# Accelerating Aging of Transmission Line Porcelain Suspension Insulators by Autoclaving

Won-Kyo Lee[a], In-Hyuk Choi, Koo-Yong Shin, and Kab-Cheol Hwang
*Transmission Technology Group, KEPRI,*
*103-16 Munji-dong, Yuseong-gu, Daejeon 305-380, Korea*

Se-Won Han
*Advanced Material and Application Research Lab., KERI,*
*28-1 Seongju-dong, Changwon-si, Gyeongnam 641-120, Korea*

[a]E-mail : leewonkyo@kepco.co.kr

(Received July 11 2008, Accepted August 14 2008)

Porcelain suspension insulators aged for 1, 5 and 10 years on Korean transmission lines and new insulators are tested for autoclave expansion. The compressive strength of the insulators aged in an autoclave with conditions of 250 °C and at 20 atm for 30 minutes, was about 7.6 kgf/mm$^2$, which is close to that measured on insulators aged for 10 years in the field. From simulation results, the cement displacement changed linearly with temperature. At a temperature of 200 °C, the shear stress was approximately 7 kgf/mm$^2$; a stress that is brought about by a 0.07 % expansion of the cement. It is evident that the cement would fracture at a 0.07 % expansion, because the cement has about 7 to 9 kgf/mm$^2$ flexure strength. A turning point in the shear stress with mechanical load occurred at 0.02 % cement expansion. From an analysis of the porcelain body it is shown that there is sufficient margin of strength to guard against fracture of the porcelain body even for a cement expansion more than 0.12 %.

*Keywords* : Aging, Porcelain, Insulator, Autoclaving

## 1. INTRODUCTION

In Korea, more than 99 % of insulators for transmission lines are of the ceramic type and these suspension insulators are used for the mechanical support and electrical insulation of overhead lines. As the failure of any insulator string is detrimental to the operation and safety of an overhead line, it can be stated that the reliability of overhead lines depends largely on the electro-mechanical integrity of ceramic suspension insulators. One type of failure of ceramic suspension insulators in Korea is the fracture failure of the porcelain by aging deterioration or transient stress. This is a well known phenomenon reported in other countries[1,2].

The important aging cause of many porcelain suspension insulators for transmission lines is the mechanical stress at the interface between porcelain and the cement[3,4]. The autoclave test is used as a means to accelerate cement expansion and to provide an index of potential delayed fracture that is caused by cement growth. In this study, the aging characteristics of porcelain insulators removed from the field have been compared to insulators aged by autoclave tests through mechanical tests and simulation studies.

## 2. EXPERIMENTAL AND SIMULATION

### 2.1 Insulator samples

The test samples were porcelain suspension insulators aged for 1, 5 and 10 years, on Korean transmission lines and on new insulators for autoclave expansion tests. Table 1 shows the characteristics of the test samples.

Table 1. Characteristics of test samples.

| Sample | Insulator Condition | Porcelain |
|---|---|---|
| A | 1 year field aged | Alumina |
| B | 5 years field aged | Alumina |
| C | 10 years field aged | Cristoballite |
| D | New | Alumina |

### 2.2 Test methods

The test for autoclave accelerating of porcelain insulators was according to ASTM C151. The maximum temperature and pressure was 250 °C and 300 psi, respectively. Mechanical strength, SEM and EDAX analysis were used for estimating the state of the aged samples.

### 2.3 Simulation conditions

Figure 1 illustrates the configuration and components of the suspension insulator modeled in this study. The electro-mechanical tensile strength was 36,000 lbs and diameter was 254 mm.

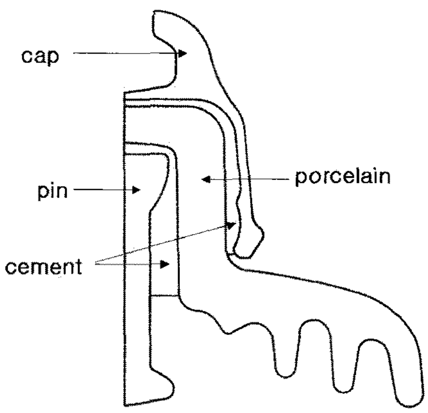


Fig. 1. Cross section showing the components of a suspension insulator.

The physical properties of the insulator components used in the modeling are listed in Table 2.

The software used for simulation is NASTRAN produced by MSC. The parameters for analysis are listed in Table 2.

Table 2. The physical properties of the alumina insulator components.

| Components | Modulus [kg/mm$^2$] | Thermal Expansion [$10^{-6}$/K] | Poisson's Ratio |
|---|---|---|---|
| Pin | 14,060 | 12 | 0.25 |
| Porcelain | 6,890 | 7 | 0.20 |
| Cement | 2,250 | 10 | 0.22 |

The temperature range that provided the displacement to cement was from room temperature to 500 °C. The electromechanical tensile load of suspension insulators studied here was according to Korean power line standard specification. Therefore in order to review of loading effects with cement expansion, 1/2, 1/3 and full electromechanical tensile loads are applied as a modeling factor.

Combined mechanical and electrical (M&E), accelerated M&E, thermal and mechanical (T&M) are used to determine whether the insulators will have high reliability during a long service life. The magnitude, average, and standard deviation data from these tests are useful in calculating the homogeneity and evaluate the long-term reliability of the porcelain insulators[5].

## 3. RESULTS AND DISCUSSION

### 3.1 Cement mechanical properties

Figure 2 shows the compressive strength of Portland insulator cements with the length of time in service.

It can be noted that the compressive strength increases linearly with service life, appearing to saturate after about 10 years in the field, reaching a compressive strength for sample C (10 years field service) was about 7.7 kgf/mm$^2$; which is 1.5 times higher than that measured on new insulator cement. These results are used for estimating the accelerated condition by autoclave tests.

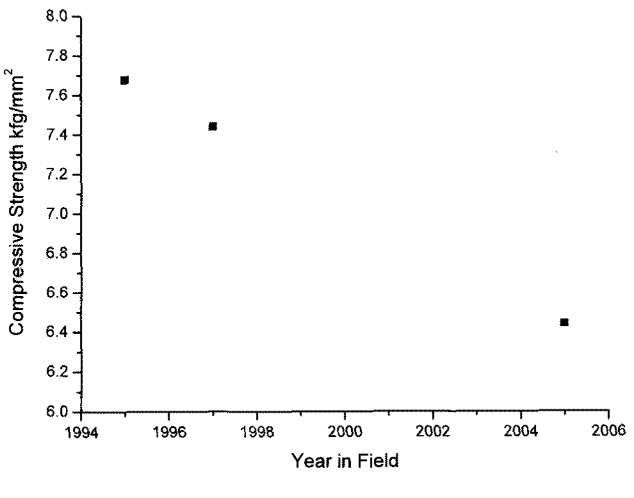


Fig. 2. The compressive strength of insulator cement with field exposure.

### 3.2 Autoclave accelerated tests

Figure 3 shows the results of compressive strength tests of cements with various field service times after exposure to autoclave tests as per ASTM C131(250 °C, 300 psi).

In this test, the insulator samples did not reach fracture as the interface displacement is below 0.08 %, therefore, there is no problem insulator reliability.

The compressive strength of new samples without field aging was about 7.6 kgf/mm$^2$ and this result corresponds to 10 years in the field. But the compressive strength of C sample, after 10 years in field, was about 9.9 kgf/mm$^2$ and this value is exceeds the strength of cement, and as a result, C sample fractured as can be seen in Fig. 4.

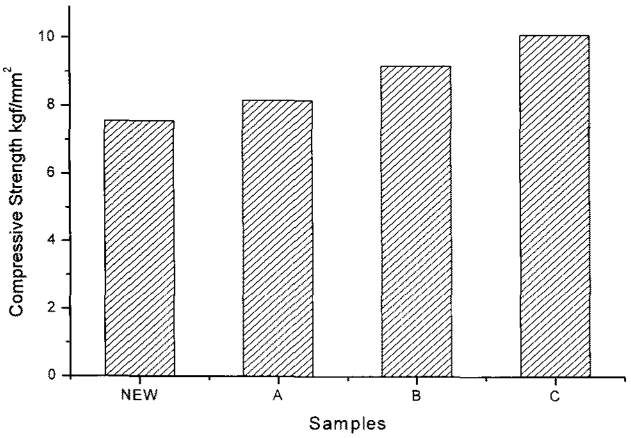


Fig. 3. The compressive strength of sample cements with time of field service.

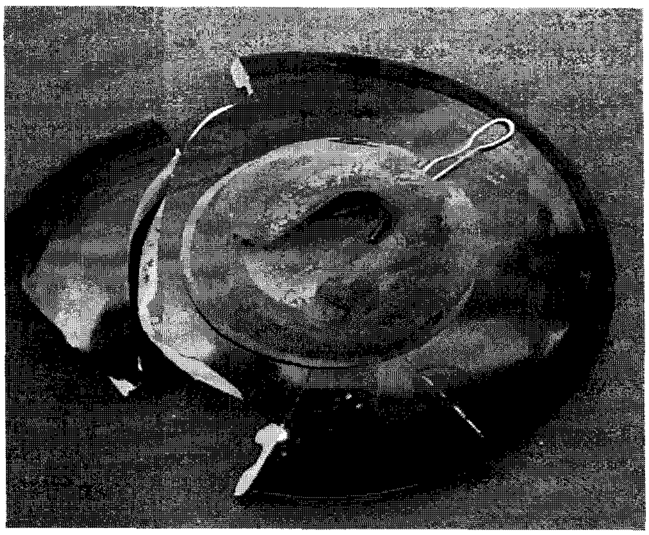

Fig. 4. The C sample after autoclave test.

The increase of compressive strength of sample cements by autoclave tests with field service is shown in Fig. 5.

In the case of sample C, the increase is greater than the other samples and this result suggests that the sample aged in the field has some deterioration at the interface.

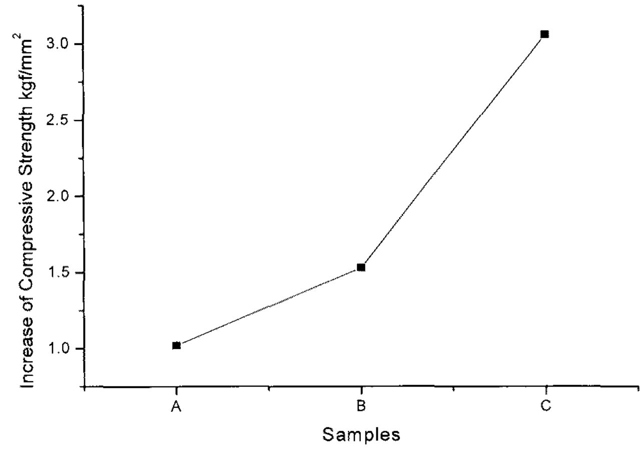


Fig. 5. Compressive strength of sample cements with field service time.

Table 3 shows the analysis of Portland cement. The hydration expansion due to Gypsum may be the main reason for cement growth failures of porcelain suspension insulators.

Table 3. Main chemical components of Portland cement.

| Components | CaO | $Al_2O_3$ | $SiO_2$ | MgO | $Fe_2O_3$ | $SO_3$ | loss |
|---|---|---|---|---|---|---|---|
| wt% | 61.9 | 5.6 | 20.5 | 2.6 | 3.1 | 4.4 | 0.7 |

### 3.3 Simulation of autoclave tests

Expansion of Portland cement produces mechanical stresses that act on the cement, porcelain and metal components of an insulator. The simulated shear stress distribution on cement at 200 °C is shown in Fig. 6.

The maximum compressive stress was 5.2 kgf/mm$^2$ that occurs near the top edge of pin.

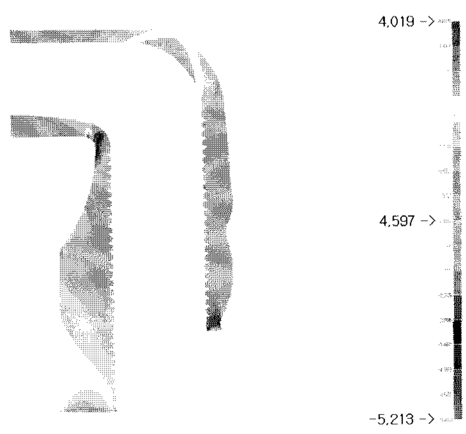


Fig. 6. The shear stress distribution on cement at 200 °C.

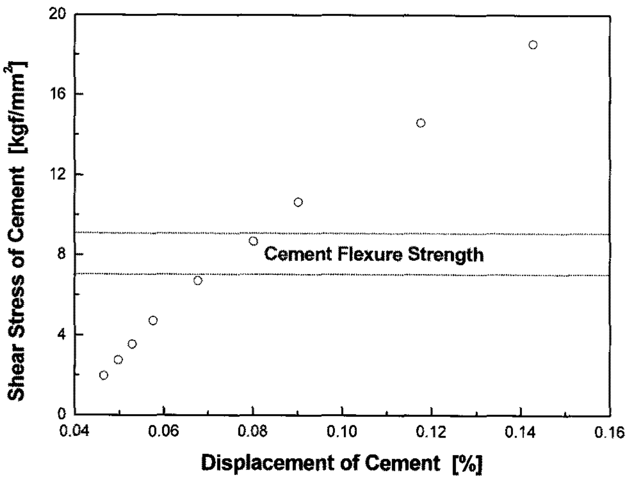


Fig. 7. Simulation of shear stress on cement with cement displacement.

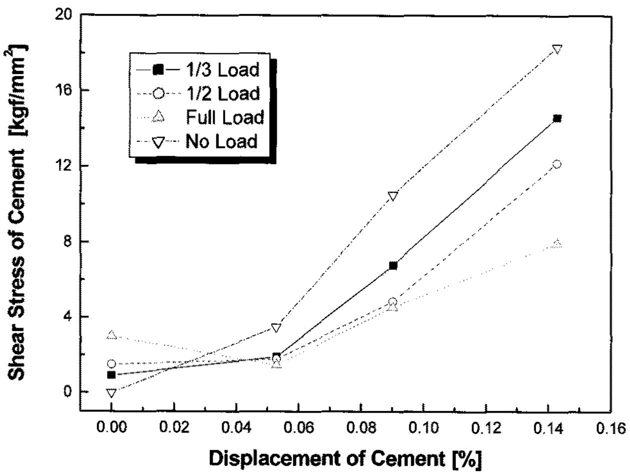


Fig. 8. Shear stress behavior on cement with cement displacement under various insulator loads.

The simulation result of shear stress on cement with cement displacement was shown in Fig. 7.

The shear stress was about 7 kgf/mm$^2$ at 0.07 % displacement at 200 °C and at this value of cement expansion, it shows that the cement would fracture because the cement has about 7-9 kgf/mm$^2$ flexure strength. In previous research, there is no simulation of mechanical load with cement displacement[2,6]. But in this study both are simulated.

Figure 8 shows the shear stress of cement with cement displacement under various insulator mechanical loads. An increase in shear stress is noted below 0.02 %, as a turning point, with an increase in mechanical loading. Above 0.02 % cement displacement, the shear stress decreased with increased mechanical load.

For the 1/2 load condition, the shear stress reached about 4 kgf/mm$^2$ at 0.09 % cement displacement, which was about 50 % lower than the shear stress without mechanical load.

From these phenomena it was considered that the mechanical load dispersed the stress resulting from cement displacement.

## 4. CONCLUSION

Porcelain suspension insulators removed from the field having service times of 1, 5 and 10 years on Korean transmission lines and new insulators were tested for autoclave expansion. The compressive strength of the insulators aged in an autoclave with conditions of 250 °C and at 20 atm for 30 minutes, was about 7.6 kgf/mm$^2$, which is close to that measured on insulators aged for 10 years in the field. From simulation results, the cement displacement changed linearly with temperature. At a temperature of 200 °C, the shear stress was approximately 7 kgf/mm$^2$; a stress that is brought about by a 0.07 % expansion of the cement. It is evident that the cement would fracture at a 0.07 % expansion, because the cement has about 7 to 9 kgf/mm$^2$ flexure strength. A turning point in the shear stress with mechanical load occurred at 0.02 % cement expansion. When the cement displacement was over 0.02 % the shear stress decreased with mechanical load applied to the insulator. From simulation studies, it is shown that there is sufficient margin of strength to guard against fracture of the porcelain body even for a cement expansion more than 0.12 %.

## REFERENCES

[1] S. W. Han and H. G. Cho, "A study on electrical and mechanical simulation for designing porcelain insulators with high strength", ICEE 2002 Proceeding, Vol. 13, p. 1191, 2002.

[2] E. A. Cherney, "Cement growth failure of porcelain suspension insulators", IEEE PAS, Vol. PAS-102, No. 8, p. 2765, 1983.

[3] S. W. Han and H. G. Cho, "Study on performance and aging test of porcelain insulators for transmission line", J. of KIEEME(in Korean), Vol. 16, No. 9, p. 842, 2003.

[4] J. S. T. Looms, "Insulators for high voltages", Chpter 2, IEE Power Engineering Series 7, Peter Peregrinus Ltd, 1988.

[5] K. Morita, Y. Susuki, and H. Nozaki, "Study on long term reliability of suspension insulators", TIEE Japan, Vol. 117-B, No. 12, p. 1529, 1997.

[6] J. Bellerive, "Performance of porcelain insulator, forty years experiences at Hydro Quebec", CEA Paper, March, 1990.