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A Study on the Fire Retardant Performance Depending on Accelerated Degradation of Non-Class 1E Cable

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1. Introduction

In nuclear power plants (NPPs), cables have an important role to operate and control safe-shutdown equipment and also cables are main contributor of fire loads in NPPs. For this reason, fire retardant performance of cables in NPPs shall be verified in accordance with IEEE-383 which endorsed in NUREG-0800, "Standard Review plan for the Review of Safety Analysis Reports for Nuclear Power Plants". However, it has been found that the results of flame test for Class 1E cables tend to be inconsistent with aged conditions [1] and the flame test for Non-Class 1E cables has not been conducted for the aged conditions. Therefore, the methodology for flame test of Non-Class 1E cable needs to be developed to verify the fire retardant performance during life time. In this study, flame retardant performance of Non-Class 1E cables for aged conditions is verified and suggests the suitable methodology of flame test for NPPs.

2. Test methods

2.1. Accelerated Aging Test

Specimens for this flame test are Non-Class 1E cables supplied to NPPs. Since the cable manufactured in 2017 was used for the study, acceleration aging method was used for the cable to simulate the degraded condition. Activation energy was estimated by using Kissinger Method[2], and acceleration aging factor was estimated by using Arrhenius equation[3]. The results of calculation for activation energy and acceleration aging factor are shown in table I. The required time for acceleration aging is shown in table II and it is calculated with acceleration factor of table I

2.2. Flame Test

Flame test for cables was conducted in accordance with IEEE-383. Two different editions of flame test standards, IEEE-383, have been applied to currently operating NPPs based on plant specific code cut-off date. Some information in IEEE-383 standard has been amended in the points of the procedures, conditions, facilities and acceptance criteria [4,5,6]. Major amendments are shown as follows. Firstly, IEEE-1202(1991) describes the detail and specific enclosure and ventilation method different from IEEE-383(1974). Secondly, flame projection shall be at an angle of 20±2 degrees to the ground in accordance with IEEE-1202(1991) compared to parallel to the ground in IEEE-383(1974). Thirdly, cables shall not be burn more than 2.4m according to in IEEE-383(1974), on the other hand, the cable length of burning is limited to 1.5 m. Comparison of these standards is shown in table III.

In this study, the cables certificated according to IEEE-383(1974) were used for the flame test. Cables for the test are composed of insulation (EPR) and jacket (CR) and diameter of cable is 25 mm.

3. Test results and discussion

3.1. Test results

After flame tests were completely finished, the lengths of cable damaged for each test were obtained. Five sample cables were mounted on each vertical cable tray according to the test standard. Same tests were conducted three times for each cable condition. Average lengths of cable damaged were shown in Table IV and Fig. 1 described average those length of cable damaged from test.

Table I: Parameters for acceleration aging of cable

Activation Energy (eV)	1.834
Boltzmann Constant (eV/K)	0.00008617
Operation Temperature (K)	333
Acceleration Temperature(K)	373
Acceleration Aging Factor	948.81

* Acceleration Temperature: 100℃(373K)

Table II: Acceleration aging time per aging condition

Aging Condition (Years)	Aging Time for cable	
	Hours	Days
10	92	3.8
20	185	7.7
30	277	11.5
40	369	15.4

Table III: Comparison of IEEE 383(1974) and IEEE 1202(1991)

	IEEE-383(1974)	IEEE-383(2003) (IEEE-1202(1991))
Internal volume of the enclosure	No restrictions	14.5 ㎥~36.0 ㎥
Ventilation method	Natural ventilation	Forced ventilation
Flame ignition source	1,500°F(816 ℃)	20kW
Test duration	20 min	20 min
Distance between each cables in tray	1/2 of cable diameter	Less value between "1/2 of cable/bundle diameter" and 15 mm
Direction of flame	Parallel to the ground	Angle of 20±2 degrees to the ground
Burner	Ribbon-type propane gas burner	Ribbon-type propane gas burner
Flow condition	Control with manometer	Air: 1,280 cm³/s Propane: 220 cm³/s
Acceptance condition	Damaged within 2.4m	Damaged within 1.5m

Table IV: Test results: average length of cable damaged for tests

Y	N	Sample Cable		
		T	H	L
0	1st	5.4	46	612
	2nd	6.6	42	644
	3rd	6.3	40	648
10	1st	5.3	52	788
	2nd	8.1	50	784
	3rd	8.3	52	854
20	1st	6.2	53	828
	2nd	10	45	742
	3rd	9	54	800
30	1st	8.4	34	786
	2nd	8.4	34	798
	3rd	7.8	33	816
40	1st	9.4	35	772
	2nd	8.6	34	800
	3rd	7.9	40	750

Y: Aging condition
N: Test number
T: Temperature of enclosure (℃)
H: Relative humidity of enclosure (%)
L: Average values of the damaged length (mm)

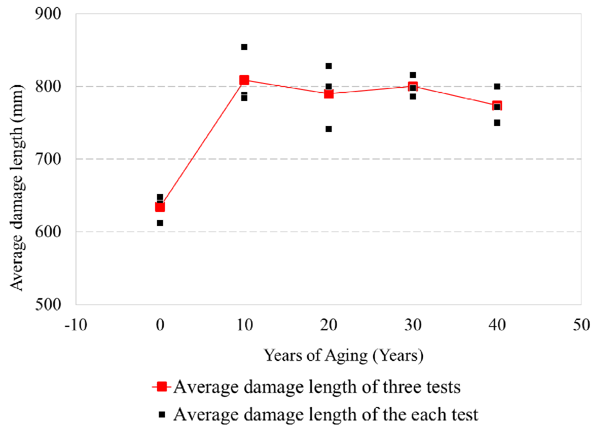

Fig. 1. Test results: effects of aging on length of damage

3.2. Analysis for length of cable damaged

One-way ANOVA (Analysis of variance) was performed for the cable to determine if the differences in damaged length are valid at different aging condition. The results of the analysis are shown as follows.

Firstly, one-way ANOVA on non-aged and aged cables was conducted at the significance level of 95% (α=0.05). The null and alternative hypothesis are as follows.

H_0: There is no significant difference in damaged length based on aging condition
H_1: There is significant difference in damaged length based on aging condition

H_0 is rejected and there is a significant difference in damaged length based on aging condition. Because the F-value is larger than the critical value of F at α=0.05 and the P-value is smaller than the level of significance.

Table V: One-way ANOVA for unaged and aged cables

Source of variation	SS	DF	MS	F	P	CF
Treatment	62286	4	15572	16.514	0.00021	3.478
Error	9429	10	943	-	-	-
Total	71716	14	-	-	-	-

SS: Sum of squares
DF: Degree of freedom
MS: Mean squares
F: F-value
P: P-value
CF: Critical value of F

Secondly, multiple comparisons of Tukey at 95% confidence level are conducted to check the amount of difference between aging conditions. Horizontal bars in fig.2 indicate Confidence intervals (CI) with 95% confidence levels. Confidence interval is a range of values within which a result is expected to exist with a specific probability. It is found that there is a significant difference between aged and unaged cables. But there is no significant difference between aged cables. Therefore, the one-way ANOVA was performed again focused on the aged cables as shown in table VI.

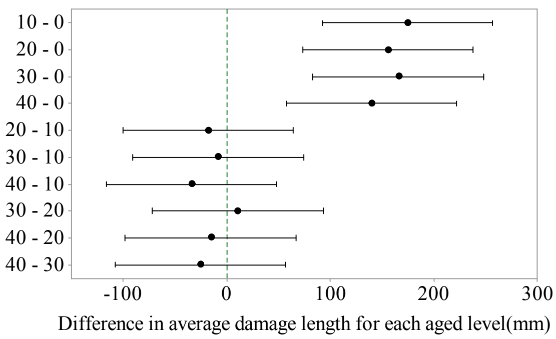

Fig. 2 Multiple comparisons of Tukey at 95% CI

Thirdly, one-way ANOVA between aged cables is conducted at the significance level of 95% (α=0.05). The null and alternative hypothesis are as follows.

H_0: There is no significant difference in damaged length based on aging condition
H_1: There is significant difference in damaged length based on aging condition

Statistically, there is no significant evidence that there is a difference in damaged length based on aging condition. Because H_0 is not rejected because the F-value is smaller than the critical value of F at α=0.05 and the P-value is larger than the level of significance.

Table VI: One-way ANOVA for aged cables

Source of variation	SS	DF	MS	F	P	CF
Treatment	1993	3	664	0.614	0.625	4.066
Error	8651	8	1081	-	-	-
Total	10644	11	-	-	-	-

SS: Sum of squares
DF: Degree of freedom
MS: Mean squares
F: F-value
P: P-value
CF: Critical value of F

It can be concluded that the aged cable has a longer average of damaged length than the unaged cable, but significant relationship between aged cables is not found.

4. Conclusion

Flame tests with accelerated aging conditions for Non-Class 1E cables used in NPPs were conducted as described above. Cables were tested in accordance with IEEE-383(1974). The result of this study shows that the average length of cable damaged for aged condition is longer than those of cable for the unaged condition. However the significant relationship between aged cables was not found.

The aging effect of cable on fire retardant performance is found by this study. For further study, cables with variable material, class and sizes will be tested to establish the methodology of flame test for considering the aging effect, environmental conditions and composition of cables, etc.

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