating films, cable insulations and epoxy-type-impregnated resins were exposed to neutron and gamma radiation of nuclear reactors, both at ambient and cryogenic temperatures, and were subsequently mechanically tested. The results show that the radiation degradation is never worse in a cryogenic fluid than it is in usual ambient conditions.

1. INTRODUCTION

Future multi-TeV particle accelerators like the CERN Large Hadron Collider (LHC) will use superconducting magnets where organic materials will be exposed to high radiation levels at temperatures as low as 2 K. A representative selection of organic materials comprising insulating films, cable insulations and epoxy-type impregnated resins were exposed to neutron and gamma radiation of a nuclear reactor. Depending on the type of materials, the integrated radiation doses varied between 180 kGy and 155 MGy. During irradiation, the samples were kept close to the boiling temperature of liquid nitrogen, i.e. 80 K, and thereafter stored in liquid nitrogen and transferred at the same temperature into the testing device for measurement of tensile and flexural strength. Tests were carried out on the same materials at similar dose rates at room temperature, and the results were compared with those obtained at cryogenic temperature.

2. SELECTED MATERIALS

The materials selected for this programme are being considered for the LHC machine and/or experimental detectors; they are listed in Table 1. They range from the most common materials such as PETP films, polyolefin cable insulations and standard epoxy resins up to high performance materials such as Kapton films and carbon fibre reinforced composites. All of them are halogen-free and comply with the safety regulations of CERN.

3. IRRADIATION CONDITIONS

The irradiations at room temperature RT were carried out either in a nuclear reactor in Austria, at a dose rate of the order of 200 kGy/h, and where the neutron dose is less than 5% of the total dose, or with a cobalt 60 source, at a dose rate of the order of 4 kGy/h.

The irradiations at liquid-nitrogen temperature (77 K) were carried out in a nuclear reactor in the Russian Confederation, at a dose rate of the order of 20 MGy/h, depending on the material composition; the neutron dose is of the order of 50% to 70% of the total dose.

It has also been checked that the dosimeters currently in use for absorbed dose measurements in the CERN accelerators are suitable for measurements at cryogenic temperatures. The results have shown that calibration curves can be drawn at each temperature for the alanine-based dosimeters, and a temperature coefficient has been calculated [2]; the radio-photoluminescent dosimeters (RPL) can be used up to 1 kGy without any correction, but cannot be used above that level [3].

TABLE I. LIST OF SELECTED MATERIALS

Ref. No.	Material	Type
M 701	Polyethylene terephtalate	*Mylar* sheet (250 μm)
M 702	Polymide, pure, amorphous	*Kapton* H film (125 μm)
M 702'	Polyimide + $Al_2(OH)_3$	*Kapton* AH film (125 μm)
M 703	Polyether-etherketone	*Litrex* a film(amorphous) (125 μm)
C 763	Cable insulation	EPR + acetate copolymer 85-2/179
C 764	Cable sheath	Vinyl Acetate Copolymer thermoplastic 85-4/20
C 1011	Wire insulation	Olisafe (= Siltem) (PEI + silicone)
C 1027	Cable insulation	Polyethylene DFDM 6005
C 1028	Cable sheath	Polyolefin EVA BPD 537
C 1047	Cable sheath	EPR = ethylene-propylene rubber
C 1048	Cable sheath	EVA = ethylene-vinyl acetate
R 422	Epoxy resin	*Araldite* EPN1138/MY745/CY221/HY905/DY73
R 423	Epoxy resin	*Araldite* MY 745/HY 906/DY 073 (100/90/1.5)
R 453	Epoxy moulding compound	XB 3183
R 455	Epoxy moulding compound	XB 3192
R 533	Thermoplastic resin	PEI = polyether-imide
R 534	Thermoplastic resin	PES = polyether-sulfone
R 535	Thermoplastic resin	PSU = polysulfone
R 538	Epoxy laminate (prepreg)	*Vetronite* epoxy G 11 (epoxy + glass)
R 545	Epoxy laminate (prepreg)	Epoxy + glass fibres
R 546	Epoxy laminate (prepreg)	*Vetronite* (epoxy + glass)
R 547	Epoxy laminate (prepreg)	Epoxy + E glass fibres
R 548	Epoxy laminate (prepreg)	Epoxy + E glass fibres + *Kevlar*
R 549	Composite	Epoxy + carbon fibres
R 550	Composite	Epoxy + carbon fibres

4. MECHANICAL TESTS

After irradiation, the samples were kept close to the boiling temperature of liquid nitrogen, i.e. 80 K, and thereafter stored in liquid nitrogen and transferred at the same temperature into the testing device for the measurement of their mechanical properties. The mechanical tests were performed according to the recommendations of the International Electrotechnical Commission publication 544 [4]. The rigid materials were submitted to three-point flexural tests carried out in accordance with the ISO 178 standard. The flexible materials were submitted to tensile tests carried out in accordance with the ISO R527 standard. The speed at which these tests have been performed ranged between 2 mm/min for the flexural tests at 77 K to 50 mm/min for the tensile tests at RT.

5. RESULTS AND DISCUSSION

The results are discussed separately for each type of materials.

5.1. Films

The initial values of the ultimate tensile strength is higher at 77 K than at RT. When the samples are irradiated in air at RT, they degrade by radiation and oxidation. The degradation is less pronounced in the liquid nitrogen. Figure 1 compares the degradation at 77 K and at RT for the PEEK film.

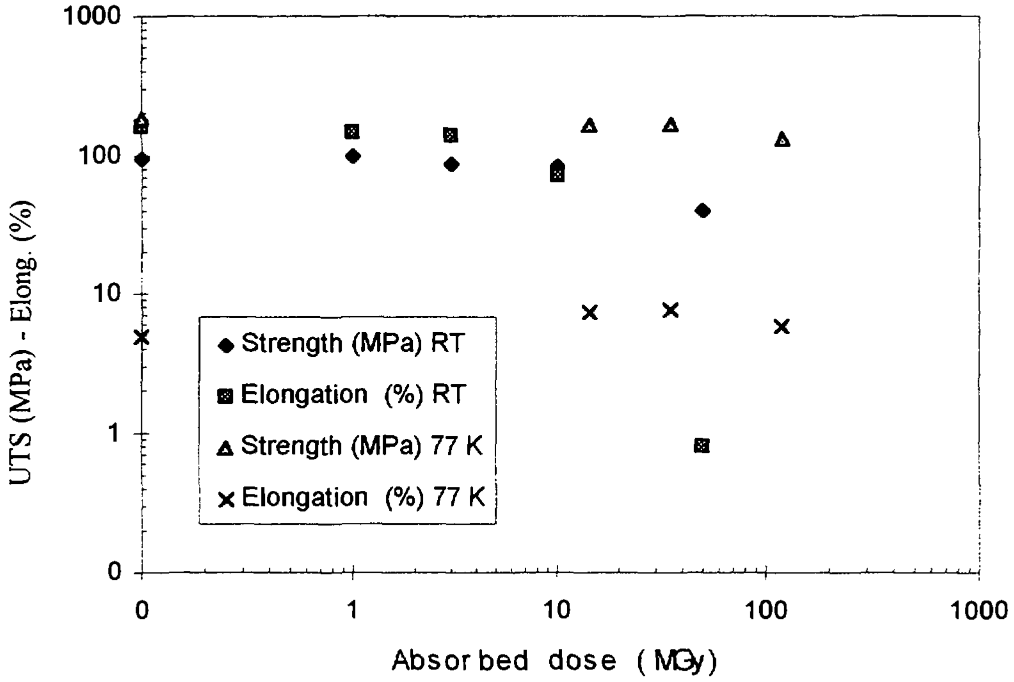

Fig. 1. Radiation effects on polyether-ether-ketone film M 703.

5.2. Cable insulations

The elongation at break of these types of materials is dramatically reduced at 77 K. The most common cable insulations such as polyolefins and rubbers cannot be used at cryogenic temperature because they become too brittle.

Only the copolymer of silicone and polyether-imide (C 1011) is a possible candidate for use in cryogenic application; its degradation is also less severe in the liquid nitrogen than in air.

5.3. High-performance thermoplastics

The change of the initial mechanical properties with the testing temperature of these selected materials (PEI, PES and PSU) stays within a factor of two. This makes them suitable for cryogenic applications. Again, the radiation degradation is less pronounced in a cryogenic fluid than in air. Figure 2 compares the degradation at 77 K and at RT for the polyether-sulfone (PES) thermoplastic resin.

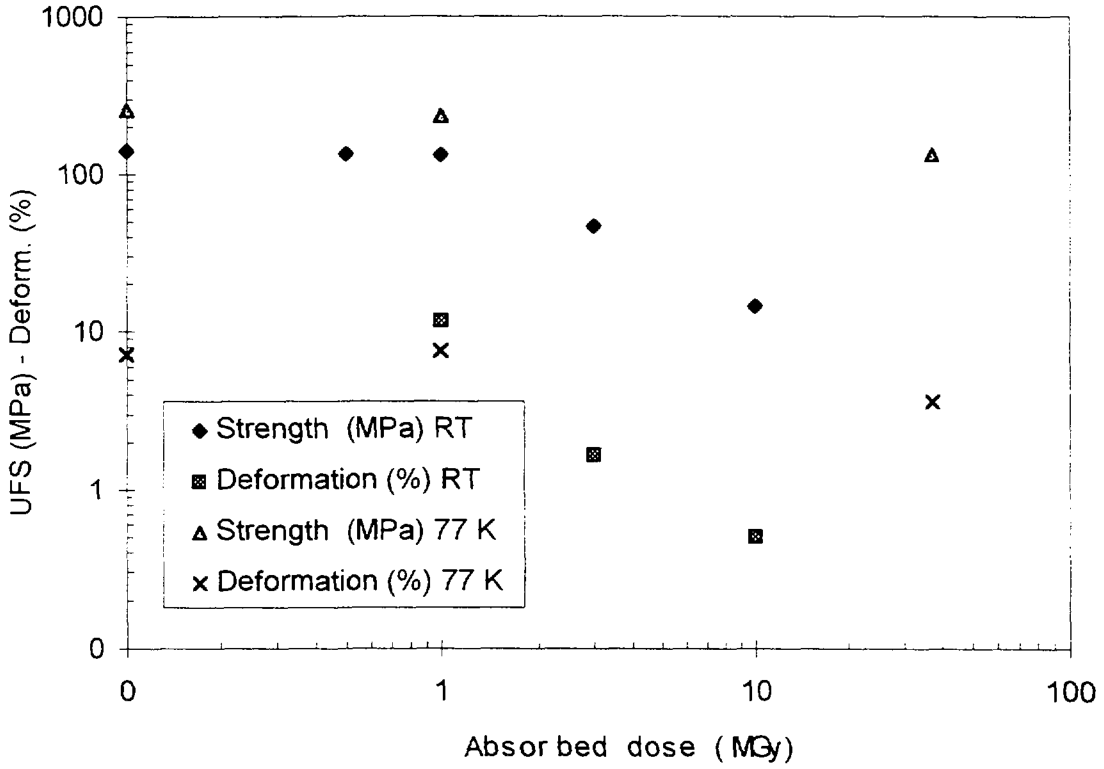

FIG. 2. Radiation effect on Erta-PES R-534.

5.4. Thermosets

The influence of the testing temperature is almost insignificant for these materials. The results show that the most recent epoxy moulding compounds are usable beyond 100 MGy, both at room temperature and at cryogenic temperature.

5.5. Laminates and carbon-epoxy composites

The more recently developed composites, with glass-fibre or carbon-fibre reinforcements, have excellent radiation resistance, both at RT and at 77 K, up to the highest dose obtained in this experiment, i.e. 156 MGy. Figure 3 compares the degradation at 77 K and at RT for a prepreg based on epoxy resin reinforced with Kevlar and glass fibres.

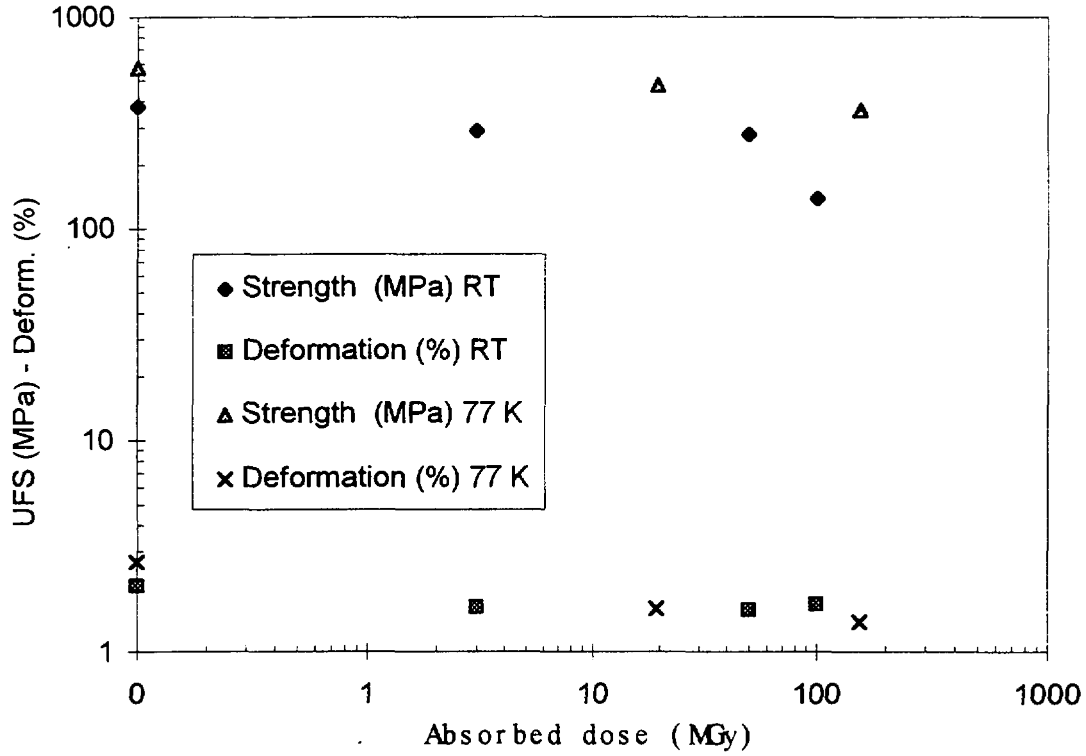

FIG. 3. Radiation effect on epoxy-glass-kevlar laminate R 548.

6. CONCLUSIONS

A representative selection of organic materials have been irradiated both at room temperature and at 77 K, at similar dose rates. Mechanical tests were carried out at the same temperature, without any warm-up between the irradiation and the test, and the mechanical properties were compared.

The results show that, the radiation degradation of thermoplastic materials is less pronounced in a cryogenic fluid than in air. This could be related to the absence of oxygen during irradiation. The effect is very pronounced with thin films.

No significant influence of the irradiation temperature is observed on the radiation degradation of thermosets and composites. Within the selected dose range, a number of organic materials are suitable for use in the radiation field of the LHC at cryogenic temperature.

REFERENCES

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[3] ZENELI, D., TAVLET, M., CONINCKX, F., "Responses of radiophotoluminescence dosimeters irradiated at cryogenic temperatures," Rad. Prot. Dos. Vol. 66, No 1-4 (1996) 205-207.

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