# Thermal Impact Characteristics by Forest Fire on Porcelain Insulators for Transmission Lines

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In this study the thermal impact characteristics by forest fire are extensively investigated using temperature controlled ovens. The test conditions for thermal impact damage are simulated according to the characteristics of natural forest fire. The test pieces are suspension porcelain insulators made by KRI in 2005 for transmission lines. In the thermal impact cycle tests with 300 °C thermal impact gradient (-70 to 230 °C), cycling in 10 minute periods, no critical failures occurred in the test samples even with long cycle times. But in tests with thermal impact gradient from room temperature to 200-600 °C, cycling in 10 to 30 minute periods, there were critical failures of the porcelain insulators according to the thermal impact gradient and quenching method. In the case of thermal impact by forest fire, it was found of that duration time is more important than the cycling time, and the initiation temperature of porcelain insulator failures is about 300 °C, in the case of water quenching, many cracks and fracture of the porcelain occurred. It was found that the thermal impact failure is closely related to the displacement in the cement by thermal stress as confirmed by simulation. It was estimated that the initiation displacement by the thermal impact of 300 °C is about 0.1 %. Above 1 % displacement, it is expected that the most porcelain insulators would fail.

*Keywords* : Thermal impact, Porcelain, Insulator, Forest fire

## 1. INTRODUCTION

In Korea, about 8 % of the porcelain insulator failures on transmission lines is from forest fires(Fig. 1). In recent years, due to increase of transmission power capacity, it has been recognized that the reliability of power networks depends on the long-term performance of the suspension insulators used on the lines. Since a failure of any one insulator will interrupt the operation of the entire power network, it is required for all of the insulators to maintain its electrical and mechanical performance for a long period of service even under harsh natural environmental conditions such as wind, ice, snow and especially forest fire[1].

In order to evaluate the long-term performance of suspension insulators, various laboratory test methods have been studied simulating environmental conditions. In addition, the important factors to produce reliable insulators were clarified taking into account of the causes of insulator deterioration influencing the long-term performance of the insulators[2-5].

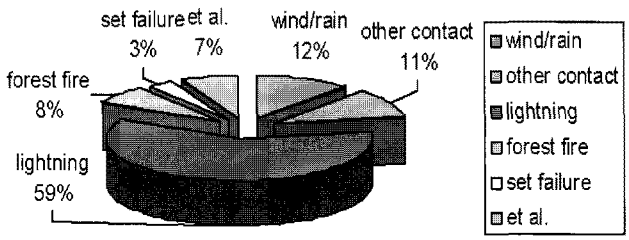


Fig. 1. Pie chart showing porcelain insulator failures on Korean transmission lines.

In this study the thermal impact characteristics of porcelain suspension insulators, which is the most important factor to estimate damage by forest fire, are extensively investigated using temperature controlled ovens.

## 2. EXPERIMENTAL AND SIMULATION

### 2.1 Samples

The test pieces are suspension porcelain insulators made by KRI in 2005 for transmission line. The basic performance specification is listed in Table 1.

Table 1. Basic performance specification of ES 131 suspension insulators.

| Item | | Requirement |
|---|---|---|
| Dry Power-Frequency Flashover Voltage (kV) | | 80 |
| Wet Power-Frequency Flashover Voltage (kV) | | 50 |
| Critical Impulse Flashover Voltage (kV) | Positive | 125 |
| | Negative | 130 |
| Power-Frequency Puncture Voltage (kV) | | 110 |
| Radio-Influence Voltage | Low Freq. Test Voltage(rms kV) | 10 |
| | Max. RIV(dB. At 500kHz) | 37 |
| Electro Mechanical Failing Load(kg) | | 16,500 |
| Mechanical Impact Test Load(kg-cm) | | 104 |
| Tensile Test Load(kg) | | 8,250 |
| Mechanical Routine Test Load(kg) | | 11,000 |
| Leakage Distance(mm) | | 280 |

### 2.2 Thermal impact test methods

For the thermal impact cycle tests, we used two temperature controlled ovens, cycling between them in 10 minute periods. The ovens and test cycle are shown in Fig. 2 and Fig. 3, respectively.

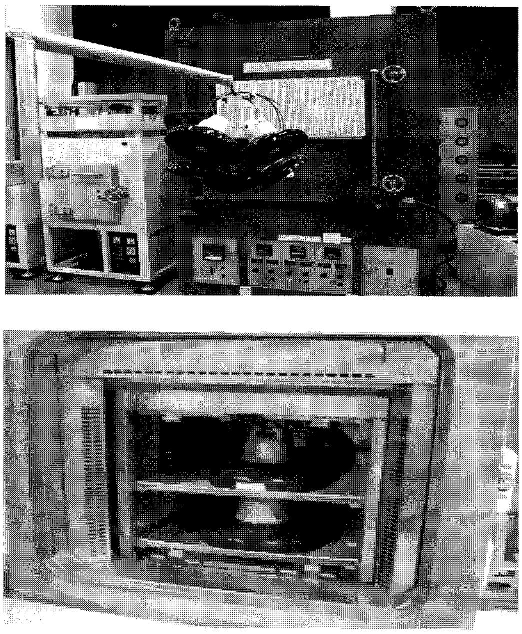

Fig. 2. Ovens for the thermal impact tests.

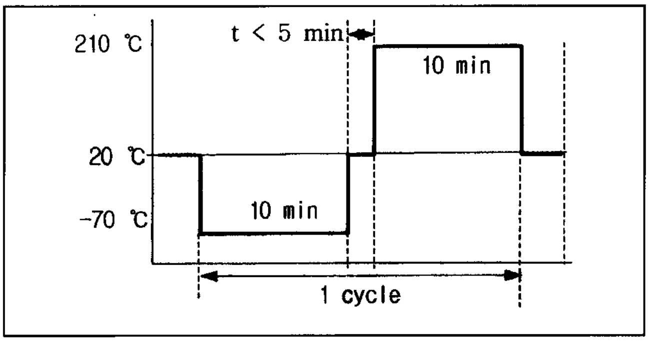


Fig. 3. The thermal impact cycle.

Testing for the performance estimation of porcelain insulators aged in the thermal impact environment was as follows:

- Dry and wet power frequency flashover voltage
- Impulse flashover voltage
- Power frequency puncture voltage
- Electro mechanical failure load test
- Thermal mechanical performance test and accelerating

### 2.3 Simulation conditions

The ANSYS/NASTRAN software is applied for more systematic and analytic simulation in which the boundary conditions are as follows:

- Basic tensile strength: 8,250 kg
- Applied tensile strength: 5000, 10000, 17000 kg
- Analysis dimension: 3 dimension
- Equation: ANSYS 6.0 plane 42 elements
- Elements: 2800 nodes
- Calculated pressure on top: 1,535 kg/mm$^2$ for 5,000 kg
- Displacement of 0.1 %: 100 K thermal gradient

## 3. RESULTS AND DISCUSSION

### 3.1 Thermal impact cycle characteristics

Table 2 shows the test results of general performance tests of type ES 131 suspension insulators after thermal impact cycle aging. All samples passed these tests but some samples failed the cooling-heating performance test. The cycling repeat number was 20 in order to ageing samples in thermal impact cycle test[1,4].

As a result, it is found that the cooling-heating performance test is a better method of detecting deterioration within the porcelain body. Therefore, the cooling-heating thermal impact test is better suited to evaluate the deterioration from forest fire.

Table 2. Results of general performance tests of type ES 131 suspension insulators after thermal impact cycle aging.

| Items | Results |
|---|---|
| Power frequency puncture test | Pass |
| Electro mechanical failing load | Pass |
| Mechanical impact teat load | Pass |
| Impulse flashover voltage | Pass |
| Electro mechanical failure load | Pass |
| Thermal mechanical test | Pass |
| Cooling-Heating test | Some Failures |

### 3.2 Thermal impact characteristics

For the thermal impact test, which is another typical condition in forest fire, we studied it with the conditions of 200 to 400 °C thermal impact gradient (room temperature to 200-600 °C with 10 to 30 minutes at the elevated temperature. Figure 3 shows one sample after a thermal impact of about 300 °C for 30 minutes and Fig. 4 shows many samples after a thermal impact of 600 °C for 30 minutes. Most samples experiencing a 300 °C gradient showed trace cracking or partial fracture, while all of samples subjected to 600 °C gradient showed cracks and porcelain fractures.

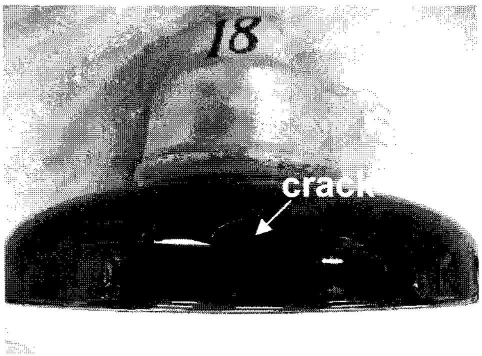


Fig. 4. Insulator sample after thermal impact test(room temperature to 300 °C and held for 30 minutes).

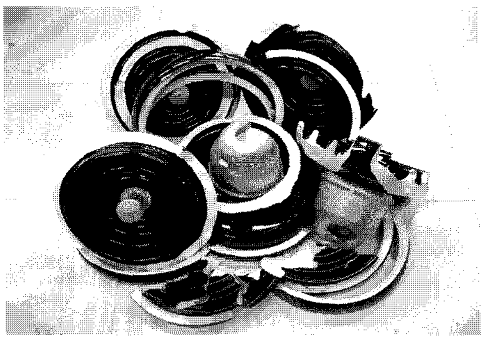

Fig. 5. Insulators after thermal impact test(room temperature to 600 °C and held for 30 minutes).

This test condition has different factors in temperature gradient intensity and quenching time compare to the previous thermal impact cycle test. From these results, in the case of thermal impact by forest fire environment on porcelain insulators, it was found of that duration time is more important than the cycling time, and the initiation temperature of porcelain insulator degradation by thermal impact is about 300 °C, in the condition of water quenching, many samples developed cracks and fracture of the insulator surface.

### 3.3 Calculation of thermal impact characteristics

The most important environmental factor affecting cement expansion is temperature. As the various components of an insulator have different thermal expansion coefficients, Fig. 6 shows the simulation results regarding the cement displacement with temperature. In normal conditions, ceramic insulators are applied in environments in which the temperature is below 100 °C. But in order to assure the deterioration quality of cement, the expansion property must be tested for forest fire with 100 to 600 °C.

Figure 6 shows the results of the displacement of cement with temperature, and it can be seen that the cement displacement changes linearly with temperature. At room temperature, the cement displacement is about 0.05 % but at 400 °C, it was over 0.1 %. This result has an analytic meaning comparing to other research in which given cement expansion artificially in the aspect of approaching methods[5,6].

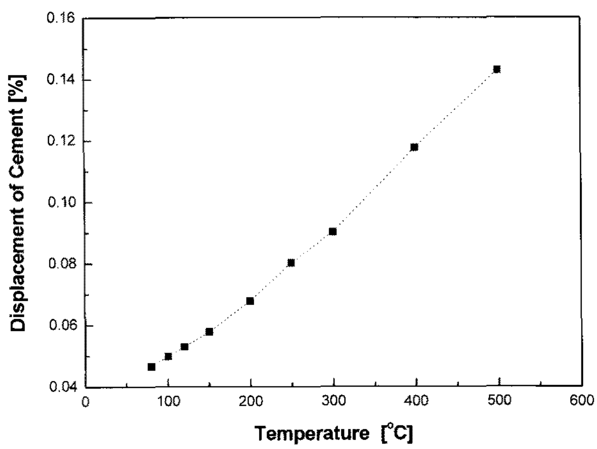


Fig. 6. The cement displacement with temperature gradient.

The simulation result of shear stress on a porcelain insulator with cement displacement is shown in Fig. 7. The shear stress in the porcelain at 300 °C is about 11 $kgf/mm^2$ at 0.1 % cement displacement. Also, it can be seen that the porcelain body would fracture if the cement displacement is above 0.1 %, because the quartz insulator body has about 7-9 kgf/mm$^2$ flexure strength. From this calculation, it is shown that the thermal impact failure is closely related to the displacement in cement interface by thermal stress as observed in the tests on suspension insulators. It was calculated that the initiation displacement by the thermal impact of 300 °C is about 0.1 %. Above 1 % displacement, it is expected that the most of the porcelain insulators would fail.

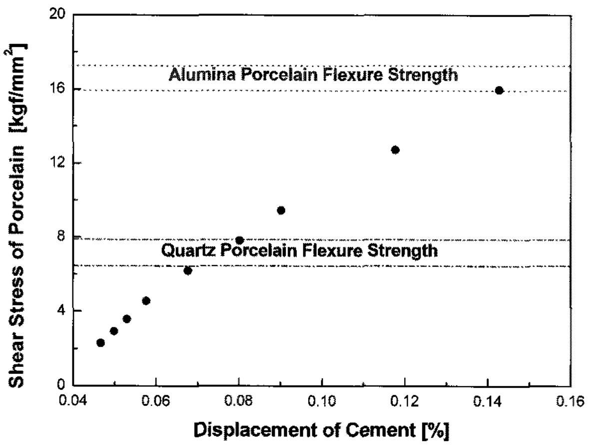


Fig. 7. The simulation result of the shear stress on cement with cement displacement.

## 4. CONCLUSION

In thermal impact cycle tests with the conditions of 300 °C thermal impact gradient (-70 to 230 °C) cycling in 10 minute periods, there were no critical failures of porcelain suspension insulators even after a very long period of cycling. But in thermal impact tests with the conditions of thermal impact gradient (room temperature to 200-600 °C with 10-30 minutes in a temperature controlled oven), critical failures of porcelain insulators occurred according to the thermal impact gradient and quenching method.

In the case of thermal impact by forest fire environment on porcelain insulators, it was found of that duration time is more important than the cycling time, and the initiation temperature of porcelain insulator by thermal impact is about 300 °C.

In the condition of water quenching, many cracks and fracture developed in the tested insulators. It was found that the thermal impact failure is closely related to the displacement of the cement by thermal stress which was supported by simulation.

It was calculated that the initiation displacement by the thermal impact of 300 °C is about 0.1 %. Above 1 % displacement of the cement, it was anticipated that most of the porcelain insulators would fail, which was observed in the tests.

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