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Development of Highly Radiation-Resistant Cables

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Compounds were formed by adding some additives with large radiation-resistance improving effects to flame-retardant non-halogen EP rubber and to flame-retardant non-halogen ethylene-acrylic elastomer. From these compounds cables were prepared, and their radiation resistance was tested. It was found that they could still retain high electrical property and flexibility even after 10-MGy irradiation.

1. Introduction

Various kinds of polymer materials are used for electric wires and cables employed in nuclear power-stations. Among insulating materials are ethylene-propylene rubber, crosslinked polyethylene, silicon rubber and polyvinyl chrolide, while chlorosulfonated polyethylene, polyvinyl chloride and chloroprene rubber are commonly used as the jacketing materials. The maximum radiation resistance required for those cables for nuclear power stations prepared from these materials is 2 MGy.

On the other hand, those cables used in some highly radioactive places of the nuclear fuel reprocessing plants and uranium enrichment plants having been built in recent years must withstand 10 MGy.

To develop the cables that can stand 10 MGy and do not generate toxic hydrogen halide gases when they are burnt or irradiated, studies have been made regarding the selection of polymer and additives of radiation degradation resistance. As a result, it was found that the radiation resistance of cables could be improved considerably by using flame-retardant non-halogen EP rubber as their insulating materials and flame-retardant non-halogen ethylene-acrylic elastomers as their jacketing materials with an addition of effective additives for radiation degradation resistance1)−3).

Based on the results thus obtained, the formulation for the preparation of practical cables was examined in the present work from the viewpoint of their manufacturing and application, and the cables were prepared on an experimental

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basis for evaluating their radiation resistance.

2. Experiment

2.1 Radiation resistance of materials.

2.1.1. Test specimen

Materials used for this test are shown in Table 1. Pressed sheets with a thickness of about 1mm were prepared from the materials listed.

Table 1 Materials used for the test

Use	Symbol	Composition
Insulating materials	NH-EPR	Flame-retardant non-halogen ethylene-propylene rubber
	URR-EPR	Material with an addition of the mixture diaryl-p-phenylenediamines to NH-EPR by 4.2 wt%
Jacketing materials	NH-AEM	Flame-retardant non-halogen ethylene-acrylic elastomer
	URR-AEM	Material with an addition of 4, 4'-Thio-bis (6-tert-butyl-3-) methylphenol to NH-AEM by 23 wt%.

2.1.2. Irradiation method

Irradiation of the test specimens were made with gamma-rays from a cobalt-60 sources (dose rate:0.8 MR/h) at room temperature and under air atmosphere. The gamma-ray doses applied were 2, 5 and 10 MGy.

2.1.3. Test items and test method

Specimens were tested for their tensile strength and elongation, volume resistivity and A.C. breakdown voltage.

Tensile strength and elongation: The specimens were cut from the samples after gamma-ray irradiation by using the No.3 dumbbell of JIS K 6301, and the specimens were pulled at a rate of 200 mm/min.

Volume resistivity: This test item was measured one minute after a voltage of D.C. 500 V was applied to the test specimen.

A.C. breakdown voltage: Steel-ball electrodes were attached to both sides of an irradiated sheet kept in oil, and this test item was measured by applying an A.C. voltage between the electrodes; the voltage was continuously increased at a rate of 750 V/sec.

2.1.4. Results and discussion

Figure 1 shows the relationship between irradiation dose and tensile strength. It became apparent that the tensile strength of NH-AEM decreased at the irradiation dose of 2 MGy but no significant change of the parameter occurred at the higher irradiation doses above 2 MGy.

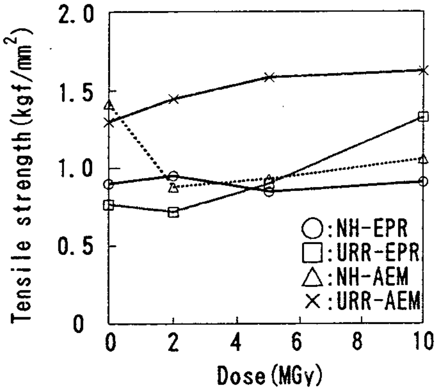

Fig. 1 Dose vs. tensile strength (sheets)

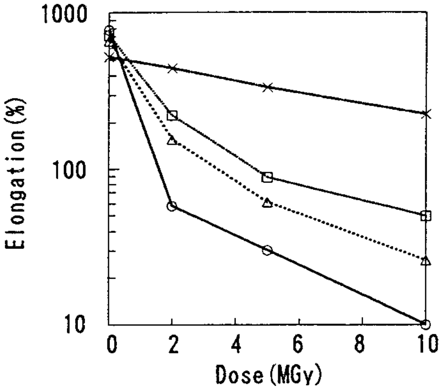

Fig. 2 Dose vs. elongation (sheets)

Figure 2 shows the relationship between irradiation dose and elongation. In all the test specimens, their elongation values decreased significantly with increasing radiation doses. However, the lowering trend in elongation values of URR-EPR and URR-AEM with an addition of radiation deterioration inhibitors was significantly improved in comparison witn NH-EPR and NH-AEM without addition of radiation deterioration inhibitors.

Table 2 shows the results of analysis using a microscopical FT-IR spectrometer of the carbonyl-group concentration in both the surface and inner section of NH—EPR test specimens before and after 10-MGy irradiation. These results indicate that polymer material is oxidized and that the degree of oxidation is more significant near the surface with gamma-ray irradiation in air. That is, it is considered that an addition of radiation deterioration inhibitor suppresses the oxidation of polymer material, thereby causing the decrease of elongation values.

Table 2 Absorption ratio of carbonyl-group/methylene-group between surface and inner after 10-MGy irradiation

	Carbonyl-group/methylene-group
Surface	0.0620
Inner	0.0062

Figure 3 shows the relationship between irradiation dose and volume resistivity, while Fig.4 the relationship between irradiation dose and A.C. breakdown voltage. The EPR shows much better electrical properties because of its lower polarity compared with the AEM. However, no noticeable change with increasing irradiation doses was found for all the test specimens.

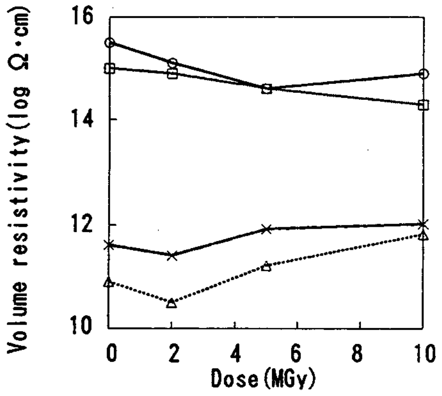

Fig. 3 Dose vs. volume resistivity (sheets)

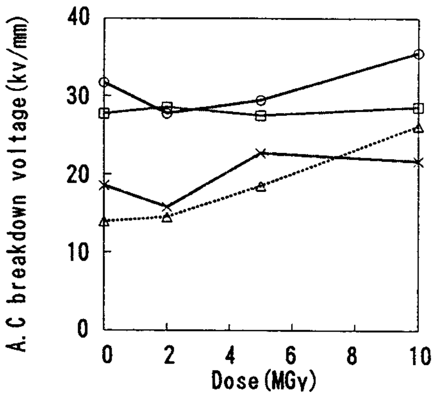

Fig. 4 Dose vs. A.C.breakdown voltage (sheets)

2.2. Radiation resistance of cable

2.2.1. Construction of cable

Using URR-EPR as an insulating material and URR-AEM as a jacketing material, the cable was prepared. For comparison purpose, the same type of cables as used in nuclear power-stations today were also prepared. The structure of the cables is shown in Fig. 5, while the materials used for them in Table 3.

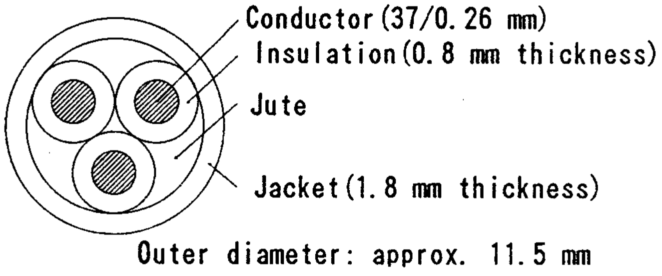

Fig. 5 Cable construction.

Table 3 Structure of cable

Cable symbol	2PHCT	2PNCT	URR-2PACT
Use	Nuclear power stations	General	High radiation area
Insulation	FR*1−EPR	ER−EPR	URR−EPR
Jacket	FR−CSM*2	CR*3	URR−AEM
Cable size	3×2mm^2		

*1 : Flame-retardant
*2 : Chlorosulfonated polyethylene
*3 : Chloroprene rubber

2.2.2. Test items and method

After these cables were irradiated with gamma-rays using the same method as described in Sec. 2.1.2., their individual components, the insulating material and the jacket, were tested for tensile strength and elongation, insulation resistance, A.C. breakdown voltage and bending.

Tensile strength and elongation: A tubular test specimen as a insulation material was prepared by removing the conductor from the cable after gamma-ray irradiation. On the other hand, a JIS No.3 dumbbell-shaped test specimen as a jacketing material was cut out from the same cable after its inner uneven surface was smoothed by polishing. Both tensile strength and elongation were measured by pulling these test specimens at a rate of 200 mm/min.

Insulation resistance: The test cable was immersed in water kept at 20 centigrade for one hour and insulation resistance was measured one minute after a voltage of D.C. 500 V was applied between conductors and between the conductor and water.

A.C. breakdown voltage: The test cable was first exposed to a withstand test at A.C. 2.5 kV for 5 minutes, and then the increasing voltage was applied for the test cable at a step-up rate of 2.5 kV/min until its insulation was broken. This voltage is its A.C. breakdown voltage.

Bending test: By winding an irradiated test cable around the mandrels of different outer diameters, the possibility of crack formation on the surface of its jacketing was tested.

2.2.3. Results and discussion

Figure 6 shows the relationship between irradiation dose and tensile strength. It was impossible to cut out the specimens from the jacketing materials of 2PHCT and 2PNCT after 5 and 10-MGy irradiation, respectively, because of their severe hardening. For all materials, no significant change in tensile strength with increasing irradiation dose was observed, but hardening and embrittlement

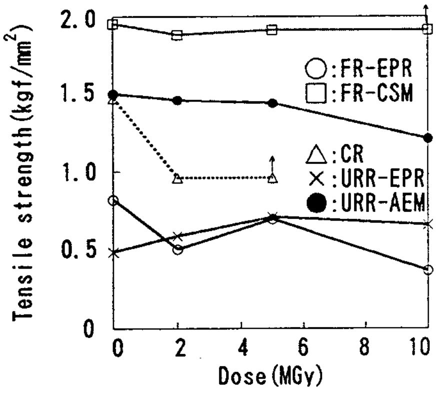

Fig. 6 Dose vs. tensile strength (cables)

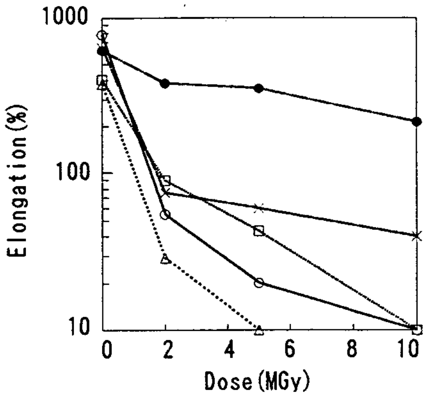

Fig. 7 Dose vs. elongation (cables)

took place. Especially the embrittlement of EPR appeared to be severe.

Figure 7 shows the relationship between irradiation dose and elongation. It is apparent that elongation values for both materials decrease with the increasing irradiation dose. When compared with the results for the insulation materials shown in Fig. 2, it is obvious that elongation values for cables test specimens are slightly higher than those for sheet test specimens. This is considered to be caused by the fact that the degree of deterioration by oxidation for the cable test specimens is lower than that of the sheet test specimens, because the insulating material of the cable test specimens covered with jacketing provides less chance for its surface to come into contact with air.

Figure 8 shows the relationship between irradiation dose and insulation resistance. In sheet test specimens, no significant change with increasing irradiation dose was observed in terms of volume resistivity. However, in both 2PHCT and 2PNCT of cable test specimens their volume resistivity values decreased with increasing irradiation dose. In URR-2PACT, on the other hand, no decreasing tendency in insulation resistance with increasing irradiation dose was noticed, indicating satisfactory results.

Figure 9 shows the relationship between irradiation dose and A.C. breakdown voltage. With regard to this parameter there was no definite relationship with irradiation dose.

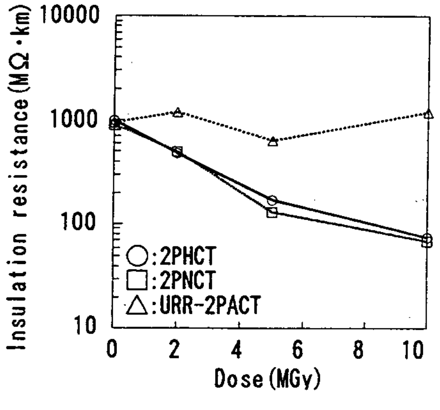

Fig. 8 Dose vs. insulation resistance (cables)

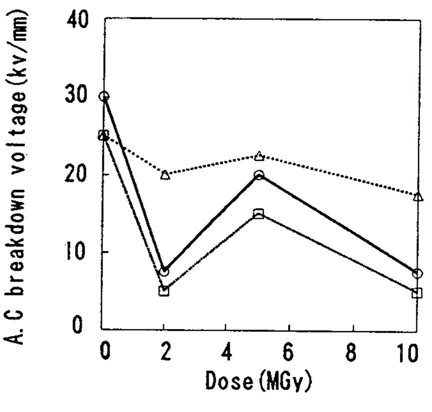

Fig. 9 Dose vs. A.C. breakdown voltage (cables)

Figure 10 shows the relationship between irradiation dose and the result of bending test. For both 2PHCT and 2PNCT, severe hardening of the jacketing material with increasing irradiation dose occurred by showing marked increase of the crack-formation bending diameter. For UFR-2PACT, on the other hand, though its hardening gradually proceeded with increasing irradiation dose, it did not show any crack even when the self-diameter bending test was applied to it after 10-MGy irradiation, because it still retained high flexibility.

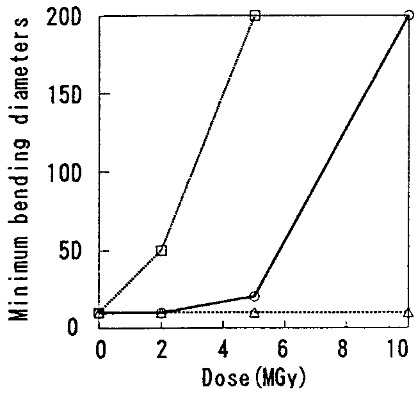

Fig. 10 Dose vs. minimum bending diameters of cable

3. Conclusion

Test cables prepared from the compounds formed by blending the mixture diary-p-phenylenediamines with flame-retardant non-halogen EP rubber, and also 4, 4'-Thio-bis(6-tert-butyl-3-)methylphenol with flame-retardant non-halogen ethylene-acrylic elastomers; and their radiation resistance was examined. It was found that they could retain high flexibility and electrical insulating property even after 10-MGy irradiation. These cables can be used for various practical purposes in highly radioactive places for which the demand for such cables is expected to increase.

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