論 文
34～11～3

폴리에틸렌 내에서 워터트리가 확산하는데 염용액이 미치는 영향

An Effect of the Salt Solution on the Water Tree Propagation in Polyethylene

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요 약

염용액이 워터트리 확산에 미치는 영향을 물에 포함된 염의 농도에 따라 조직적으로 실험을 통하여 보여주고 있다.

이 연구를 토대로 하여 워터트리의 확산은 아마도 염용액의 전기화학적 혹은 화학적 액션의 영향과 관련되어 있지 않나 하는 것을 제의할 수 있는데, 이러한 영향의 정도의 차이는 트리의 크기의 정도에 관련되어 있는 것 같이 생각된다. 또한 이 연구는 전기적 스트레스를 받은 상태에서 워터트리의 구조를 연구할 필요가 있다고 지적하고 있다.

Abstract

An effect of the salt solution on the Water Tree Propagation was shown systematically from the actions of the salt concentration in deionized water.

It may be able to suggest that the tree propagation is possibly to be connected with an intervention of the electrochemical or chemical actions of the salt solution on water tree propagation, which may likely depend on the growth level of the trees.

We have pointed out that it is necessary to study the structure of water tree under the electrical stress.

1. Introduction

Some better reasonable understandings on the water tree propagation have been asked in pursuit of the efficient countermeasures against this kind of aging phenomenon observed in the polyethylene insulation of high voltage power cables in contact with enviroment. In our recent work about the mechanical aspect of the propagation of water trees in PE, many a study has been proposed from the possible actions of environment; such as by chemical, physico-chemical or electrochemical factors. They may be combined with each other on the water tree propagation, which has been obscure up to present time[1]. Regardless of some other authers' contributions[2)~5)] devoted to those actions using test samples similar to ours, no comprehensive and coincident interpretation on their experimental results have been obtained up to now.

In this work an experimental investigation has been performed on some interesting actions of

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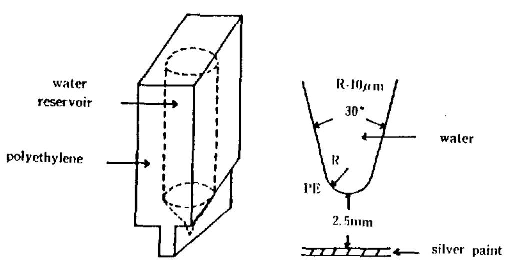
physico-chemical factors of environment on the water tree propagation; one of these factors has been studied from the actions of the salt concentration in water.

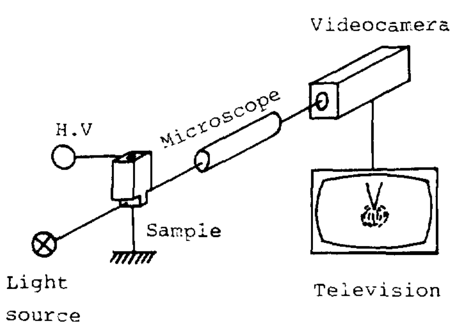
2. Experimentals

Each laboratory specimen contained one water needle(conical needle typed depression, with 10$\pm$ 1μm of tip radius, filled with acqueous solution) placed in such a way that its optical image could be made through a microscope during the test (Fig.1-(a)). All the samples were compression moulded with low densithylene, free from additives, supplied by CDF chemie(reference; lotrène cx3640; density 0.9222kg/dm^3 molecular weight 80000). The distance between the tip point and the silver painted plane electrode is 2.5$\pm$0.1mm (Fig.1-(a)).

Our optic system enabled us continuous observation on the same water tree throughout its whole propagation even under electric stress (Fig.1-(b)).



(a) Sample



(b) Observation system

Fig. 1 Experimental apparatus.

Water tree length is defined as an average of three maximum lengths measured from the tip of the water needle in the direction such as;

- along the axis on the observed image of the water needle
- perpendicular to the two lines limitting the observed image of the water needle.

At least four nearly identical specimens are under the test voltage of 20kVpp, through the platiunm electrode in contact with acqueous solution, in the frequency range 50Hz-33kHz at the room temperature in order to characterize the water tree propagation curve for each test.

3. Results

The growing legth of water trees as a function of time is shown on Fig.2 for the different concetration of NaCl solution; the tree length

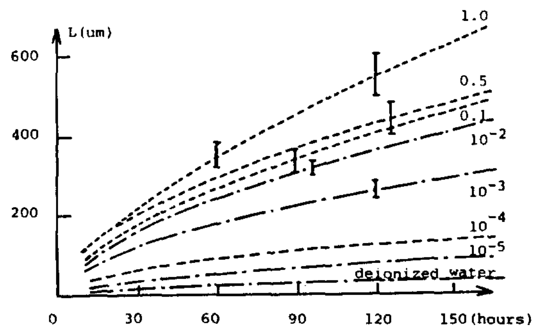


Fig. 2. Water tree propagation as a function of time: effect of the concentration of NaCl dissolved in deionized water ; Concentrations are given in mole/ℓ;
(f=2kHz, r=5μm, U=20kVpp).

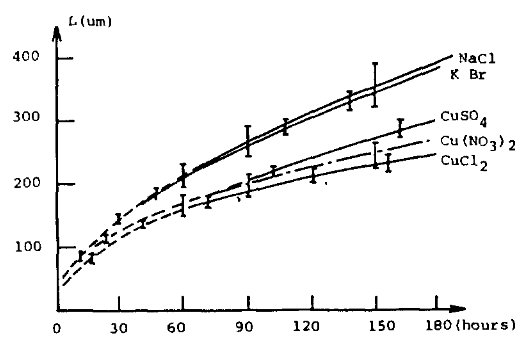


Fig. 3. Water tree propagation as a function of time (f=2kHz, r=10μm, U=20kVpp, c=0.5mole/ℓ) ; effect of the nature of salts.

is increasing continuously with the concentration from C=0 Mole/ℓ (deionized water) to C=1 Mole/ℓ. The propagation as a function of time for the solution of nearly same resistivity obtained from different nature of salts is shown on the Fig.3; the difference in propagation is turned up with time.

4. Discussion

It has not yet been given some explanations to this action of the salt. However we have contemplated three different effects of the salt such as:

- effect, by means of electromechanical action, on the electrical conduction of the liquid contained in the water tree.
- effect, by means of electrochemical reaction, on the by-product which may react upon the polyethylene.
- effect, by means of chemical action, on the direct chemical degradation of the polyethlene.

From the photo throughout the microscope, it might be able to be suggested that water can exist in the shape of microscopic channels starting from the tip of the water needle and that they follow the force of the electric field. Having accepted this assumption, we may consider that the force for the tree propagation, in the form of the related phenomenon to the stress cracking, may be originated from the electrostatic surface pressure which can act upon the polyethylene at the end of suggested channels.[6)]

For the present work we are firstly interested in our first contemplation; the increase in the concentration of NaCL solved in water can cause the increase in the condcutivity of the water. But we are not sure whether tree grows with this increase in conductivity of the water contained in microchannels. If there exixts such a correlation, we may be able to suppose that the increase in tree growth is related to the force suchas an electrostatic surface pressure. If the water contained in microchannels behaves as an insulator, the pressure at the end of the channel upon the polyethylene is given by:

$$P_e=\frac{1}{2}\varepsilon_0(\varepsilon_w-\varepsilon_p)\cdot\frac{\varepsilon_w}{\varepsilon_p}E_0^2 \quad \varepsilon_w$$

(E_0: mean electric field, ε_w, ε_p: permittivity for water and polyethylene respectively). If the water contained in microchannel behaves as a conductor and if the channel is considered as a cylinder (radius r, length ℓ), the pressure is given by:

$$P_e=\frac{1}{2}\varepsilon_0\varepsilon_p\left(\frac{\ell^2}{2r^2}\right)^2E_0^2$$

This force, estimated from our porposed model at the high resistivity of the solution, is so small that the result obained is in good agreement with our suggestion; very small length of propagation with deionized water throughout the same applied time, more over nothing was observed with very perfect insulating liquid such as carbonate propylene.

But the electrical behaviour of the water contained in microchannels depends on many factors such as; geometry of the channels, test conditions and the resistivity of the chosen solutions.[7)] According to SLETBACK, the electrical behaviour transition frequency is given by:

$$f_0=\left(\frac{\nu}{\ell}\right)^2 J/2\pi\varepsilon_0\varepsilon_p\rho$$

where ρ is resistivity of the water,

$$J=\frac{1}{2e^3}\left\{L_n\left(\frac{1+e}{1-e}\right)-2e\right\},\quad e=\left\{1-\left(\frac{\nu}{\ell}\right)^2\right\}^{1/2}$$

If the test frequency is much lower than fo, the water behaves like a conductor. Otherwise the water behaves like an insulatior.

Theoretical calculation shows that, for the observed microchannels, the water behaves as an conductor at our test frequency in the range 10^3 Ω·cm-10Ω·cm (10^{-3} mole/ℓ~1 mole/ℓ). Therefore the force is independant on the risistviity of the water under the given condition. Thus we have expected to obtain same growth level of propagation, which is nearly verified from our test at the considerably early moment of the test time. On the other hand, as shown of Fig.3, the different solutions in nature give practically no difference in tree propagation up to about 200 μm of tree length. Apparently it may be said that the application of the electrical conduction phenomenon of liquid is very probable for a fairly small water tree. Casually this supposition is born out by the results concerning the influence of the amplitude of the test voltage and different tip radius.[8]

But we can observe in the results shown on Fig.2 that the clear difference in propagation is turned up with time. How can we explain it? This difference makes us wonder whether our model is valid in order to explain the tree propagation. Besides the effect of the nature of the salt may be appreiciably emerged in Fig.3; NaCL and KBr have given longer propagation than the copper salt does. Anyway this difference by the nature of the salt is completely different from our anticipation ; we have expected longer propagation with copper salts than NaCL,[9] shotter one with KBr than with NaCL,[10] and similar one with $CuCL_2$ to that with NaCL.[11]

5. Conclusion

We have investigated the effect of the concentration of the NaCl solution, dissolved in water, on the tree propagation under the well defined and reproducible test condition.

Although we can not put forward a definite conclusion, this work pointed out that it is necessary to study systematically the structure of water tree under electrical stress in order to elucidate the mechanism of the actions of the salt by examining a certain number of assumption. Also the study suggest that the tree propagation is possibly to be connected with an intervention of the electrochemical or chemical actions of the salt solution on water tree propagation, which may likely depend on the growth level of the trees.

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