Effect of Elastic Elongation on Dielectric Strength (Study Based on Self-Fusing Silicone Tape)

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Abstract: Elastomeric insulating tapes are routinely used in electrical systems manufacturing. The dielectric strength of the material being used is of utmost importance in these applications and it is often assumed that typical reported values will be achievable in the final application. However, due to process variability in the elongation of elastomeric polymers when they are wrapped around electric coils and other components, the possibility of altering the effective dielectric strength of the insulation material arises. In this paper we examine the relation of the elongation of a silicone-based self-fusing tape to its dielectric strength. Changes in thickness as a result of elastic elongation alter the dielectric strength predictably.

I. INTRODUCTION

Self-fusing silicone rubber tapes have been used as high voltage electrical insulation for years. The dielectric strength of these tapes, or ability to withstand electric voltage without failure, is routinely tested per ASTM D149. This method tests the dielectric strength in the relaxed state, with no tension applied, by measuring the voltage at which an insulating material is broken down or arced through in volts per mil of thickness. In contrast, the practical application of some insulating tapes involves tensioning and the resulting elongation. The elastic elongation of these tapes can reach up to 300 percent. Along with this tape elongation, there is a corresponding reduction in thickness (and width). We have found no previous investigation on the effect of elastic elongation on tape dielectric strength.

Dielectric breakdown results in the catastrophic formation of a narrow discrete channel, or a tree-like pattern of channels of destruction. These channels form in what might appear to be initially a homogeneous medium. It is a massive dissipation of energy in a very confined volume. The stress of material elongation could have an effect on this phenomenon by causing the material to resist the applied electric field in a different way than if not stressed.

This paper will investigate the relationship between elastic tape elongation and dielectric strength through the study of self-fusing silicone tapes. A key finding will be whether the stress of elastic elongation promotes dielectric breakdown of the tape. All testing will be conducted in air at room temperature.

II. DISCUSSION

A. Thickness Versus Elongation

The first half of the investigation consisted of establishing the relationship between tape elastic elongation and tape thickness. To this end, a 4.5 inch long section of tape was measured and marked for reference. The specimen thickness was measured at the approximate center using a deadweight micrometer to establish the relaxed, or zero elongation thickness. Then the sample was stretched bi-directionally to the desired elongation by applying tension manually. Tension was applied until both ends moved away from each other to the desired elongation. While securely held in place with clamps, the specimen thickness at the approximate center was again measured using the micrometer.

These measurements were collected from five samples of tape for each of the elongations of interest. An average of the five measurements was calculated to determine the thickness of the tape at each elongation. Figure 1 is a graph of this result for tapes with original nominal thicknesses of 0.020 inch and 0.050 inch.

B. Dielectric Strength Versus Elongation

After establishing the relationship between elongation and thickness, the dielectric strength was investigated. For each of the elongation percentages investigated, 30 tape samples were obtained from the same lots. Each of these samples was elongated to the desired elongation percentage in the same manner used in the thickness studies. The elongated samples were then clamped in place on a polycarbonate test fixture. This

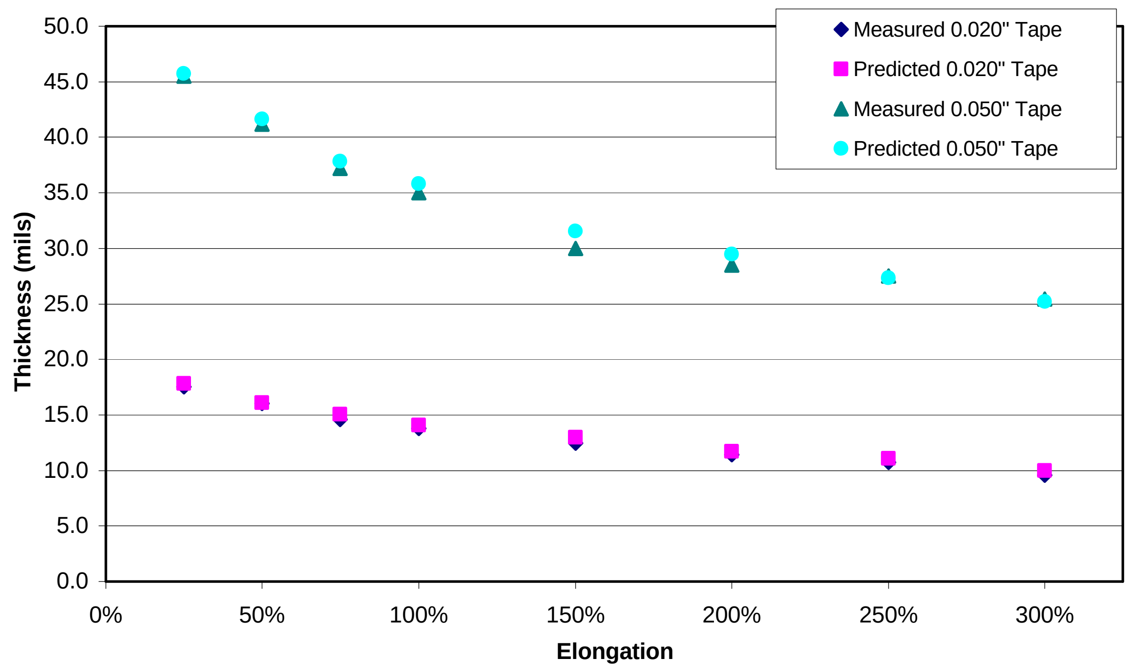

Figure 1. Thickness for tape elongated at various percentages. Predicted values from Equation (2).

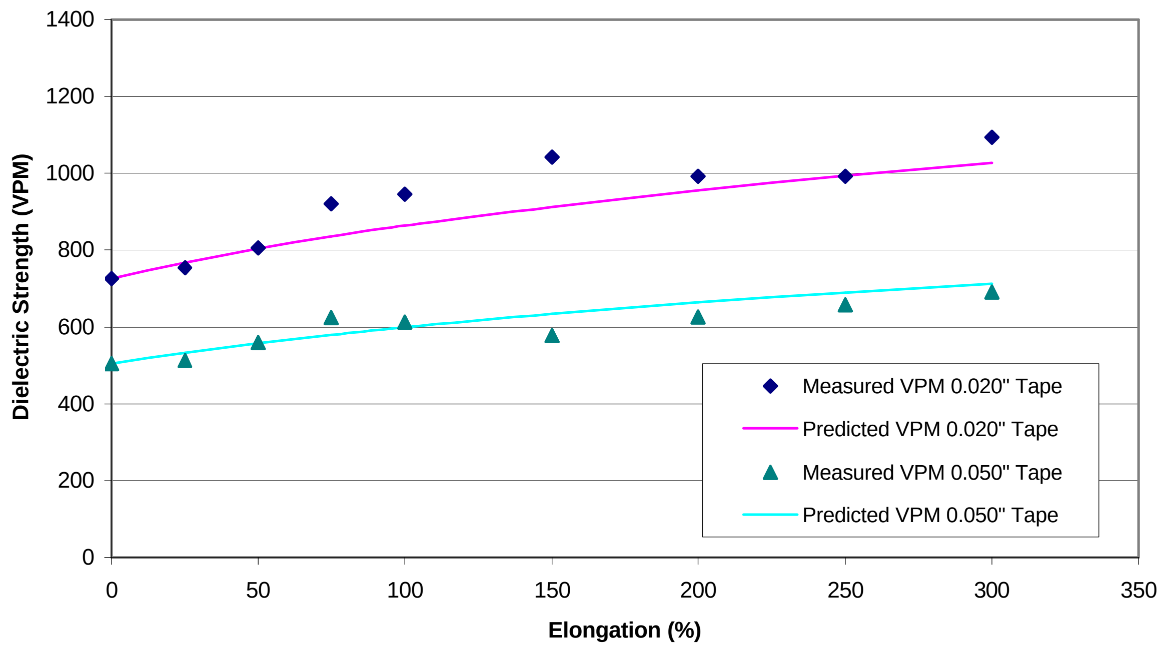

Figure 2 – Tape dielectric strength versus elongation. Predicted values from Equation (3). Measured values are the average of 30 samples, and all are within one standard deviation of predicted values.

test fixture was developed to hold the tape at the desired level of elongation, and at the same time prevent arcing around the tape during dielectric strength testing.

The tape in the fixture was then tested for dielectric breakdown voltage using Hipotronics Model 750-2/D149-15A cabinet. The voltage was divided by average tape thickness at each respective elongation to calculate the dielectric strength of each test specimen. The dielectric strengths for the 30 samples were averaged to determine a final value, as shown in Figure 2.

C. Tautscher's Formula

The following formula developed by Carl J. Tautscher can be used to estimate dielectric strength for any thickness of the same material.

$$Vpm = Vpm_0 \frac{\sqrt{t_0}}{\sqrt{t}} \qquad (1)$$

where

Vpm = Dielectric strength at thickness t

Vpm_0 = Dielectric strength at thickness t_0

t_0 = The thickness in mils of the known test specimen.

t = The thickness in mils of the insulation for which the strength is to be calculated.

This method can be used to predict dielectric strength at a desired thickness provided that an accurate dielectric strength is known along with the specimen thickness that was used to obtain it, and the samples are at the same temperature.

Tautscher's equation (Equation (1)) illustrates the well known fact that thinner materials display higher dielectric strength than the same materials with greater thickness. The measurements of dielectric strength collected in this study agree with the predicted values from Tautscher's equation. This agreement between data collected in this study and calculated values shows that Tautscher's equation is applicable even if the change in the thickness dimension is the result of elastic elongation rather than initial dimensions.

Since the tape in this study is homogeneous and isotropic, an equation like Tautscher's can be developed to predict the relationship between elongation and thickness. The tape specimen resists volume change as a result of elongation (incompressible), so it follows mathematically,

$$lwt = l_0 w_0 t_0$$

where

lwt is the volume after elongation

$l_0 w_0 t_0$ is the volume before elongation

Then

$$\left(\frac{t}{t_0}\right)\left(\frac{w}{w_0}\right) = \frac{l_0}{l}$$

Substituting

$$\frac{l_0}{l} = \frac{1}{l/l_0} = \frac{1}{\frac{l_0 + l - l_0}{l_0}} = \frac{1}{\frac{l_0}{l_0} + \frac{l - l_0}{l_0}} = \frac{1}{1+e}$$

and taking advantage of material isotropy allows

$$\left(\frac{t}{t_0}\right)\left(\frac{w}{w_0}\right) = \left(\frac{t}{t_0}\right)^2$$

providing the useful result

$$\left(\frac{t}{t_0}\right)^2 = \frac{1}{1+e}$$

Solving for t

$$t = \frac{t_0}{\sqrt{1+e}} \qquad (2)$$

where

t = predicted thickness in mils at elongation e .

t_0 = thickness at zero elongation (relaxed state)

e = elongation percentage (strain) (i.e., 25% = 0.25)

Figure 1 illustrates the excellent agreement of this equation with the experimental data.

III. CONCLUSIONS

Having investigated and identified the relationships between elongation and thickness, and between thickness and dielectric strength, it is now possible to identify the effect of elongation on dielectric strength. Substituting Equation (2) into Equation (1) yields the following insight:

$$Vpm = Vpm_0 \frac{\sqrt{t_0}}{\sqrt{\frac{t_0}{\sqrt{1+e}}}}$$

When simplified,

$$Vpm = Vpm_0 \sqrt[4]{1+e} \qquad (3)$$

Figure (2) illustrates the excellent agreement of the measured data to the predicted values. Since Equation (3) does not add any factor to account for the stress of elastic elongation, it can be concluded that there is no effect on the dielectric strength. In other words, the dielectric strength is only dependent upon the thickness of the material, and is independent of whether the material is in a relaxed state, or stressed as a result of elastic elongation.

The utility of Equation (3) is that resultant dielectric strength can be predicted knowing only the original dielectric strength (relaxed state) and the elastic elongation. When insulating with elastic materials, it is now a simple calculation to predict the dielectric strength obtained from a known elongation. Equally useful, it is also possible to calculate permissible elastic elongation of insulation materials given the required dielectric strength.

This relationship provides a practical focus for the use of tape in electrical insulation systems. The installation process can control the dielectric strength by controlling the thickness or the elongation of the insulation tape. In some cases, it may be possible to achieve substantial efficiencies by eliminating unnecessary safety factors in the form of excessive tape wraps.

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