An Assessment on Brittle fracture of Composite Insulators' Rods and Factors
Improving Their Properties

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SUMMARY

Different mechanisms of brittle fracture of composite insulator's rods, manufactured by pultrusion process with a given percentage of fiberglass (70-75% by weight) has been investigated in this research. The epoxy-fiberglass composites made in this way show high tensile strengths under normal conditions, but they are sensitive to environmental factors while under electrical and mechanical stresses, and thus corrosive environments, temperature and stress can affect their properties with time. This is due to the fact that the composite consists of a large number of fiber-resin interfaces. Occurrence of failure in any of these interfaces will lead to the diffusion of moisture which in turn will be condensed to water. Therefore, assuming that the rod will be in direct contact with water in service, a series of Dumbbell shaped samples were obtained from the rod according to the standard the samples were then placed under tensile load (10% SML), in a special water reservoir provided to stimulate the exact service environment, for different periods of time (3 to 120 hours).

The tensile properties of the samples were then tested. Afterwards, the samples were subjected to scanning electron microscopy (SEM) and it was observed that cracks which were initiated in the fibers on the surface of the rod, later propagated inside the rod. After a crack has been initiated in a fiber, it will pass the fiber-resin-fiber path, depending on the fiber percentage in composite. From the results of SEM analysis it can be seen that the ions leach out as the crack propagates through the rod, hence the crack propagation mechanism is "Ion Exchange." It can be concluded from the results that the following factors greatly influence the brittle fracture of the rod: Type and chemical composition of resin and the fiberglass used, and fiber weight percentage in the rod. Thus by changing the chemical composition of fibers and also by increasing the fiber-resin compatibility, the long-term tensile properties of the rod can be significantly improved.
Recherche sur la Fracture Tendre des tringles (Noyaux) de l’Isolateur en Composite et les Facteurs Efficaces pour l’Amélioration de ses Propriétés

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Cle du mot: Noyau, pultrusion, fracture tendre, tension de corrosion, solide mécanique

RESUME

Dans cette recherche les différents mécanismes en fracture tendre de l’isolateur en composite ont été vérifiés par la voie du procédé de pultrusion avec le pourcentage de poids de 70-75 des fibres de verre. Les composites de la résine Epoxy - les fibres de verre fabriquées par cette méthode ont une haute solidité de tension dans les milieux ordinaires. Mais contre les facteurs atmosphériques sous les tensions électriques et mécaniques ils sont le plus sensible et par conséquent, en passant le temps, ils seront brisés sous l’influence des facteurs tels que:

Les milieux d’érosion, la chaleur et la tension.

Cet est la base de fracture tendre des composites avec un haut pourcentage de la limite commune de la fibre et de la résine et si la fracture est leu dans cette limite, l’humidité penetre dans cet endroit et avec l’augmentation de l’humidité, cette dernière sera reduite en eau. Nous supposons donc que le tringle (noyau) lors de fonctionnement est en contact avec l’eau. Dans ce but, une serie des echantillons (sous forme de petit haltere) ont été construits conformément ou standard des tringles (noyaux) composites et furent installées sous la charge (%10 SML) dans un milieu aqueux special pour produire les conditions du service dans les différents temps 5-120 heures.

Les proprietes de tension des echantillons furent mesurees apres le test. Puis les echantillons furent verifiees par un Microscope electronique (SEM) et nous avons vu que les fissures dans les fibres de verre ont été formées sur le plan du tringle (noyau) composite et puis elles penetreront a l’interieur du tringle (noyau).

Apres traverser d’une fissure d’une fibre, elle entre sur le parcours de fibre-resine-fibre et ce parcours depend de pourcentage de fibre en composite. Les resultats obtenus de l’analyse de (SEM) montrent le déplacement ionique et cela causera le déploiement de la fissure dans le tringle (noyau) et pourtant le mécanisme de la croissance de fissure est le changement ionique.

Les resultats du travail montrent qu’il y a beaucoup de facteurs pour le fracture tendre du tringle (noyau) tels que: le genre et la composition chimique de la resine et des fibres usés pour produire le tringle (noyau) ainsi que le pourcentage du poids de la fibre employée pour le tringle (noyau).

Par consequent, le changement de compositions chimiques de la fibre ainsi que l’augmentation de compatibilité de fibre et de résine peuvent avoir un grand role pour l’amélioration des propriétés de la tension du tringle (noyau) pour une lonuge duree.
AN ASSESSMENT ON BRITTLE FRACTURE OF COMPOSITE INSULATORS' RODS AND FACTORS IMPROVING THEIR PROPERTIES

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ABSTRACT

Different mechanisms of brittle fracture of composite insulator's rod, manufactured by pultrusion process with a given percentage of fiberglass (70-75% by weight), have been investigated in this research. The epoxy-fiberglass composite made in this way show high tensile strengths under normal conditions, but they are sensitive to environmental factors while under electrical and mechanical stresses, and thus corrosive environments, temperature and stress can affect their properties with time. This is due to the fact that the composite consists of a large number of fiber-resin interfaces. The occurrence of failure in any of these interfaces will lead to the diffusion of moisture which in turn will be condensed to water.

It can be concluded from the results that the following factors greatly influence the brittle fracture of the rod: type and chemical composition of resin and the fiberglass used, and fiber weight percentage in the rod. Thus by changing the chemical composition of fibers and also by increasing the fiber-resin compatibility, the long-term tensile properties of the rod can be significantly improved.

INTRODUCTION

Composite insulator's rods manufactured by the Pultrusion Process, have a high tensile strength in normal environments. However, while under electrical and mechanical stresses these rods are susceptible to environmental factors and under conditions where corrosive environments, stress and temperature are applied, the rods are in time prone to fracture. The fracture can take place at stresses as low as 20% of their theoretical strength [1].

Various parameters affect the brittle fracture of composite insulators. The occurrence of fracture via stress corrosion mechanism is one of the main reasons of this phenomenon in composite insulators, in which a crack initiates and propagates with the help of the existing chemicals [2]. There is a period of concealment for crack formation which depends upon the amount of applied stress rather than the chemical's concentration. Figure (1) is a schematic display of crack formation in the rod.

Stress corrosion mechanism in the rod is mainly that of ion exchange [3,4]. This is exclusively related to fiber composition. Since fiber glass has a low resistance to organic and inorganic acids, small H⁺ ions of the acids replace the cations in the fiber and cause a tensile stress [5].

The stress produced in this way along with the tensile stress applied in service, leads to initiation and then propagation of the crack. The cracks formed on the surface will then continue to propagate inside the rod. Before penetrating into the rod, the crack spreads over the surface. The location of these cracks on the surface, depends on fiber length and the bond strength between fiber and the polymer matrix, when a crack has passed a fiber, it may move to another fiber or take the fiber-resin-fiber path, depending on fiber volume fraction in the rod. If the crack reaches the resin from a fiber, the acidic ions are usually transferred to the next fiber by the diffusion mechanism and the crack propagation continues. When the crack has penetrated as deep as 2/3 of the rod diameter, fracture occurs.

It is therefore the aim of this paper to investigate the stress corrosion mechanism in the rod. First a rod, 10mm in diameter, was pultruded. E-glass fibers were used in the rod. The composition of the glass fibers used has been determined by Wet Chemical Analysis. The weight fraction of fibers in the rod is 72%, which indicates that most fibers are in contact with each other. Pictures taken under a microscope show rich resin phases in the rod, one such picture taken from the rod is shown in figure (2).

In the next step, tensile tests were conducted on several samples. Figure (3) gives a schematic display of the equipment used. The stress corrosion mechanism was investigated by conducting tensile tests on the samples in seawater.

The use of seawater will simulate the harsh service conditions. Table (1) gives the chemical analysis of the seawater used in corrosion tests.
Table 1 - Seawater analysis (mg/lit)

<table>
<thead>
<tr>
<th>Na⁺</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>Cl⁻</th>
<th>SO₄²⁻</th>
<th>HC O⁻</th>
<th>K⁺</th>
<th>NO₃⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.32</td>
<td>5.04</td>
<td>1.433</td>
<td>1.9683</td>
<td>2.06</td>
<td>1.34</td>
<td>2.41</td>
<td>0.046</td>
</tr>
</tbody>
</table>

In order to make the samples, several rods were cut to the length of 150 mm, and were then machined to form dumbbells. A rectangular container, with the dimensions given in figure (3), was prepared and the samples were clamped from one side to the edge of the container. From the other side, a weight was attached to the sample (equal to 20% of the rods tensile strength) so that the samples were under tensile stress during the whole course of the experiment. The clamps were protected from seawater by a 1etlon coating. The samples were tested for 3, 24, 48, 72, 96 and 120 hours. The strength versus time graph was drawn for each sample. Finally a microscopic view of the sample’s cross section was provided by SEM.

RESULTS AND DISCUSSIONS

The stress corrosion mechanism was investigated using seawater. In order to enhance the corrosive conditions, small amounts of acid were added to the water, so that the pH of the solution was in the acidic range. Since the stress corrosion mechanism is that of ion exchange, it is possible that the H⁺ ions replace the cations in the fibers. Cracks were observed on this surface, having the length of 3-4 fibers. In those samples that have been under the test conditions for more than 96 hours the cracks have penetrated deep within the rod. It was observed that these cracks have penetrated as deep as 150 fiber diameters (3 mm). Figure (4) displays the strength versus time. It can be seen that an increase in time, will lead to a decrease in strength. This can be explained by the ion exchange mechanism as a result of which the small H⁺ ions substitute the cations in the fiber composition and cause a tensile stress. This stress accompanied by the applied tensile stress will lead to crack propagation. With more cations being replaced in the fibers.

The crack propagation mechanism continues. X-ray experiments showed that the amount of calcium and aluminum ions is less in the crack path. Figure (5) is the change in Al³⁺ and Ca²⁺ peaks versus time in the EDX test. It can be concluded that the H⁺ ions selectively replace calcium and aluminum ions. It can be inferred that with the same mechanism, H⁺ ions may replace the sodium ions in the fiber, but since their concentration in the fiber is low, it is not possible to detect their reduction with the existing equipment.

Also due to the fact that Ca²⁺ and Al³⁺ ions act as networking agents in the fiber, their replacement has a much severe effect in fiber network destruction and thus in crack propagation.

When the crack has passed through the width of a fiber, it can take one of the two paths possible, based on fiber volume fraction. The crack may move from a fiber to another or it may take the fiber-resin - fiber path. If the crack reaches the resin from a fiber, two cases are predictable. In one case the resin remains intact and the acid reaches the second fiber by diffusion mechanism, resin bridges are formed in this case.

In the second case the resin itself is cracked and the crack will continue to the next fiber. It can be seen that in this case the crack has propagated in the next fiber before any fracture has taken place in the resin. In other words the diffusion factor of the acidic ions in the resin is high and therefore no chemical reaction occurs between the acid and the resin, and acid transfer from resin to fiber is mainly through diffusion.

CONCLUSION

1. One of the main factors influencing the brittle fracture phenomena in the composite rod of the insulators is the stress corrosion that takes place in the rod, by the ion-exchange mechanism.
2. The cracks are first spread on the surface and if the conditions are right (i.e. stress and acidic environment), they move deep down the rod, so that in the first stages of the test, only surface cracks are observed.
3. It was observed that the emission of calcium and aluminum ions from the fiber network, leads to crack propagation. This can be explained by the fact that these ions act as networking agents in the fiber.
4. Crack propagation from a fiber to another is mainly through diffusion from the resin layer. In the final stages of crack propagation, fracture occurs within the resin.

It seems that the application of ECR glass fibers is inevitable in long life composite insulators.

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REFERENCE


Fig 1- Schematic display of crack formation in the rod

Fig 2- SEM image show rich resin phases in the rod with magnifications of (a) x1000 (b) x200
Fig 3 - Schematic display of equipment used in corrosion test

Fig 4 - Diagram of the strength versus time

Fig 5 - The variation $\text{Al}^{3+}$ and $\text{Ca}^{2+}$ concentration versus time in the EDX test