Electrical Resistivity of Phenolic Polymer

While phenolic polymers have been known and used for over sixty years, there is still only a limited amount of information available about their electrical and thermal properties. In particular, while it is well established that these materials are excellent dielectrics, very little has been published on the temperature dependence of the dc volume resistivity of resole-type phenolic polymers. Many years ago, Hazen[1] presented a plot of resistivity versus temperature for a phenolic polymer but gave few details about the polymer.

The polymer which we studied is a resole-type phenolic polymer manufactured by the Monsanto Company under the name Resinox SC-1008. It is supplied in the form of a 62% average solution in isopropyl alcohol. This solution was poured into a cylindrical electrode[2] and the polymer was polymerized directly to the electrode. Polymerization was carried out at a slow rate starting at 38°C for 24 hr, increasing the temperature 25°C for each following 24-hr cycle with the final cycle being 24 hr at 177°C. By means of this slow cycle, crack-free specimens were produced.[3]

Once polymerization was complete, the temperature dependence of the resistivity was determined. A test for complete polymerization is to be able to exactly reproduce a plot of resistivity versus temperature after an additional thermal cycle at a temperature about 25°C above that of the last thermal cycle. If additional polymerization has occurred, the slope of the plot of resistivity versus temperature will remain approximately constant but the entire plot will be shifted toward higher temperature. If degradation occurs, the slope will be reduced. The data

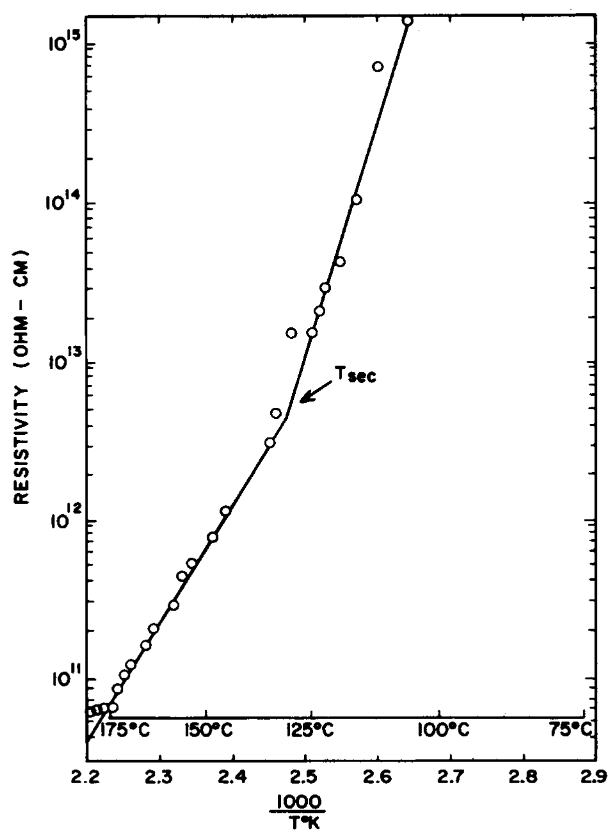

Fig. 1. Resistivity of a phenolic polymer as a function of temperature.

obtained at 205°C reproduced exactly the data obtained at 177°C; therefore, insofar as thermal polymerization is concerned, this polymer is completely polymerized.[3]

A semilog plot of electrical volume resistivity versus the reciprocal of the absolute temperature is shown in Figure 1. Over the temperature range considered, plots of this type are, in the absence of any transitions, crystallization or decrystallization or degradation, linear with the reciprocal of the absolute temperature. However, in the present case, a change in slope occurs at about 125°C. While it has been established[4a,b,c] that changes of slope, like that in Figure 1, are indicative of transitions, resistivity data do not indicate the exact type of transition.

The existence of this transition was confirmed by bulk compressibility and specific heat measurements made as a function of temperature.[3,5] All the available evidence[3] indicates that this is a secondary transition, T_{sec}, occurring in the glassy state.

The resistivity at temperatures lower than 125°C exhibits a very high temperature dependence from which a value of 69 kcal/mole can be calculated for the activation energy of the electrical conduction process, E_c. This is the highest value which we have ever encountered[4a] and is typical of a highly crosslinked amorphous solid. Furthermore, if one extrapolates the plot to 25°C, a value of the resistivity at 25°C, $\rho_{25°C}$, of $\sim 10^{26}$ ohm-cm is obtained. Again, this is the highest estimated value of $\rho_{25°C}$ we have encountered. However, these values of E_c and $\rho_{25°C}$ are not unreasonable. Previously,[4a] we have shown that there is a general relationship between E_c and $\rho_{25°C}$, and this phenolic polymer fits the previously obtained relationship very well. The relationship between E_c and $\rho_{25°C}$ is a convenient manner by which the relative microviscosity of a polymer can be estimated, and the results indicate that this phenolic has the highest microviscosity of any polymer we have studied. In different terms, the ionic current carriers have more difficulty in diffusing through this polymer than any other encountered to date.

The extremely high values of $\rho_{25°C}$ and E_c are greater than any previously reported for any polymer and show the excellent dielectric properties of phenolics.

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