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Pearl-chain-type Trees in Silicone Gel Under AC Voltage

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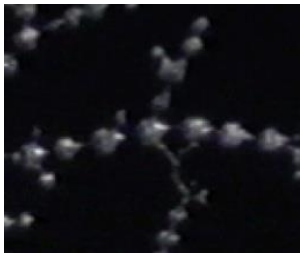
Graphical abstract



Peal-Chain-Type Tree

Abstract

The tree growth has been usually classified to three stages; inception, propagation and runaway stage under AV voltage. When the two-dimensional (2-D) specimen of silicone rubber was used, the propagation stage was divided to two stages: straight and isotropic growth stages. 2-D specimen is useful to observe AC trees with many branches since the number of the branches of AC tree is usually larger than DC and impulse tree. When the silicone rubber is fabricated, two types of silicone gel is mixed up; one includes catalytic agent. If the mixed ratio is changed from 1:1, silicone rubber has fluidity or viscosity. In theses cases, breakdown or partial discharge phenomena also change. Under certain conditions of gel, tree has been developing with bubble-like and string-like pattern alternatively. This tree is called pearl-chain-like tree. At first the tree developed like bubble and then a projection like cone was generated on the surface of the bubble. The tip of the cone expanded and formed a new bubble. This process was repeated. If two tips of the cone are formed on the surface of the bubble, the branching occurs. The shape of tree is like pearl-chain. The pattern of the tree is usually string (or straight) channel and branching. However In the pearl-chain like tree, string channel has consisted of two channels; bubble and string. Branching has occurred at bubbles. These data is important to investigate the mechanism of tree.

Keywords: Tree; breakdown; silicone rubber; gel; pearl-chain-type tree

1.0 INTRODUCTION

Development of electrical trees has been observed to investigate the mechanism of the tree under various applied voltages to avoid electrical accident in electrical instruments. In a solid insulator, especially power cable, an electrical tree has been developed toward a counter electrode. The trees are usually composed of inter-connected hollow tubes [1]. When the front of the tree arrives at the counter electrode, flashover occurs. The tree has many branches, which can be observed using transparent materials. We have used a transparent silicone rubber to estimate the pattern of the tree using fractal, multi-fractal and local fractal dimension [2].

The tree or the branches were disappeared after 24 hours. Two reasons were considered; (1) The gas in the tree leaked from the electrode and (2) silicone rubber gel flowed into the inside of branches. In order to consider the effect of the silicone rubber gel, the silicone rubber has been fabricated by irregular way. Silicone rubber is usually fabricated by mixing two kinds of material with same volume. If the mixing ratio is changed, the stiffness of silicone rubber changes, i.e. its stiffness can be controlled and the fabricated rubber is gel. Under AC voltage, it is easy to observe the development of the tree because the growth speed is very slow. The stages of the development have been classified into three ones: (1) Linear tree at 1st stage, (2) The branches isolated at 2nd stage, and (3) the development of selected branches at 3rd stage. The patterns or shape of the trees depends on the mixed ratio; tree with no branch, spherical, or pearl-chain type one.

In this paper, the development mechanism of the tree in the different type of silicone rubber/gel has been investigated. The two-dimensional (2-D) specimen of silicone rubber was used, since 2-D specimen is useful to observe AC trees with many branches[3-7]. The pearl-chain-like tree that consisted of a series of two parts (bubble and string one) also has been observed under certain condition.

2.0 EXPERIMENTAL

Figure 1 shows 2-dimenaional specimen. Two sewing needles (iron; Fe) were used as electrode; one was used as a needle electrode and another as counter electrode. The tip of the former was electrochemically polished up. The diameter of the needle is 0.7mm. The length and the width of the glass plate are 36 mm and 26 mm, respectively. The gap length between the electrodes was 1 or 2 mm. Silicone rubber (Shin-Etsu Chemical Co., Ltd. KE-1935A (base body) and B (cross-linking agent)) was used as specimen. Silicone rubber gel was fabricated by changing the ratio of KE-1935A and B. Degassed silicone rubber was poured into the space between two slide glasses, and was heated for 4 hours at 80 degrees C.

The specimen consisted of double layers to observe the development of the tree easily due to control the stiffness (1:1;normal, 10:1:liquid-like and 5:1:soften). Normal silicone rubber with mixed ratio of 1:1 was set in the vicinity of the tip of the needle electrode and soften silicone rubber gel with mixed ratio of 6:1 surrounded it as show in Figure 1.

AC voltage was applied to the specimen that was put in silicone oil to avoid leak surface current. Stepwise of AC voltage was applied; 0.75kV step after each 20sec. When the tree appeared or was developing, the voltage was kept constant as shown in Figure 2 to observe the development of the tree. When the tree stop growing, the applied voltage was increased again using same step. The tree was observed by a CCD camera(SONY DXC-107A) with a optical zoom lens(SEIWA OPTICALMS-502-S40) and the image signals were transferred into a monitor and a PC as shown in Figure 3.

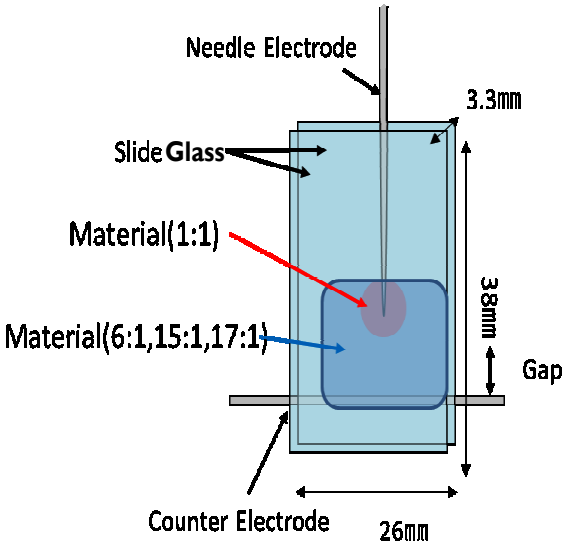


Figure 1 Composite specimen of silicone rubber/gel with double layer: normal silicone rubber in the vicinity of the needle electrode and silicone rubber gel

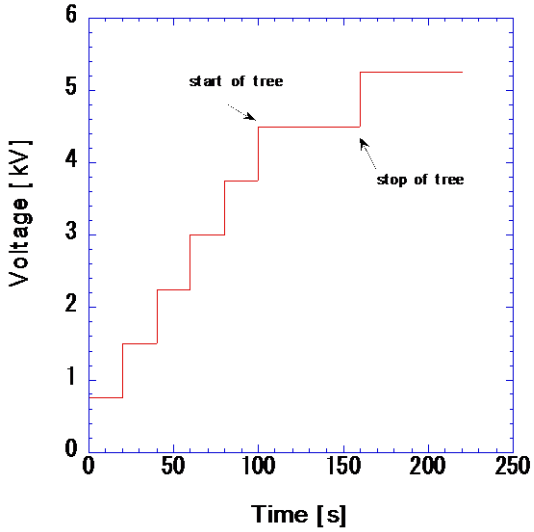


Figure 2 Applied voltage

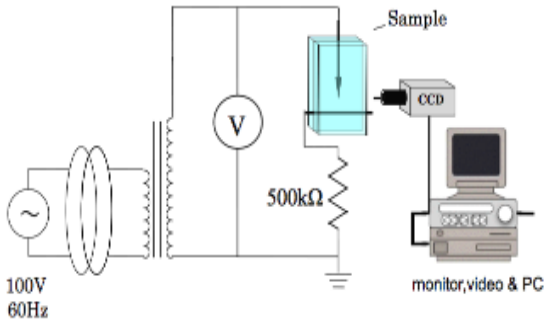


Figure 3 Experimental configuration

3.0 RESULTS AND DISCUSSION

In order to confirm the tree consists of gases, the silicone gel (the mixed ratio of 1:1 and 15:1) was used and the length of the gap is 2mm. Figure 4 shows the tree or partial breakdown. The tree appeared at 6.75kV and proceeded in the normal silicone rubber (a) and then the front of the tree arrived at the interface of the double layer. (In this photograph, the tree was traced by the color line since the tree was not clear.) It stopped the boundary. The applied voltage was increased until the tree restarted. At 9kV bubbles appeared from the tip of the tree (b). The applied voltage was increased until 10.5kV, and bubbles spread out in a cone-like form. The phenomenon of the tree in silicone rubber is explained by vaporization of material. The bubble tree can also take another form. In Figure 5 the long tube bubble developed with branching. When the tip of the long tube bubble arrived at the counter electrode, flashover occurred.

The bubble cut off from the main tree in 1:1 silicone rubber was observed because the pressure inside was not kept constant spatially. This would suggest that melting and vaporization occur at the front of the tree/bubble and the point of the vaporization is the place where the current flows into, i.e. the electrical field concentration point. The melting/vaporization point moves along the electrical force line as shown in Figure 6 and thus the hollow tube was created.

When the mix ratio of the second layer was 6:1 or 5:1, the tree that consisted of bubble parts and straight parts was observed. The bubble part and straight part appeared alternately as shown in Figure 7. This pattern is similar to a pearl-chain. We call it pearl-chain-type tree. Figure 8 shows the pearl-chain-type tree in the upper branch in Figure 7.

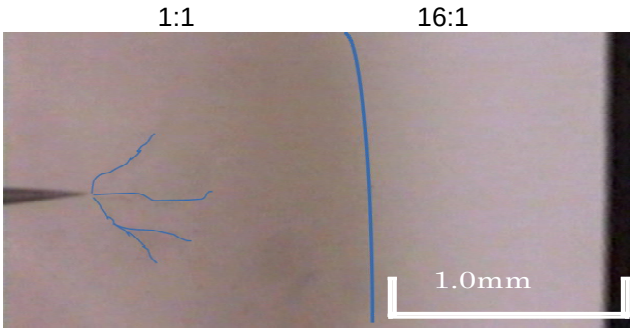
At first the string-like tree developed from the bubble surface like cone-protrusion. After some growth, the tip of the cone expanded and formed bubble away from first one. The bubble grew as same size as previous one and then the next cone was formed on the surface of the bubble. These processes were repeated. Figure 9 shows another pearl-chain type tree. When two cone-protrusions were created on the surface of the bubble, the branching was occurring. The branching was observed on the bubble not on straight part. This phenomenon is very important to consider the model of tree development. The branching started from one bubble part.

These phenomena suggest the mechanism of the tree in silicone gel as following:

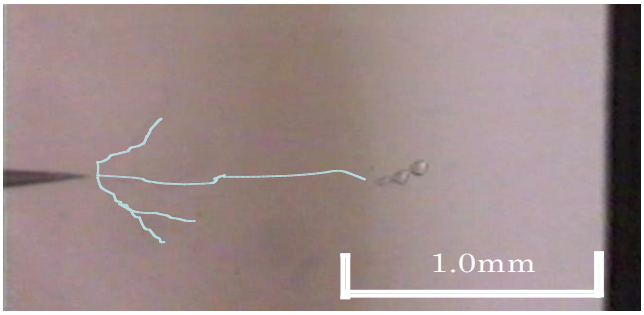
(1) Vaporization occurs on the tip of the needle electrode by Joule heat of current and then the bubble is formed.
(2) One point on the bubble is heated and then melts/vaporizes. This melting point is moving along the electrical force line and thus the cone-shape hollow is formed. Finally long tube(backbone of the tree) is formed.

(3) The pressure inside increases and bubble is formed if the material is soft. Next, process (2) is repeated.

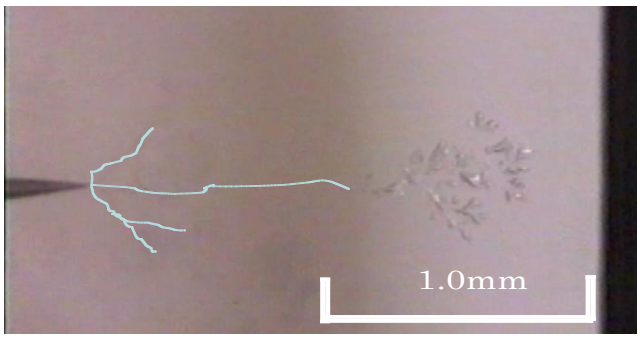
If two melting points are formed on the surface of the bubble, two cones grow and the tree has two paths or branches.



(a)



(b)



(c)

Figure 4 Tree/partial breakdown from normal silicone rubber to gel (mix ratio of 16:1) (a) 6.75 kV (b) 9 kV and (c) 10.5 kV

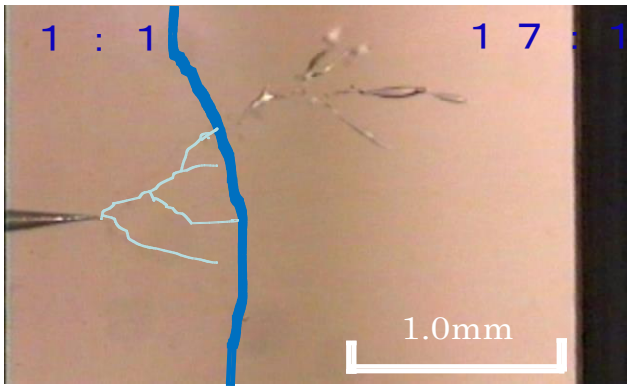


Figure 5 Long tube bubbles with branches in gel (mix ratio of 17:1) at 10.5kV tree/partial breakdown from normal silicone rubber to gel

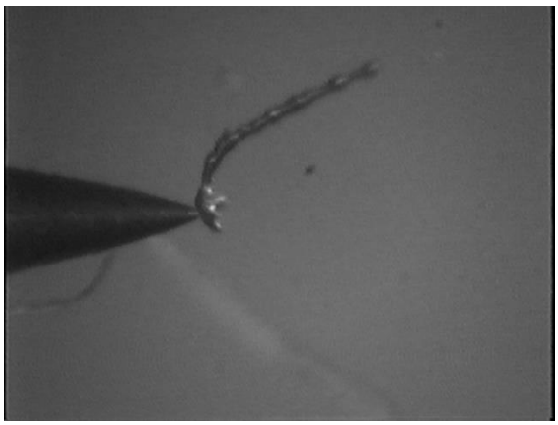


Figure 6 Curved long tube tree (mix ratio of 5:1) at 3.5kV

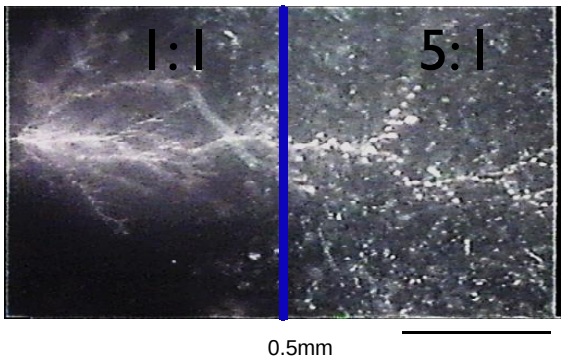


Figure 7 Tree that consists of babble and straight parts

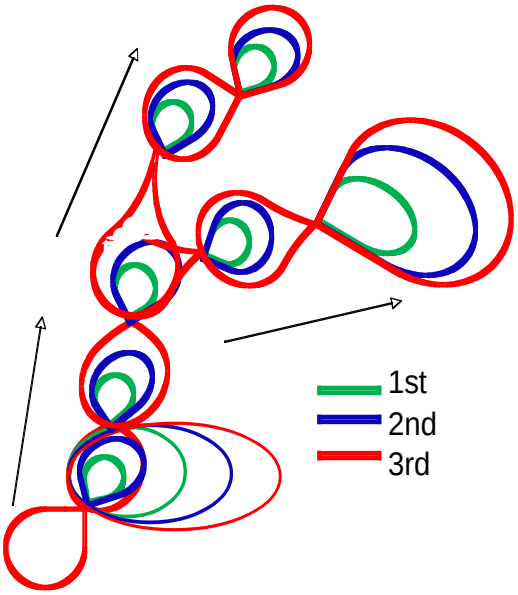


Figure 8 Process of development of pearl-chain type tree

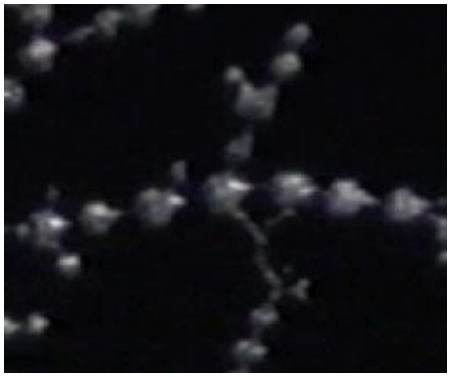


Figure 9 Branching point (the ratio of 6:1)

4.0 CONCLUSION

The tree in silicone rubber gel has been investigated. The gas in the tree was confirmed by the bubble out of the tip of conventional tree. Under certain conditions of gel, tree has been developing with bubble-like and string-like pattern alternatively. This tree is called pearl-chain-like tree. At first the tree developed like bubble and then a projection like cone was generated on the surface of the bubble. The tip of the cone expanded and formed a new bubble. This process was repeated. If two tips of the cone are formed on the surface of the bubble, the branching occurs. The shape of tree is like pearl-chain. The pattern of the tree is usually string (or straight) channel and branching. However in the pearl-chain like tree, string channel has consisted of two parts; bubble and string. Branching has occurred at bubbles. These data is important to investigate the mechanism of tree. The model of development tree was suggested.

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