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# A Study on the Properties of 36,000lb Porcelain Insulators by Contained Alumina of Raw Materials

**In-Hyuk Choi† , Jang-Hyun Choi*, Yoon-Hwan Jung* and Dong-Il Lee***

**Abstract** - In order to analyze the properties of domestically produced 36,000lb porcelain insulators by change of the alumina addition to raw materials, 36000lb ball socket type suspension insulators that were manufactured in 1989, 1995 and 2001 were removed from transmission lines and an experiment was performed. The results indicated that 8 [wt.%] alumina, which influences the mechanical properties and arc resistance properties in the case of insulators that were manufactured in 1989 was contained, and the relative density and the fracture toughness of insulators appeared by 94.2% and 1.4 [Mpa·$M^{1/2}$], respectively. However, 12 [wt.%] alumina was contained in the case of insulators that were manufactured in 1995, and the relative density and the fracture toughness of insulators appeared preferably lower by 92% and 1.3 [Mpa·$M^{1/2}$], respectively. The greatest amount of alumina was contained by 17 [wt.%] in the case of insulators that were manufactured in 2001. It was confirmed that the electrical and mechanical characteristics such as the relative density and the fracture toughness appeared remarkably by 96% and 1.7 [Mpa · $m^{1/2}$], respectively.

**Keywords:** Alumina, Fracture toughness, Porcelain insulator, Relative density, Tanδ

## 1. Introduction

With the current high level of industrial technology, diversified studies to transmit power in a reliant and stable means are on track, including increasing power transmission capacity and raising voltage. Specifically, insulators are widely used as the major material connecting the transmission tower and transmission lines as well as supporting wires. Clay, feldspar, pottery stone and alumina are employed as the foremost types of raw materials for insulators [1]. Porcelain insulators are manufactured by mixing water and raw materials, ball milling, controlling the water content to make shaping easier, drying the formed shape by the jiggering method, and then sintering in the tunnel kiln at the high temperature of 1300℃ [2-5]. In the initial stages of the insulator industry, numerous problems were encountered, such as the breakage of insulators from transmission lines and earth faults from poor insulation due to faulty insulators, resulted from poor technology in mixing and sintering. Most of these problems have been solved with the advancement of the technology. Insulators for the transmission of 400 [kN] of high voltage, which is used for 765 [kV], can now be manufactured. However, accidents in the high voltage and large capacity transmission lines may cause even severer damage than before. Therefore, ensuring the reliability of the insulator is important. In order to maintain high reliability of the transmission line, tests are being conducted under more rigorous conditions than those specified in ANSI C29 or IEC 60383-1. The arc resistant test, which is conducted by generating the 72 [kA cycle] of arc current, has been adopted since 1995 and is considered to be the most strict test for insulators. This particular test requires the insulator to endure several thousand instant thermal shocks. Local insulator manufacturers have developed methods to control the creation of cristobalite, which is weak against thermal shock, by increasing the amount of alumina in order to manufacture an insulator that can endure the arc resistance. As shown in Figure 1, the manufactured insulator in 1995 had about a 0.25% accident rate on the transmission line, which is the highest. The accident rate on the manufactured insulators following 1996 was significantly decreased and has recently attained almost 0%.

In this study, the properties of insulators were measured by varying the amount of additive alumina, one of the main raw materials used in manufactured insulators, to determine the correlation between the accident rate of the insulator and the crystalline constituents. The cause of defection in insulators was also studied by varying the mixing and sintering. This was done to ensure that the technology will produce highly reliable insulators with

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excellent mechanical and electrical characteristics based on the data obtained from this study.

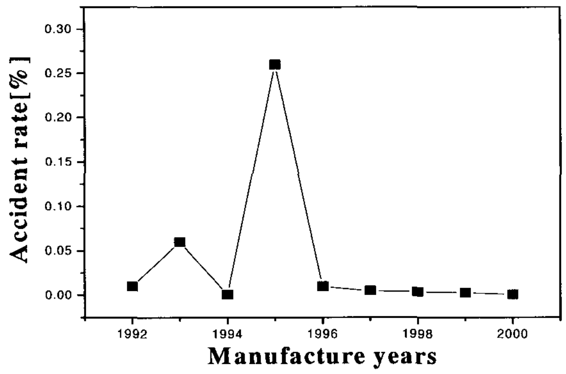



**Fig. 1** Accident distribution of insulator for transmission line on year of manufacture

## 2. Experiment Procedure

### 2.1 Sampling

In order to reflect the change of alumina content added to the porcelain, ball-socket type suspension insulators of 36000lb porcelain insulators manufactured in 1989, 1995, and 2001 were sampled from the local transmission line. The contents of alumina in the insulator by corresponding year are shown in Table 1.

**Table 1** Alumina addition quantity of insulators according to year of manufacture

| Year of manufacture | Alumina addition quantity |
|---|---|
| 1989 | 8 wt.% |
| 1995 | 12 wt.% |
| 2001 | 17 wt.% |

### 2.2 Methodology

The glaze applied on the insulator was ground out. The porcelain part was crushed into powder to analyze its chemical content using philips` x-ray fluorescence (XRF). The crystal of the same powder was analyzed using philips` x-ray diffraction (XRD) at 2°/min scanning speed. In order to evaluate the fine structure of the porcelain, part of it was cut and mounted, and then the surface was ground to observe the size and shape of the pores using a scanning electron microscope (SEM, manufactured by R.J. Lee). A specimen with the size 0.5 x 0.5 x 5 [$cm^3$] was formed to measure the linear thermal expansion of the porcelain at 650℃ using a dilatometer (Tokyo Ind.). The sintered density was measured through the Archimedes' method according to the ASTM C20. In order to measure the hardness and fracture toughness, the specimen was ground with 15, 9, 6, 3, and 1 [㎛] diamond pastes. The hardness (Hv) was then measured using a vickers hardness tester (Mitutoyo, Japan). The fracture toughness ($K_{IC}$) was obtained by measuring the indentation crack length (ICL) at 136° with the vickers indenter (Mitutoyo, Japan) [6]. In this experiment, 10 [kg] of load and 10 [sec] of hold time were applied, and the hardness and fracture toughness were calculated using the following equation.

$$H = \frac{F}{2a^2} \quad (1)$$

$$K_{IC} = 0.032H\sqrt{a}\left(\frac{E}{H}\right)^{(1/2)}\left(\frac{c}{a}\right)^{(-2/3)} \quad (2)$$

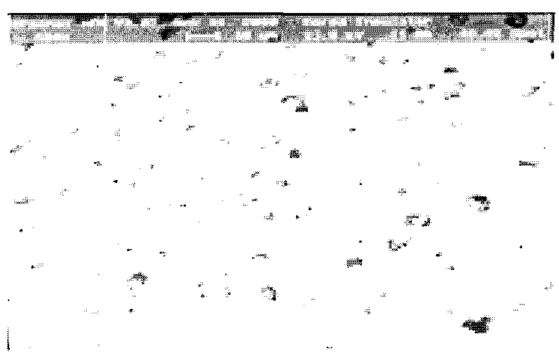
F: Load
a: Length in diagonal of vickers indent
c: Crack length
E: Young`s modulus
H: Hardness
$K_{IC}$: Fracture toughness

Tanδ, an electrical characteristic, was measured using dielectric analyzer DEA-2970 (TA instruments, USA). The voltage applied to the specimen was 5 [V]. Conducting the test inside the glass vacuum tube minimized the exterior influence to the specimen. The exact thickness of the specimen used, which was 1~2 [mm], was measured and calculated automatically. The size of the specimen was 2 ~25 [cm]. The specimen was of rectangular shape and was formed according to the size of the main electrode.

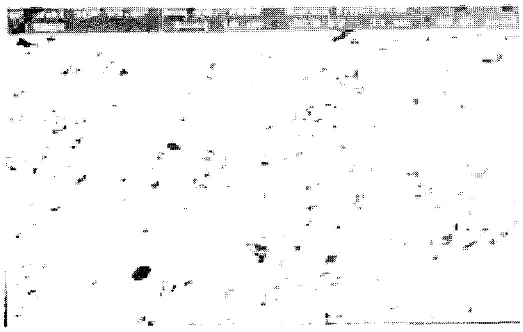
## 3. Results and Discussion

### 3.1 Structure analysis using SEM

The size and shape of pores created during sintering is one of the important factors that affect the physical



(a) 1989



(b) 1995

(c) 2001

**Fig. 2** SEM image of porcelain insulators

characteristics of the insulator. They were observed through SEM. Figure 2 presents images of fine structures of insulators produced in 1989, 1995, and 2001. It was confirmed that the insulator produced in 1989 had significantly fewer pores than the insulator produced in 2001. This means that the insulator produced in 2001 had more sintering density than the insulator produced in 1995 due to developments in the manufacturing technology, and therefore it has superior mechanical characteristics [7, 8].

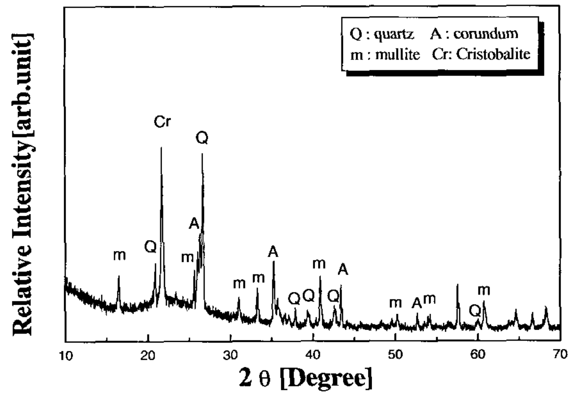
## 3.2 Chemical components analysis

According to the data measured using x-ray fluorescence, the amounts of silica and alumina, which give significant influence on the mechanical and electrical characteristics of the insulator, varied most. The $SiO_2$ content was reduced from 68.45 [wt.%] (1989) to 59.63 [wt.%] (2001). The alumina content, which improves mechanical and thermal shock characteristics, was gradually increased[9, 10].

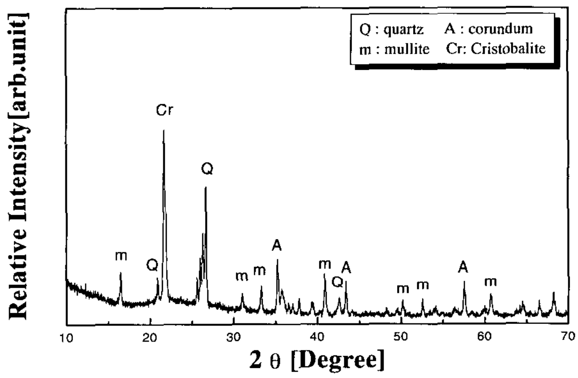
**Table 2** X-ray fluorescence results of insulators

| | 89(wt.%) | 95(wt.%) | 01(wt.%) |
|---|---|---|---|
| $SiO_2$ | 67.10 | 64.15 | 59.88 |
| $Al_2O_3$ | 27.53 | 30.24 | 34.80 |
| CaO | 0.93 | 0.75 | 0.24 |
| MgO | 0.22 | 0.25 | 1.07 |
| $Fe_2O_3$ | 1.00 | 0.81 | 0.28 |
| $TiO_2$ | 0.53 | 0.45 | 0.20 |
| $Na_2O$ | 1.76 | 1.54 | 1.78 |
| $K_2O$ | 0.93 | 1.81 | 1.74 |

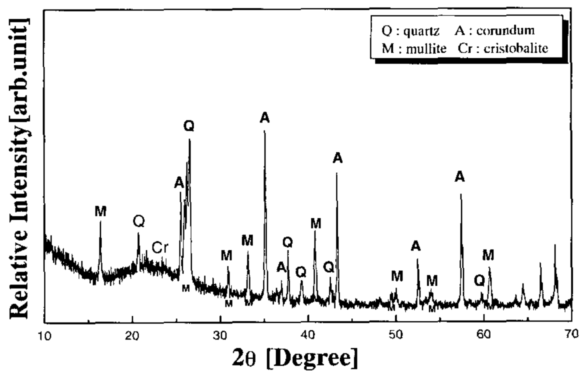
Traces of alkali metals such as Fe, Na, and K, which can affect the conductivity, are included in the insulator. However, the containing iron was significantly decreased on an annual basis due to developments in the refining technology. The chemical content data, measured using x-ray fluorescence, are given in Table 2. The crystal and crystal amount of the porcelain, analyzed using x-ray diffraction, are shown in Fig. 3.




(a) The insulator produced in 1989




(b) The insulator produced in 1995




(c) The insulator produced in 2001

**Fig. 3** X-ray diffraction results of insulators

Crystals such as mullite ($3Al_2O_3$ $2SiO_2$), quartz ($SiO_2$), cristobalite ($SiO_2$), and corundum ($Al_2O_3$) were observed. Such crystals can give significant effects to the electrical and mechanical characteristics of the insulator. Cristobalite crystal, which is weak against thermal shock, was found in the insulators produced in 1989 and 1995, but there was almost none found in the insulators produced in 2001. The increased amount of alumina (8 [wt.%] in 1989, 12 [wt.%] in 1995, 17 [wt.%] in 2001) activated the production of mullite through chemical reaction with the $SiO_2$ crystal, resulting in restriction of the cristobalite crystal. Table 3 shows the amount of crystals analyzed using x-ray diffraction.

**Table 3** X-ray diffraction results of various materials

| | 1989 | 1995 | 2001 |
|---|---|---|---|
| Mullite (%) | 12.7 | 17.11 | 11.89 |
| Quartz (%) | 5.46 | 3.72 | 3.3 |
| Cristobalite (%) | 4.0 | 5.74 | 0.5 |
| Corundum (%) | 8.10 | 9.08 | 16.4 |

The insulator produced in 2001 had a higher amount of alumina than the insulator produced in 1989. This resulted in an increased amount of corundum crystal, which improves arc resistance and impact resistance, and a decreased amount of cristobalite, which is weak against thermal impact. However, in case of the insulators produced in 1995, the alumina content was increased. Some of the $SiO_2$ reacted with alumina to form mullite while some reacted and produced cristobalite. A specimen was prepared to measure the linear thermal expansion depending on the amount of cristobalite. The linear thermal expansion was measured at 650℃ using a dilatometer in Table 4.

**Table 4** Coefficient of thermal expansion results of insulators using a dilatometer in 650℃

| | 1989 | 1995 | 2001 |
|---|---|---|---|
| Coefficient of thermal expansion ($\times 10^{-6}$/K) | 5.540 | 5.683 | 5.143 |
| Rate of thermal expansion (%) | 0.349 | 0.358 | 0.324 |

The linear thermal expansion was highest in the insulator produced in 1995 since it contained much cristobalite, which has high linear thermal expansion.

### 3.3 Mechanical Characteristics

Fig. 4 shows the relative density of insulators produced in 1989, 1995, and 2001. The porcelain produced in 1995 had about 1 ~ 1.5% lower relative density than the theoretical density of porcelains produced in 1989 and 2001. On the other hand, the relative density of porcelain produced in 2001 was very high. Therefore, the suspension insulator produced in 1995 is considered to have fewer mechanical and electrical characteristics due to its lower sintering density compared with the insulators produced in 1989 and 2001. The arc resistant test was added to the performance tests for insulators, thus the alumina content was increased to incorporate this test result in order to produce porcelain that is strong against arc resistance. However, the sintering density was decreased due to technical problems such as the sintering condition.

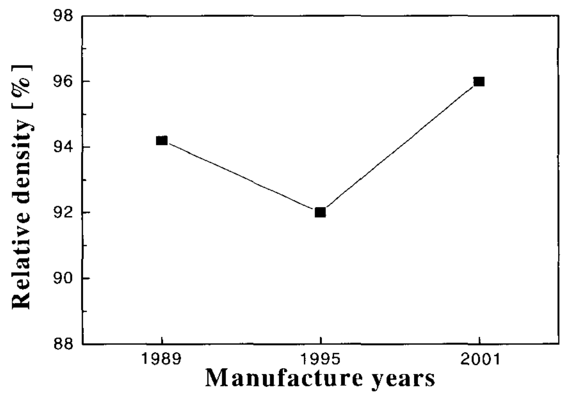



**Fig. 4** Relative density of porcelain insulators

As it can be seen in the photos obtained by SEM (Figure 2), the porcelain produced in 2001 had more pores than those produced in 1995. Therefore, the insulator produced in 1995 generally had about 10% lower mechanical characteristics as shown in Table 5.

**Table 5** Results of hardness, modulus of elasticity, and fracture toughness

| | 1989 | 1995 | 2001 |
|---|---|---|---|
| Absolute density [g/㎤] | 2.27 | 2.38 | 2.54 |
| Modulus of elasticity [GPa] | 81.6 | 73.9 | 96.2 |
| Hardness ($H_V$) [GPa] | 5.8 | 6.9 | 6.9 |
| Fracture toughness ($K_{IC}$) [$Mpa \cdot m^{1/2}$] | 1.4 | 1.3 | 1.7 |

### 3.4 Tanδ Characteristics

Tanδ was measured to analyze the electrical characteristics of insulators by year of production according to the variations of raw materials. Figure 5 demonstrates the tanδ depending on the temperature variation at 60 [Hz] of power frequency. In accordance with the density and the SEM data, tanδ of the insulator produced in 1989 and 1995, which had lower density and much more pores, was affected greatly by temperature variation. Especially, in the case of the insulator manufactured in 1995, tanδ values confirmed remarkably high results. However, the insulator produced in 2001 demonstrated very stable tanδ values. Therefore, it is considered that the insulator produced in 2001 had better long-term aging characteristics than those produced in 1989 and 1995.

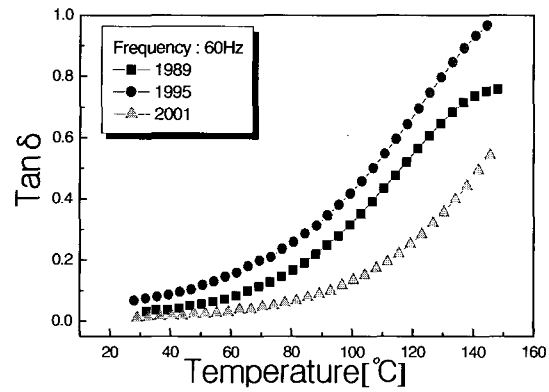



**Fig. 5** Dependence upon temperature of tanδ

## 5. Conclusion

The insulators used for transmission lines were classified by year of production according to the variations of raw materials and the crystals to analyze their chemical and physical characteristics. The following provides a summary of the results.

(1) For the insulators produced in 1995, the alumina content was increased in order to develop the porcelain that could endure the arc resistance test. However, due to the problems in the sintering condition, cristobalite crystal was formed and the sintering density was decreased. This resulted in about a 5% deterioration of physical characteristics compared with those produced in 1989.

(2) For the insulators produced in 2001, the amount of $SiO_2$ was decreased and the amount of $Al_2O_3$ increased in order to prevent production of cristobalite crystal. This lowered the linear thermal expansion of porcelain and increased the thermal shock characteristics.

(3) The insulator produced in 2001 showed about a 10% increase in mechanical characteristics compared with those produced in 1989 and 1995.

(4) According to the tanδ data obtained, the density or number of pores of the insulator, determined by the sintering condition, gave greater influence over the electrical characteristics of insulators than the characteristics depending on the aluminum content.

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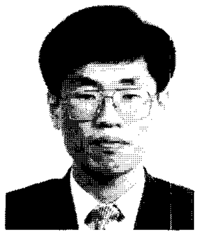

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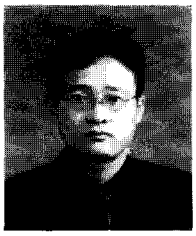

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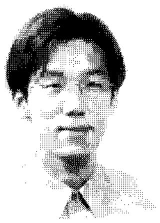

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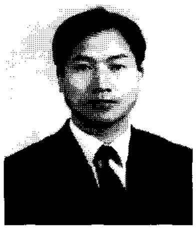

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