Changes in Physical Properties of Insulating and Jacketing Materials under Exposure to Heat and Radiation

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Changes in Physical Properties of Insulating and Jacketing Materials under Exposure to Heat and Radiation

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We exposed electric-wire covering materials (FR-EPR, FR-CR and FR-CSM) to heat, radiation, and combined heat and radiation under various conditions of accelerated aging. We then measured changes in tensile strength, elongation, volume resistivity and hardness, and studied the possibility of making nondestructive aging diagnosis for electric wires and cables. As a result, we observed correlations between hardness and elongation. The life of electric cables is judged by the elongation value of the insulating and jacketing material. Therefore, we now see the possibility of making accurate aging diagnosis for the life estimation of electric wires and cables by improving or developing a certain hardness tester that does not give any damage to wires and cables.

1. Introduction

We already reported on the property changes of electric-wire and cable covering materials under the environmental conditions of exposure to combined heat and radiation with the effective acceleration of 100, 300 and 1000 times[1-4]. However, the environments in which wires and cables are used are quite diverse; in some places the effect of heat is greater, and in others the effect of radiation is greater. Therefore, we added the aging tests of heat alone and radiation alone, and measured property changes to compare the effects on materials in different conditions. We also describe a consideration about the nondestructive aging diagnosis for wires and cables.

2. Experimental

2.1 Specimen

Specimens were prepared from the compound used as insulating and jacketing materials of wires and cables for the PCV (primary containment vessel) of nuclear power plants. We made pressed sheets of about 1-mm thickness for each compound shown in Table 1, and used them as specimens.

2.2 Conditions of aging test

The environments of cables used under the normal operation of the nuclear power plant differ according to the size and type of the power plant, the usage either at the outside or the inside of the PCV, and the location of the cables. In our test, however, we fixed the ambient temperature at 60 °C and radiation dose rate at 1.5 Gy/h. Then, we made a test of heat aging, radiation aging, and heat-radiation simultaneous aging by using the effective acceleration of 100, 300 and 1,000 times. In regard to the effective acceleration value of

Table 1 Specimens used for test

Symbol	Material
FR-EPR	Flame retardant ethylene propylene rubber
FR-CR	Flame retardant chloroprene rubber
FR-CSM	Flame retardant chlorosulphonated polyethylene

Table 2 Conditions of aging test

Aging condition	Effective acceleration value	Heating temp. (°C)	Dose rate (Gy/h)
Heat aging	100	107	-
	300	118	-
	1000	130	-
Radiation aging	100	Room temp.	150
	300	Room temp.	450
	1000	Room temp.	1500
Heat-radiation simultaneous aging	100	107	150
	300	118	450
	1000	130	1500

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heating temperature, an activation energy was obtained from the Arrhenius plot, where heating temperature and time to make a 100% decrease of FR-EPR elongation were plotted, and then the heating temperature equivalent to 60°C for each effective acceleration value was calculated. In regard to the acceleration by radiation aging, we used dose rates of 1.5 Gy/h multiplied by the acceleration value, and gamma rays from a ^{60}Co source were used for irradiation. The conditions of aging test are shown in Table 2.

2.3 Items of measurement

Specimens were taken out after aging in each condition for equivalent exposure times of 10, 20, 30, 40 and 60 years [actual aging period (years) = equivalent exposure time (years) / effective acceleration ratio], and then the following items were measured.

(1) Volume resistivity: Measurement was made after one minute under an applied voltage of 500 V D. C.
(2) Tensile strength and elongation: We made a JIS No.3 dumbbell test specimen, and then performed tension test with a test speed of 200 mm/min. at room temperature [(23±2)°C].
(3) Hardness: We piled sheets up to make a thickness of about 6 mm, and then measured hardness by a Shore D hardness tester at room temperature.

3. Test Result and Discussion

3.1 Tensile strength

Changes of tensile strength are shown in Fig. 1. In regard to FR-EPR, no appreciable change by heat aging was observed. For radiation aging, however, tensile strength decreased with increasing exposure time (equivalent year). In heat-radiation simultaneous aging, a considerable decrease of tensile strength was observed until the equivalent exposure time of 20 years, and thereafter there were little change. In any aging condition, the effect of acceleration was not observed. It can be concluded that tensile strength suffers little by heat aging, but is reduced by radiation aging; and this reduction is enhanced by simultaneous application of heat.

In regard to FR-CR, tensile strength showed a tendency of considerable decrease with increasing exposure time in heat aging and radiation aging. This decrease was greater for the smaller acceleration. For heat-radiation simultaneous aging, tensile strength decreased notably until the equivalent exposure time of 10 years. After this, however, it showed different trends depending on acceleration; it gradually decreased at the effective acceleration of 1,000 times, whereas it increased at the effective acceleration of 100 and 300 times. The reason for this is considered that specimens were hardened due to drastic degradation at the effective accelerations of 100 and 300 times.

In regard to FR-CSM, little change in tensile strength was observed for heat aging and radiation aging. The effect of acceleration was not appreciable either. For heat-radiation simultaneous aging, as seen in the case of FR-CR, tensile strength decreased considerably until the equivalent exposure time of 20 years. After this it showed a slight increase at the effective acceleration of 100 and 300 times. It is considered to have been caused by the hardening of specimens, which occurs more strongly for lower acceleration.

3.2 Elongation

Changes of elongation are shown in Fig. 2. For all materials and aging conditions, elongation decreased with increasing exposure time. For FR-EPR, the decrease by heat aging was small, but the effect of radiation aging was large. In both the cases of radiation and heat-radiation simultaneous aging, elongation largely decreased with increasing exposure time. No definite tendency was observed for the effect of acceleration. For FR-CR and FR-CSM, on the other hand, the influence of heat aging was much greater than that of radiation aging. In regard to the effect of acceleration, the decrease was greater at lower acceleration for heat aging. Both FR-CR and FR-CSM, which are polymer materials containing chlorine in the side chain, release hydrochloride gas through the reaction of chlorine with neighboring hydrogen, and then aging proceeds by creating a double bond in the main chain. The present result indicates that the effect of heating temperature is much greater than that of heating time for this process. Only for FR-CSM, definite differences due to acceleration was observed for radiation aging, i.e., the decrease in elongation was smaller for lower acceleration. This behavior is opposite to that of heat aging.

3.3 Volume resistivity

Changes of volume resistivity are shown in Fig. 3. For FR-EPR, a decrease occurred at the effective acceleration of 100 times after the equivalent exposure time of 40 years in heat aging. Volume resistivity was rather stable in radiation aging. In heat-radiation

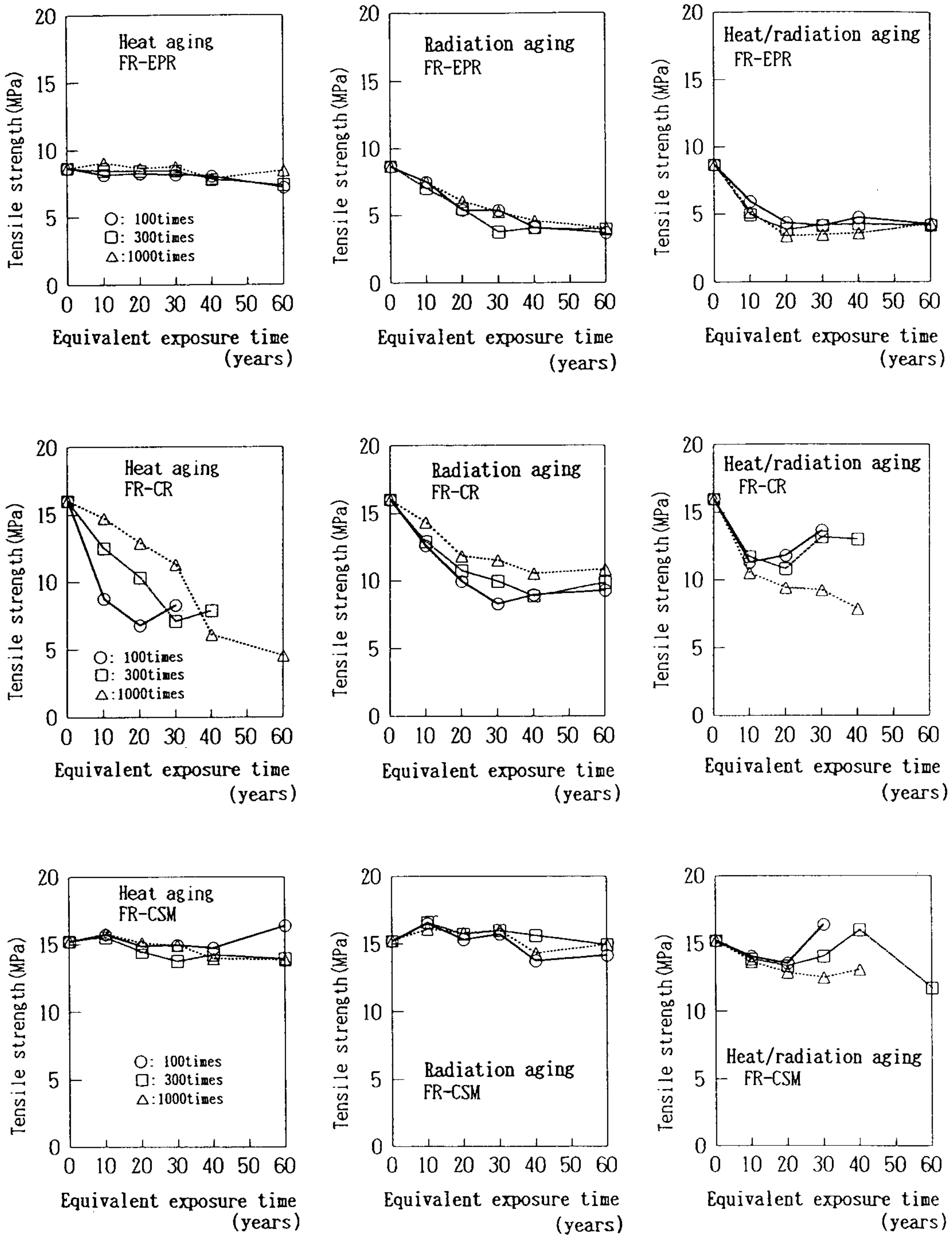

Fig. 1 Relationship between equivalent exposure time (years) and tensile strength

simultaneous aging, the sharp drop of resistivity was seen after the equivalent exposure time of 40 years. No remarkable difference was noted among the results of different acceleration values. For FR-CR, the decrease in volume resistivity was seen at the initial stage of heat aging and radiation aging, but after that the trend changed either to increase or to leveling off. For heat-radiation simultaneous aging, volume resistivity showed a considerable decrease with increasing exposure time. In heat aging of FR-CSM, volume resistivity showed almost constant values except at the equivalent exposure time of 60 years under the effective acceleration of 100-times, but a trend of decrease was observed in radiation aging and heat-radiation simultaneous aging.

3.4 Hardness

Changes of hardness are shown in Fig. 4. For FR-EPR, increase of hardness was moderate in all

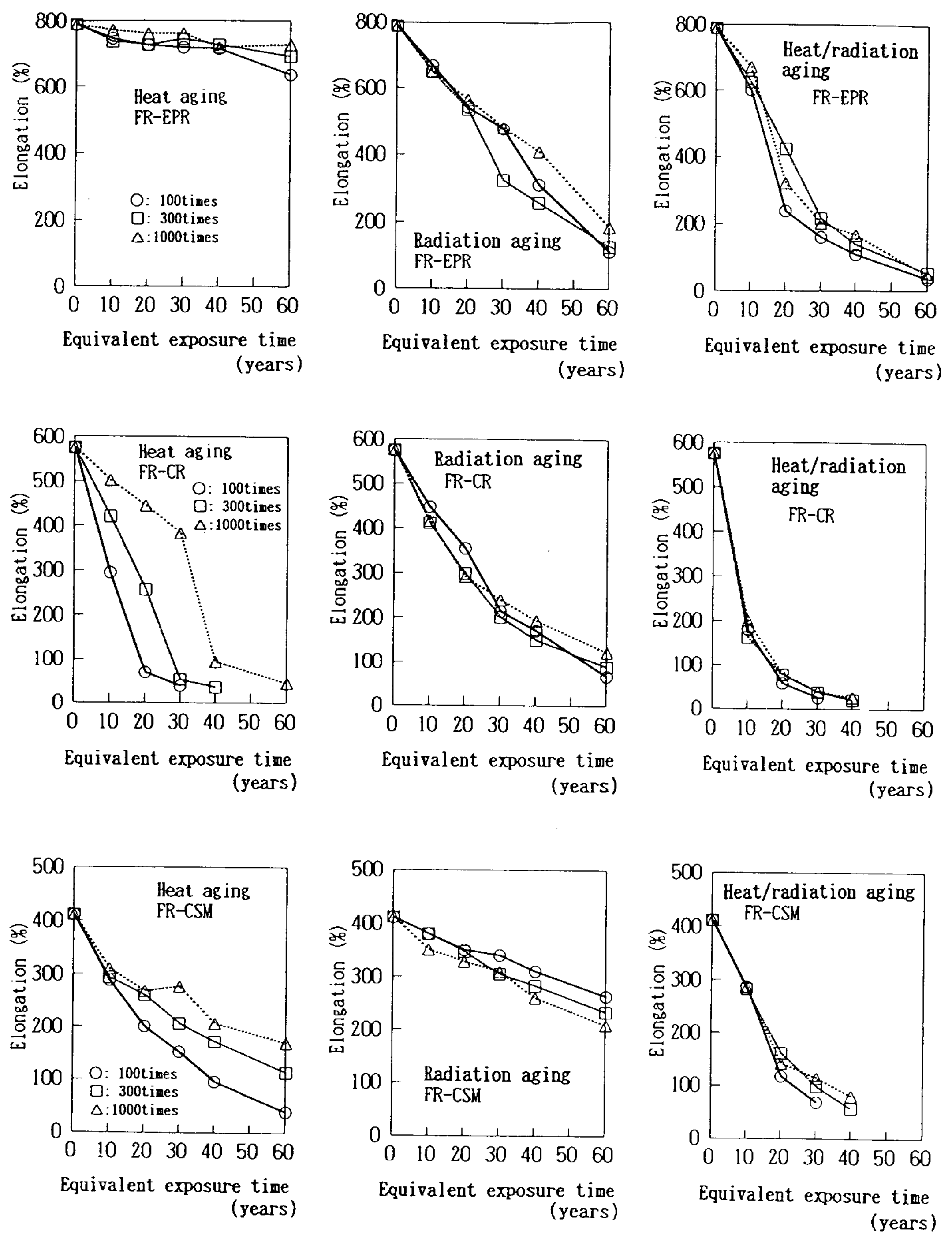

Fig. 2 Relationship between equivalent exposure time (years) and elongation

aging conditions. For FR-CR, on the other hand, a drastic increase of hardness was seen in heat aging and heat-radiation simultaneous aging. For FR-CSM, an extreme increase of hardness was observed in heat-radiation simultaneous aging. In general, when a material becomes harder, elongation decreases. For electric wires, it is considered that the end of life was reached when the elongation value of the wire-covering materials becomes 100% or 50% of the initial value. Therefore, we show the observed results of correlation between hardness and elongation in Fig. 5. Because FR-EPR is excellent in thermal aging resistance, any notable decrease of elongation did not occur in heat aging, so that a correlation in a broad range could not be obtained. In radiation aging and heat-radiation simultaneous aging, however, correlations could be observed.

In radiation aging for FR-CR, hardness increase was

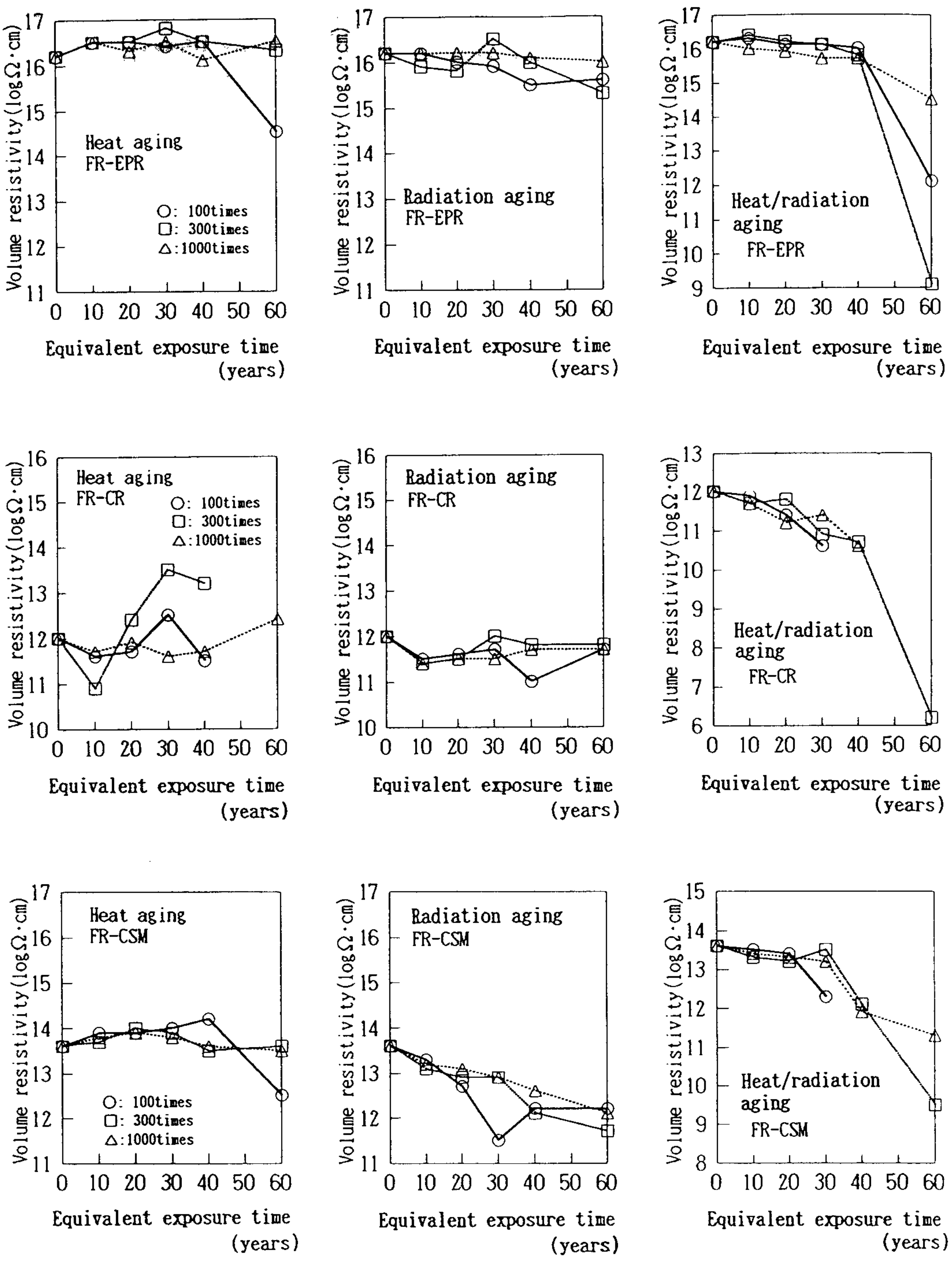

Fig. 3 Relationship between equivalent exposure time (years) and volume resistivity

seen at elongation values smaller than about 100%. No effect of acceleration was seen in any aging conditions. Good correlation curves were obtained in heat aging and heat-radiation simultaneous aging for FR-CSM. A correlation is also seen in radiation aging, but in the present test, elongation did not reach down to 200%, so that it is unable to check the correlation at lower elongation values. In all materials, the relation between elongation and hardness showed a tendency of an almost straight line in heat and radiation aging, and a tendency of a nonlinear line in heat-radiation simultaneous aging. The effect of acceleration was not seen in any material and condition.

4. Discussion on Nondestructive Aging Diagnosis

Electric wires and cables are used in various environments, and thus they are not always exposed to a

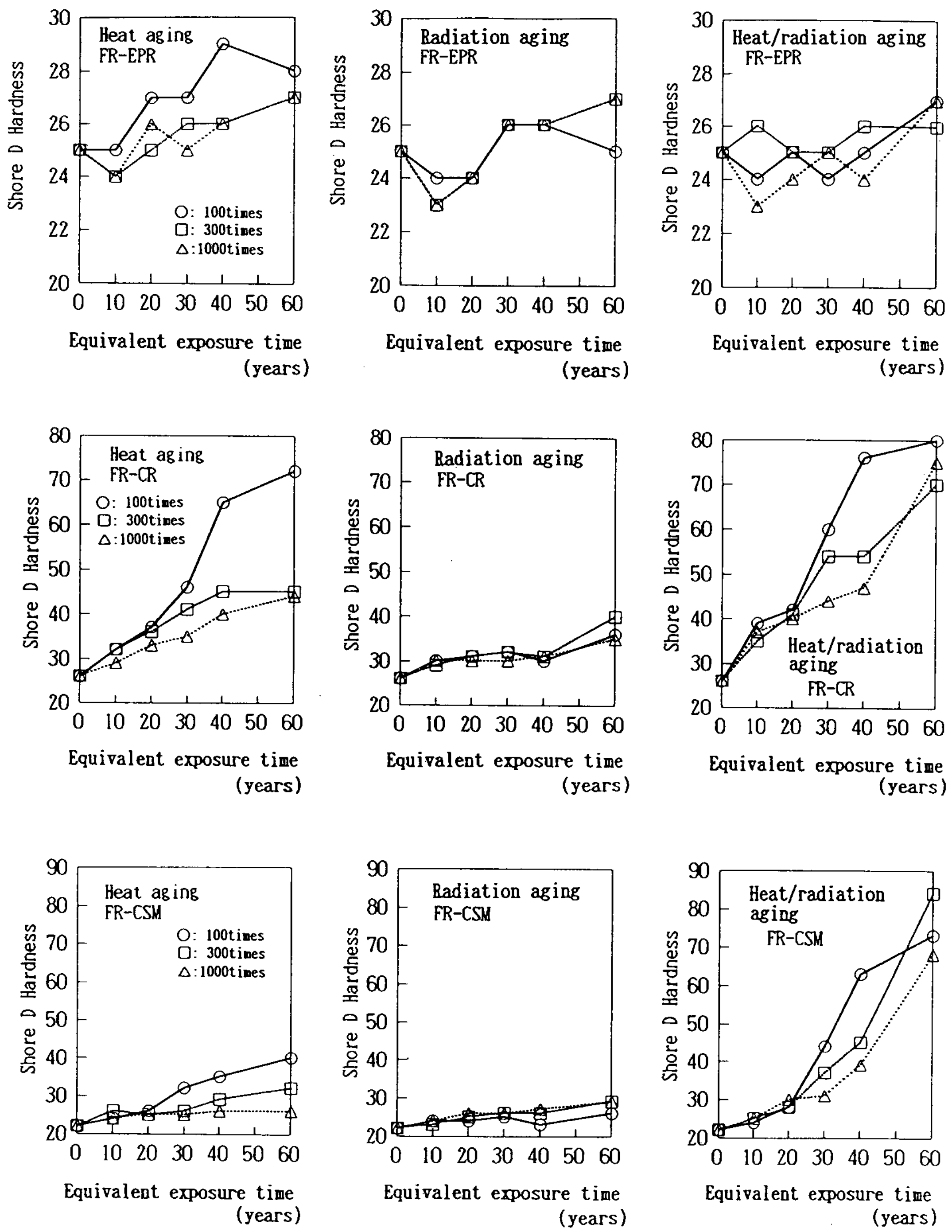

Fig. 4 Relationship between equivalent exposure time (years) and hardness

constant temperature or radiation dose rate as those in our test conditions. In some cases, more effect comes from exposure to heat, and in other cases, more comes from exposure to radiation. As shown by the results of the present test, degradation of physical properties precedes the changes in electrical properties for electric-wire covering materials in all the aging conditions. Thus it is effective for aging diagnosis to find out the changes in material elongation, which is a direct cause for a crack of wire and cable surfaces. The aging diagnosis by elongation needs a destructive measurement, but it was found in the present work that elongation values can be estimated by the measurement of hardness. A hardness tester we used for the present experiment had a needle at its end, thus making a tiny dent on the covering materials. Therefore, we need to develop a hardness tester that does not give any damage to cable-covering materials so that

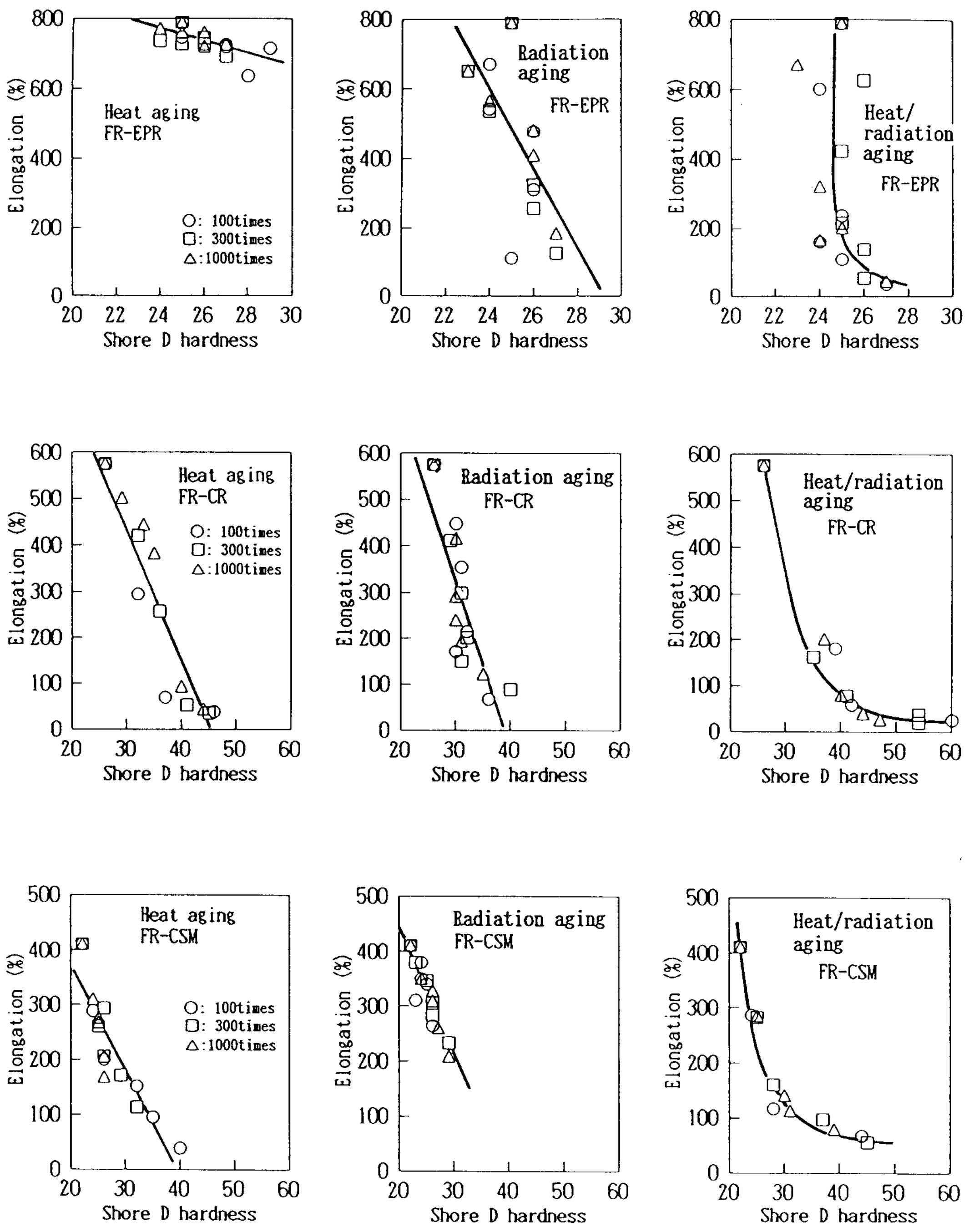

Fig. 5 Relationship between hardness and elongation under each condition

we can evaluate aging by a nondestructive method. Deterioration tendency due to aging differs according to materials used and environments. Thus, it would be important for the accurate evaluation of aging deterioration to know the actual environment and the deterioration tendency due to aging under this specific environment and to make nondestructive diagnosis based on the data corresponding to the environment.

5. Conclusion

(1) In tensile strength and volume resistivity, common property changes due to aging were not observed among different materials. On the other hand, elongation values decreased with increasing exposure time in all the materials and the aging conditions.

(2) Volume resistivity can be measured nondestructively, but it cannot be an aging index because the

change is too small, even under large deterioration of mechanical properties, to make an appropriate evaluation of aging.

(3) Hardness showed a certain correlation with elongation in almost any material, acceleration value and aging environment. Therefore, we found a possibility of making aging diagnosis accurately by the improvement or development of a certain hardness tester.

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