Stress Simulation on Suspended Porcelain Insulators with Cement Displacement

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The experimental and simulation study of insulator failure by cement growth on suspended insulators (16,500kgf) for transmission line was discussed. To get more practical and analytic calculation results, the advanced program was used. This analysis tool was possible to calculate stress behaviors with mechanical loading when cement displacement happened. From simulation results, the cement displacement changed with linear according to temperature. The shear stress was about 7 kgf/mm^2 at 0.07% displacement provided from 200°C, then it could be seen that the cement would be fractured even if 0.07% displacement acted, because the cement had about 7-9 kgf/mm^2 flexure strength. The curve patterns of shear stress with the increase of mechanical loading were changed at 0.02% as a turning point, when the cement displacement was over 0.02% the shear stresses decreased reversely with the increase of mechanical loading. From analysis on porcelain body it was known that there were enough margin to protect the fracture of porcelain body before the cement

Keywords : Porcelain insulator, Cement displacement, NASTRAN simulation, Mechanical stress

1. INTRODUCTION

In KOREA above 99% of insulators for transmission line is porcelain type, the porcelain suspended insulators has been applied normally in transmission system for the mechanical support and electrical insulation of overhead lines[1]. As 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 porcelain suspension insulators. The one of typical failure kinds of porcelain suspended insulators for transmission line in KOREA is the fracture failure on head part by transition overvoltage. It is general phenomena as other countries happened.

During the 1970's, according to an investigation on insulator failures research by Ontario Hydro and other utilities, approximately 30% of insulators (146mm) removed were found to be electrically defective. Mechanical tests indicated a reduced strength ranging form 33 to 90% of the nominal rated strength[2]. Such strength reduce have a relation to the deterioration of interface of head part. The head part of porcelain insulator was formed with insulator body and metallic fittings with a cement assembly.

Following the separation failure of a dead-end insulator assembly early in 1980 on a 500kV line, a study on the electromechanical integrity of porcelain insulators was initiated in Japan[2]. In these investigations, a second type on latent defect was identified as being present and related to the volume expansion of the neat Portland cement used in the insulator assembly. Portland cement is an impure mixture of calcium silicates and calcium aluminate, with excess calcium oxide. Gypsum, i.e. calcium sulphate, is present as a ferrite. On cement growth the picture is far from clear. Cases have occurred, as with multiple come posts, of cracking which could not have been caused by metallic corrosion, since the only materials in play were porcelain and cement. Cherney pointed out that many cements used in North America contract rather than swell with age, and that growth could be produced only by highly unrealistic thermal cycling. It has been suggested that the Gypsum, which was added to moderate the high reaction rate of the tricalcium silicate in Portland cement, may cause swelling, other sulphates were certainly known to be undesirable[3].

Though there were many point-outs about cement growth problem, until now no thorough systematic studies on these phenomenon in suspended insulators made by KOREA has been carried out. Therefore in this study, the experimental and simulating study on insulator failure by cement growth in suspended insulators (16,500kgf) for transmission line was discussed. To get more practical and analytic calculation results, the advanced program was used. This analysis tool was possible to calculate stress behaviors with mechanical loading when cement displacement happened.

2. MODELING FOR SIMULATION

2.1 Cement growth

Generally cement was contracted after curing due to a water contact, so cement was hardened. But during ageing moistures in air penetrate into cement and react with cement chemical contents, then cement is expanded again. Fig. 1 showed the typical process of contraction and expansion of cement with ageing time. It was known that the displacement from cement contraction or expansion gives serious mechanical stress to cement and porcelain body[3].

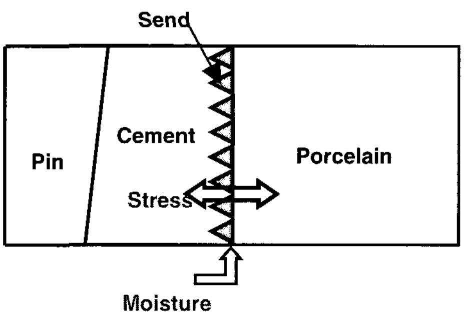

Fig. 1. The process of contraction and expansion of cement with ageing time.

2.2 Analysis Modeling

Figure 2 is the suspended insulator configuration used to be model in this study, then the electromechanical tensile strength was 16,500kgf and diameter was 254mm. The physical properties of insulator components for the solution as shown in Table 1 was measured by experimental methods.

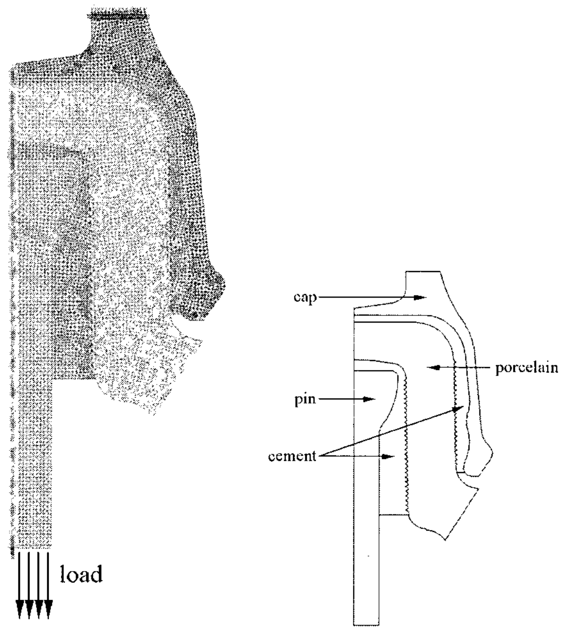

Fig. 2. The configuration and components of insulator for analysis.

The tool used for solution was the NASTRAN program. The conditions for analysis listed in Table 2. In this analysis to study more real structure, model A without sending compared with model B with triangle sending. The temperature range that provided the displacement to cement was from room temperature to 500°C. The electromechanical tensile load of suspended porcelain insulator studied in here was 16,500kgf. Therefore in order to review of loading effects when the cement displacement happened, the 1/2, 1/3 and full electromechanical tensile loads applied as a modeling factors.

Table 1. The physical properties of the insulator components.

Components	Modulus [kg/mm^2]	Thermal Expansion [10^{-6}/K]	Poisson's Ratio
Pin	21,000	12	0.28
Cap	18,300	12	0.17
Porcelain	9,700	7	0.20
Cement	3,200	10	0.22

Table 2. The conditions for analysis.

Conditions	Applied
Models	A(No send), B(Triangle send)
Node Number	27,000
Elements	13,200
Temperature Range	from room temperature to 500 °C
Applied Loads	1/3, 1/2 and full electromechanical tensile loads

3. RESULTS AND DISCUSSION

3.1 Cement properties

In recent the Portland cement was generally used as an assembly for suspended porcelain insulator. The main chemical components of Portland cement used in this study listed in Table 3. Fig. 3 showed the compression strength of Portland cements with curing time. When the curing time reached to 8 days, the compression strength was almost in saturation. Then the value of compressive strength was about 800 kgf/cm^2, it is about 1.5 times to the initiation cement strength.

Table 3. The main chemical components of typical Portland cement.

Components	CaO	Al_2O_3	SiO_2	MgO	Fe_2O_3	SO_3	I.g loss
wt%	61.9	5.6	20.5	2.6	3.1	4.4	0.7

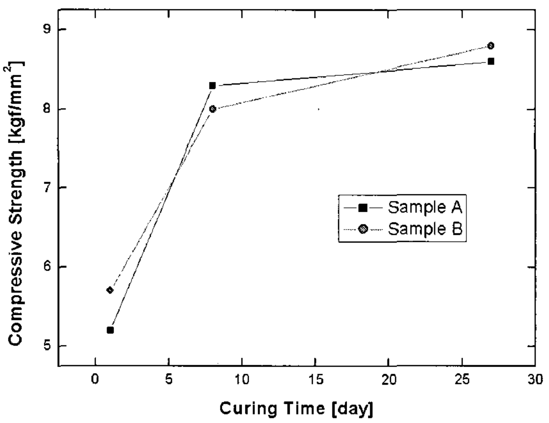

Fig. 3. The compressive strength of Portland cements with curing time.

According to the Portland cement analysis, there were mainly three compounds in Portland cement liable to cause expansion. These were magnesia, free lime and calcium sulphate($CaSO_4$) which results from Gypsum($CaSO_4$-$2H_2O$), a hydrate of calcium sulphate, that was added to the cement clinker during manufacture of Portland cement[3]. Gypsum, when present in excess, will cause excessive expansion after setting and hardening owing to the continued formation of calcium shuphoaluminate in the presence of moisture. Unfortunately it was intrinsic to contain these compounds in making cement, so it was need to do best reduce its. As shown in Table 3, it illustrated that cement could be expanded due to the high portion of Ca and Mg.

As the hydration expansion due to Gypsum is undetected by the accelerated auto-calve test for cement soundness, but proceeds slowly with time and moisture, excessive Gypsum was likely the main reason for cement growth failures of suspension insulators.

3.2 The strength of porcelain bodies

Almost of suspended porcelain insulator for high voltage was the aluminous porcelain type. These insulators had better high impact strength than Cristobalite insulators due to the reinforcement of Corundum crystal phase [1,3]. The flexure strength property with alumina compositions was shown in Fig. 4. The flexure strength of sample with 16wt% alumina composition was about 1,750 kgf/cm^2, which was about 10% higher than the sample with 6% alumina composition. Flexural strength had higher values than tensile strengths because the maximum tensile stress covers only a small cross sectional area. In the case of cement expansion and thermal areas near the interfaces, the same reasoning applied.

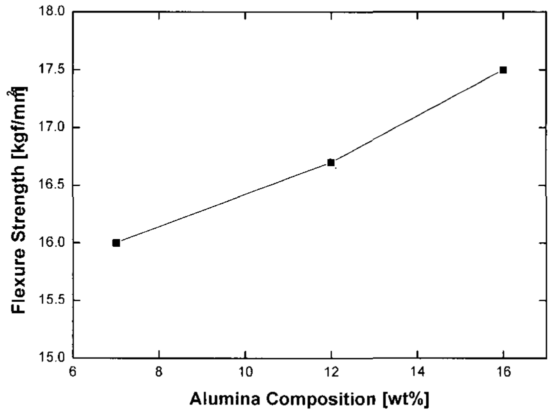

Fig. 4. The flexure strength property with alumina compositions.

3.3 The cement displacement with temperature

The most important environmental factor providing cement expansion was a temperature. Because the components of insulator had a different thermal expansion coefficients, when the temperature difference happened in each parts of porcelain insulator, the moistures in air penetrated into interface between porcelain and cement. As a result its react with cement chemical compounds as illustrated in above, then cement was expanded. Fig. 6 showed the simulation result regarding the cement displacement with temperatures. In normal porcelain insulators were applied in environment temperature of below 100°C. But in order to assure the deterioration quality of cement, the expansion property should be tested in the autoclave with 216°C in the case of the standard such as ASTM C151[2].

According to Fig. 5 it could be seen that the cement displacement changes with linear according to temperature, then the cement displacement was about 0.05% at room temperature, but when increasing to

400°C, it was over 0.10%. These result had an analytic meaning comparing to other researches in which given cement expansion artificially in the aspect of approaching methods [2,4].

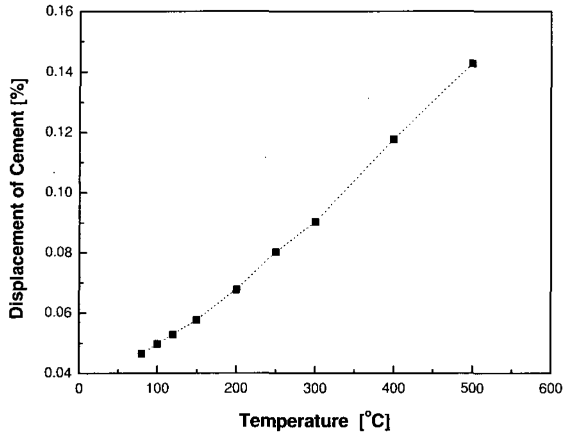

Fig. 5. The cement displacement with temperatures.

3.4 The stress properties with cement displacement

If the displacement resulting from cement expansion happens, mechanical stresses will act on the cement, porcelain and metal part. The shear stress distribution on cement at 200°C was shown in Fig. 6. The maximum stress was 5.2 kgf/mm^2 located near the top edge of pin and it was found that the type of stress is compressive.

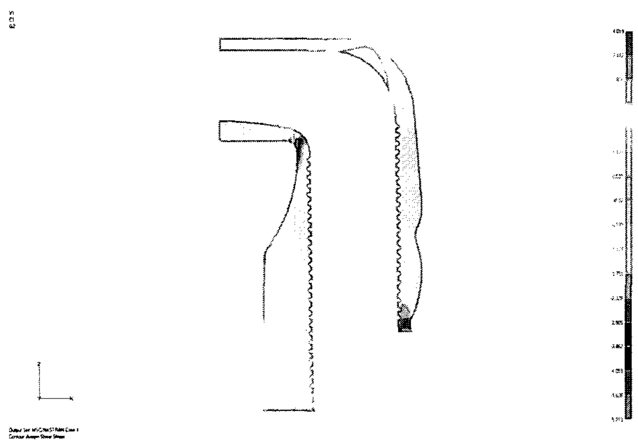

Fig. 6. The shear stress distribution on cement at 200 °C.

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 provided from 200°C, it showed that the cement would be fractured if 0.07% displacement acted, because the cement had about 7-9 kgf/mm^2 flexure strength.

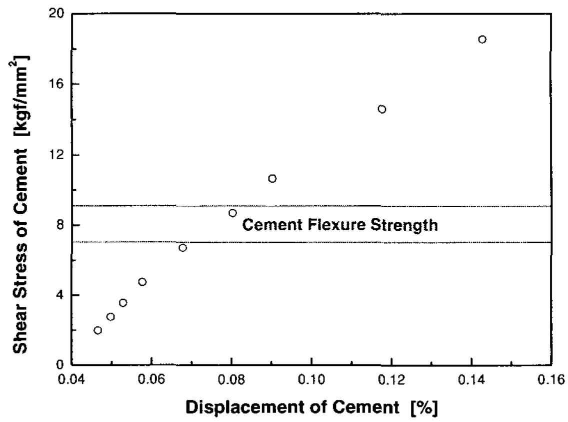

Fig. 7. The simulation result of the shear stress on cement with cement displacement.

In previous researches, there was no a calculation technique applying mechanical loading when the displacement happened in cement [2,5]. But in this study it was possible. Fig. 8 showed the shear stresses behavior on cement part with cement displacement in various mechanical loading conditions. The increase curves of shear stress were changed at 0.02% as a turning point with the increase of mechanical loading. When the amount of cement displacement was less below 0.02%, the shear stresses increased with the increase of mechanical loading, but when above 0.02% the shear stresses decreased reversely with the increase of mechanical loading. In 1/2 loading condition, the shear stress reached to 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 loading dispersed the stress happened by cement displacement.

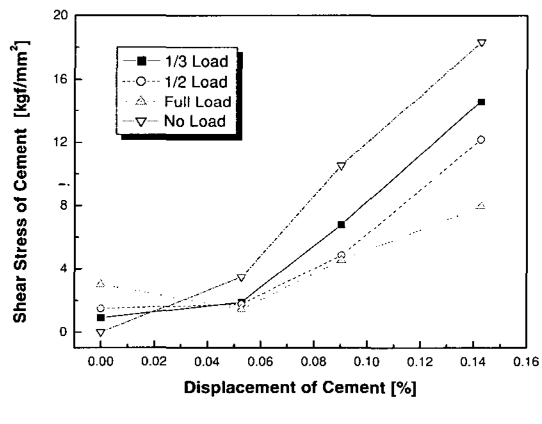

Fig. 8. The shear stresses behavior on cement with cement displacement in various mechanical loading conditions.

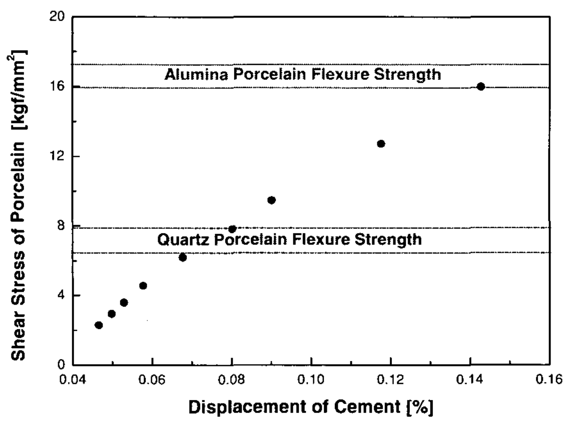

Fig. 9. The shear stresses on porcelain body with cement displacement.

Owning to the increase of displacement of cement, the part in which mechanical stresses concentrated was the head porcelain body. As shown in Fig. 9, the shear stresses on porcelain body increased with the increase of cement displacement, it was identical with the phenomena on cement. According simulation results, in the no-loading condition if the 0.08% displacement happened in cement, the shear stress on porcelain body was about 8 kgf/mm^2, which was 1/2 lower than the flexure strength of aluminous porcelain body (about 17 kgf/mm^2). But when the cement displacement was over of 0.14%, the shear stress on porcelain body reached at 16 kgf/mm^2, therefore in this time insulator will be fractured[6].

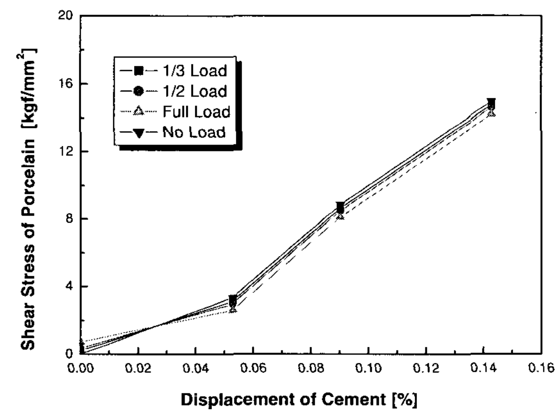

Fig. 10. The shear stresses on porcelain body with cement displacement in various mechanical loading conditions.

On other hand, in some difference of cement, even though the 1/2 or 1/3 of electro-mechanical loading acts, there was no large change of the maximum shear stress on porcelain body, as shown in Fig. 10. These results showed that there were enough margins to protect the fracture of porcelain body before the cement displacement was over 0.14%.

When there was no cement displacement, the shear stress distribution on porcelain body owing to the 1/2 electromechanical loading was shown in Fig. 11. Then the stress was distributed broadly in interface as a tensile stress type, and the compressive stress acted on top of pin. Then tensile and compressive stress value was very low. Comparing with the effect of cement displacement and mechanical loading on porcelain body, if the 0.02% cement displacement happened, then the mechanical stress strength on porcelain body was almost identical with the mechanical strength calculated in the condition of the 1/2 electromechanical loading without cement displacement.

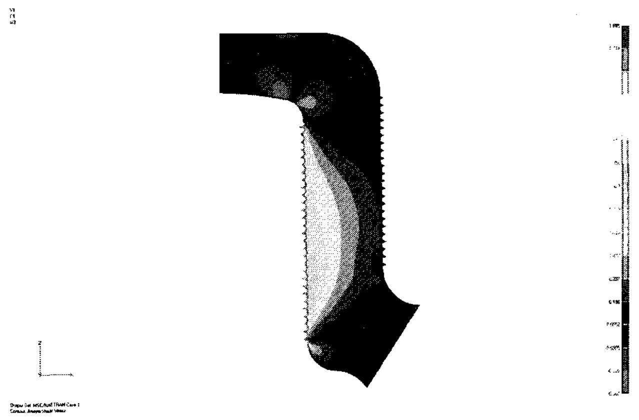

Fig. 11. The shear stress distribution on porcelain body (at 1/2 electromechanical loading without cement displacement without cement displacement).

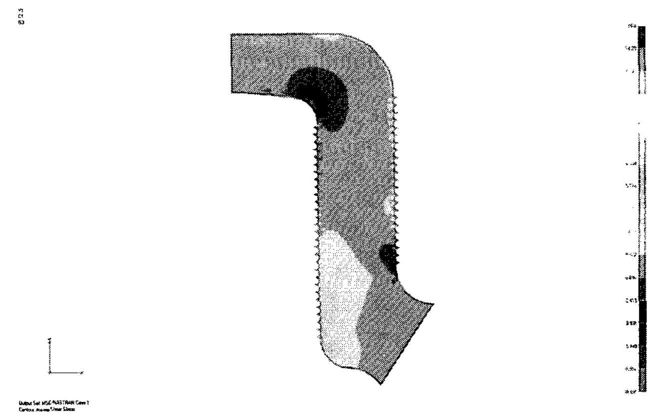

Fig. 12. The stresses distribution on porcelain body (at 0.1% displacement, 1/2 electromechanical loading).

Figure 12 showed that when there was cement displacement, the compressive and tensile stress distribution were some changed comparing to when there was no cement displacement. The concentration of tensile stress near interface was higher than the distribution in Fig.11, and the compressive stress distribution was also changed similarly. It could be seen that the cement displacement provided a concentration of stresses on porcelain body.

4. CONCLUSION

The experimental and simulation study of insulator failure by cement growth on suspended insulators (16,500kgf) for transmission line was discussed. To get more practical and analytic calculation results, the advanced program was used. This analysis tool was possible to calculate stress behaviors with mechanical loading when cement displacement happened. From simulation results, the cement displacement changed with linear according to temperature. The shear stress was about 7 kgf/mm^2 at 0.07% displacement provided from 200°C, then it could be seen that the cement would be fractured even if 0.07% displacement acted, because the cement had about 7-9 kgf/mm^2 flexure strength. The curve patterns of shear stress with the increase of mechanical loading were changed at 0.02% as a turning point, when the cement displacement was over 0.02% the shear stresses decreased reversely with the increase of mechanical loading. From analysis on porcelain body it was known that there were enough margin to protect the fracture of porcelain body before the cement displacement was over 0.12%, and the cement displacement could provide a concentration of stresses on porcelain body.

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

[4] 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.

[5] J. Bellerive, "Performance of porcelain insulator, forty years experiences at hydro quebec" CEA Paper, March, 1990.

[6] S. W. Han, H. G. Cho, and B. C. Woo, "A simulation on the displacement stress of cement in porcelain insulators for transmission", Proceeding of the KIEE ME Annual Autumn Conference 2002, Vol. 15, p. 476, 2002.