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A Study on the Insulation Breakdown of Mica-Epoxy Composites

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Mica-Epoxy 복합재료의 절연파괴에 관한 연구

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Abstract In large generators in power plants, stator winding insulation is exposed to a combination of thermal, electrical, mechanical, environmental stresses in service. These combined stresses cause insulation aging which leads to final insulation breakdown. In order to identify the breakdown mechanism, the stator winding insulation materials which are composed of mica-epoxy is analyzed by the component of materials with EDS, SEM techniques. We concluded that the potassium ions of mica are replaced by hydrogen ions at boundary area of mica-epoxy and/or mica-mica. It is proposed that through these phenomena, the conductive layers of potassium ions enable high voltage fields or multiple stresses to create voids and microcracks.
Keywords : Generator Stator Winding, Breakdown Mechanism, Mica-epoxy Material, Hydrogen Effect, Potassium Ion.

1. Introduction

Over the past few decades, one of the more preponderant and unresolved questions in the area of stator winding insulation has focused on the creation of voids and microcracks and, in particular, as to whether or not they implicated in the aging process of mica-epoxy materials under normal operation conditions. In large generators and motors in power plants, stator winding insulation is exposed to a combination of thermal, electrical, vibrational, thermo-mechanical and environmental stresses during service operation. In the long term, the multi-stresses cause an aging which leads to final insulation breakdown. For the reason, it is important to estimate the remaining insulation integrity of the winding after a period of service time. Previous studies have utilized non-destructive values such as insulation resistance, polarization index, dielectric dissipation factor and partial discharge to diagnose an insulation condition and the relationship of these values and breakdown voltage have proposed new life factors by way of a comparison of model bars and the stator windings of an operating generator[2]. However, according to the types of insulation material and test conditions, opposite opinions existed, too[3]. At present, although vacuum impregnation and resin rich mica-epoxy stator insulation has been employed in high voltage generators in order to resist degradation due to partial discharge, voids inclusion which are usually introduced during the various manufacturing steps associated with the formation of the insulation structure are inevitable. Also, it is proposed in this paper that through these phenomena, the conductive layers of potassium ions enable high voltage fields or multiple stresses to create voids and microcracks. In particular, the creation process of potassium layers due to the substitution of hydrogen ions and voids due to high electric field or atomic radius difference is identified by SEM, EDS techniques.

2. Experimental System

The stator winding studies in this paper is used in the water-cooled generator of 500MVA, 22kV. To test the insulation breakdown of material by accelerated aging, an end winding has been manufactured with straight line type as shown in Fig. 2-1(a). Fig. 2-1(b) shows the front view of stator winding.

Also, to compare electric aging test of stator winding in hydrogen with electric aging test of stator winding in air, a pressure hydrogen apparatus which can measure electric aging of stator winding under pressure hydrogen is manufactured and applied to 420Hz, 27.5kV/mm voltage a stator winding. The bushing of 77kV is installed at upper part of a pressure hydrogen apparatus. As shown in Fig. 2-1(a)(b), specimens are

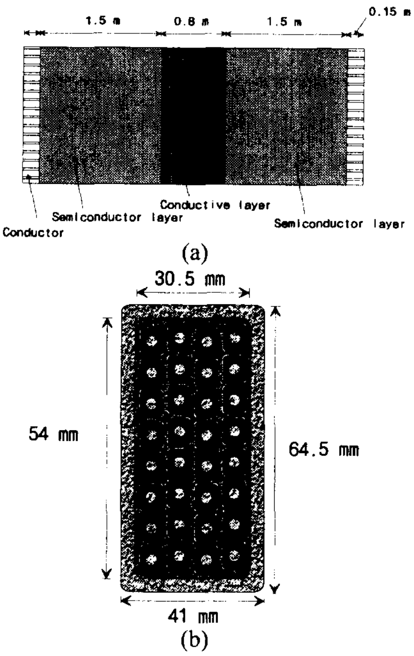

Fig. 2-1. The dimensions of stator winding used by testing

made as follows:

1. The stator winding(30.75 × 54mm) with a strand (4.27 × 7.14mm) is wound mica-epoxy tape, 1/2 folds and 14 wind.
2. It is inserted in tank and hardened at 130℃.
3. A conductive bonding material is spread.
4. After a glass tape is wound, it is dried more than 8 hours in air.

A low resistance painting is applied on the straight line part of a stator winding and a high resistance painting is applied on the arm part. The final dimension of stator winding is 41 × 64.5mm. A general method to age electrically is to heighten the voltage. And the typical insulation of a stator winding is designed to operate between 2kV/mm~3kV/mm. In accelerated aging specimen with voltage above 6kV/mm, aging is progressing abnormally, so it is tested with a limit value of 5.5kV/mm, which does not generate partial discharge[5]. JSM-6400 Model, SEM is manufactured by Jeol Co. has been used and equipped with EDS, 6209 Model from Oxford Co.

3. Results and Discussions

3-1 The analysis of mica crystal structure

The chemical structure of mica crystal is analyzed the breakdown mechanism of stator winding which is composed of mica-epoxy. It is assumed the cause of insulation breakdown by way of identification by SEM technique. Fig. 3-1 shows that the crystal structure of micas and pyrophillites. In this structure, they are sheets both above and below a central layer. Isomorphous substitution of cations is common, with , sometimes substituting for some of the ions in the tetrahedral network and , , and others substituting for one another in the octahedral network. These are isomorphous substitutions lead to a net negative charge under structure. This negative change is balanced in the mica structure by potassium ions which occupy positions between the large open cavities in the sheets. The potassium ions occupy large holes between twelve oxygen atoms so that the K-O electrostatic bond strength is only one-twelfth. These bonds are easily broken and the mica's accordingly possess very perfect cleavage parallel to the layers[6,7]. Fig. 3-2 show the boundary of mica epoxy and the distribution of potassium layers in boundary area. It can be assumed that the potassium layers are substituted by, ions and then accumulated at the boundary area of mica-epoxy.

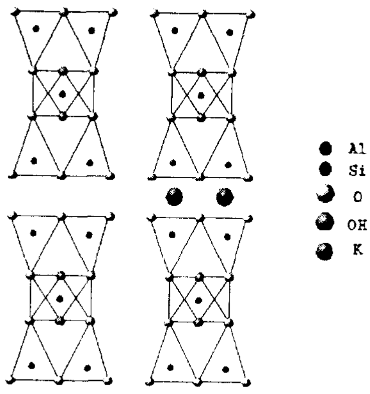

Fig. 3-1. The structure of pyrophyllite and muscovite with layer structures

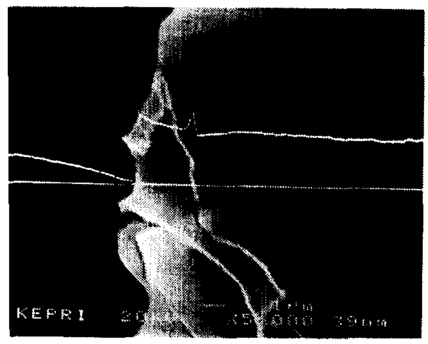

Fig. 3-2. The components analysis of potassium(K) layers inside mica-epoxy material

On components made of mica, a potassium ion of big atomic radius is replaced by hydrogen ion of small atomic radius. The voids are created by the difference of radius progressed by combined stresses.

Metal ions such as potassium which can be replaced by hydrogen in metal layers, is formed at the interface parts of mica-mica and mica-epoxy because these con-

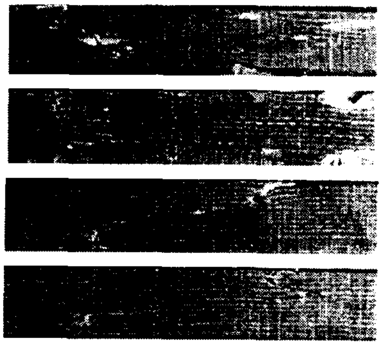

Fig. 3-3 The breakdown model of stator winding materials in air by optical microscope

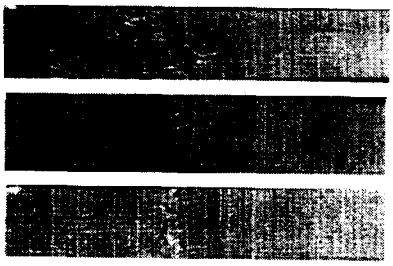

Fig. 3-4 The breakdown model of stator winding materials in hydrogen by optical microscope

ductive layers are progressed with the connection as time goes by. The tree is generated by the effects of localized high electric field which is created in the adjacent area of conductive layers.

3-2 The fracture models of mica-epoxy material

The breakdown mechanism of insulation material under normal operation condition initiates due to the presence of voids which are filled with gas. It can be assumed that the energy which is accepted from applied electric field acts as the converter which is transformed mechanical, and thermal energy in insulation material. These conversion mechanisms include the insulation breakdown due to partial discharge happening to poor parts of gas layers relatively in voids with the generation of electron and ion.

The ionized particles acting in insulation material propagate with the formation of tree channel toward a surface by corrosions for the diffusion process in material and then the insulation breakdown is generated. As based on the analysis of the surface of insulation material, insulation layers, fracture parts by SEM and EDS techniques, we can consider the breakdown process of composite material as follows: The isolated defects generated by mechanical stress are connected with each other, grown up and exceeded the allowable material strength. Then, the growth of defects can occurr due to mechanical fracture. In addition to application electrical stress simultaneously, the insulation breakdown due to a treeing is generated and then mechanical fracture occurs. That is why applied voltage is increased by low permitivity of defect areas and breakdown voltage in defects is decreased. After all, big partial discharge is often generated by growth of defects and the trees are changed abnormally by local distorted electric field. In the early stages, isolated delaminations are mainly is distributed over the interface area of epoxy-mica and/or mica-mica. If the repetition number of multi-stress is increased, a tree channel is propagated by way of small delamination of the layers and cracks are formed until the tip of the tree channel reaches the middle of the insulation layer. Furthermore, if the high electric field is applied to these delamination and crack parts, partial discharges are generated and tree is being progressed continuously[10,11].

Mica flake, fiber glass debris and by-products from the epoxy generated by partial discharge form a conductive tree channel wall, which present the alleviating effects of partial discharge intensity the tree channel is steadily propagated in an axial direction as shown in Fig. 3-3. When the tip of such a tree channel reaches the middle of the insulation, a large area of delamination(approximately 4-5Cm) occurs at this central position(Fig. 3-3). A tree channel initiates again at the delamination site as described above, producing small areas of delamination until breakdown ensues. The number of discharge initiation sites depends on the level of electric stress at the edge of the electrode in epoxy-mica insulation. Such stress concentration regions are presented to interface sites of the half-lapped mica tape adjacent to the edge of the electrode. The life for such an insulation structure is expected to be shortened because, after partial discharge is initiated at the interface site of the void layers, a tree channel can be propagated easily through the void layers to the outer insulation by the delimitation mechanism previously defined. With these alleviating effects, the creation of an ionized gas which is generated by continuous partial discharge and the extinction by the diffusion inside epoxy-mica system are repeated and partial discharge according to patchen's law is repeated a creation and a extinction. The other type of breakdown process way is described as follows. The fracture mechanism which occurs around the middle of the groundwall insulation is the same as in a previous model. But it shall be assumed that the insulation breakdown model for the delamination occurring around the middle of mica-epoxy system is linked to cracks which are formed at the other area as shown in Fig. 3-3. It is observed that the expected fracture model is identified to the fracture by fatigue of an aged specimen under air atmosphere observed by optical microscope. Fig. 3-4 shows the aged specimens under hydrogen atmosphere by optical microscope. It is confirmed that local small voids are distributed to all the area of insulation materials in terms of the effects of hydrogen ions and delaminations generated by heat created when epoxy resin is hardened, are linked together. It is observed that the fracture aspects appeared to be straight.

4. Conclusions

In order to identify the cause of insulation breakdown of the mica-epoxy composites which is used in the large generator stator winding, an intensive research has been carried out from the analysis of materials. It can be concluded as follows :

i) On components made of mica, a potassium ions that atomic radius is big, is substituted by hydrogen ions that atomic radius is small. By way of this substitution, the creation of voids is caused by the difference of these radii and they are progressed by combined stresses.

ii) In case of air atmosphere, the two models failed by the progress of the tree generated by continuous partial discharge in voids and mechanical stresses applied to defects has been observed. In case of hydrogen atmosphere, it has been observed that model failed by hydrogen and potassium ions appeared to be straight.

iii) The breakdown mechanism of stator winding insulation materials which are composed of mica-epoxy, has been studied by SEM and EDS techniques. The experimental results have shown that the potassium ions of mica are substituted by hydrogen ions at boundary area of mica-epoxy and/or mica-mica. Through these phenomena, it has been proposed that the conductive layers made of potassium enable the voids to form and the cracks to create by high electric field.

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