Semi-Conductive Polyurethane in EP Systems

A Comparison of "Dynamic" to "Static" Volume Resistivity Testing of Rollers

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Abstract

This paper explores testing of semi-conductive polyurethane materials as they apply to use in EP systems. A method for measurement of volume resistivity and Electrical characteristics over time are explored in detail. A common formula for specifying resistivity is explained, as is the effect of dynamic measurement vs. static measurement. This paper is an extension of the paper presented at IS&T NIP-17 which explained basic manufacture and specification of Ionic conductive doped polyurethane as used in EP systems.

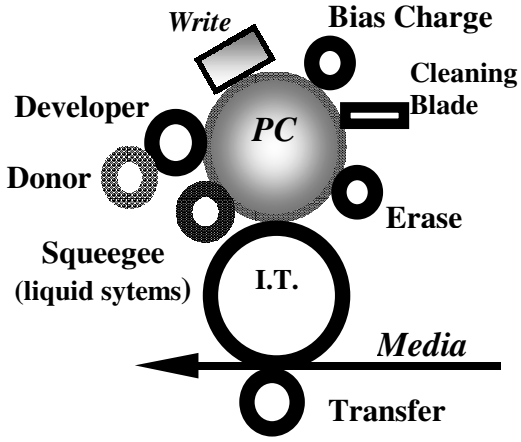

Figure 1. Current EP Applications using Semi-Conductive Ionic Doped Polyurethane Elastomers

Basic Review

Polyurethane can be formed by combining a Pre-Polymer resin, containing NCO functional groups, with a curative agent, (polyol or amine), containing OH functional groups. The ratio (molar) of active NCO sites to active OH sites is called the "Stoichiometric Ratio" or "Percent Theory" [inversely the "Index"]. This Ratio is the primary manufacturing control for the formation of the urethane. The Index can be changed and used to adjust product physical properties and sometimes electrical properties. Urethanes can be made electrically semi-conductive by doping with Ionic conductive agents. These conductive agents can be liquid or made soluble in urethane cure systems or in the reactive polyol or chain extender components within the urethane chemistry. Since these agents are not "electronic" conductors, flow of current through them depends upon, and is limited by, the nature of the ion, the total number of charge carriers, and the mobility of the ions within the cured urethane system. Since this ionic conduction can deplete over time, a realistic testing method to describe this depletion rate is desired.

Volume Resistivity

Volume resistivity is the fundamental physical electrical resistance property of a material. It is measured in units of ohm-cm and defined below in equation 1.

$$\rho_{\Omega*cm} = \frac{V \times cm^{2}_{(\text{contact area})}}{I \times cm_{(\text{thickness})}}$$

Equation 1. Volume Resistivity, General Formula

The unit "ohm-cm" is derived from voltage over current being ohms and square cm contact area over cm thickness becoming simply cm as below.

$$\rho_{\Omega*cm} = \frac{V \times cm^{2}_{(\text{contact area})}}{I \times cm_{(\text{thickness})}} \rightarrow \text{OHM} \times \text{cm}$$

Equation 1a. Volume Resistivity Ohm-cm unit derivation

Volume resistivity is measured by applying a known voltage "V", across a known contact area (in a roller this is the nip width x length) and a known thickness (wall thickness of the roller. We then measure current flow "I" and use equation 1 to calculate ohm-cm. This can be done in a variety of ways, some of them more accurate than others, and can be measured on slabs of material, or on rollers and drums directly.

Standard Volume Resistivity Testing of Slab Material

Volume resistivity can be measured on slab stock of materials for comparative, quality assurance, or developmental purposes. When measured in this fashion, a slab of material, typically around 0.250" thick, is placed between two conformal, low resistance, contact plates. Since Volume Resistivity changes over time, it is important to specify at what time this measurement is to be taken.

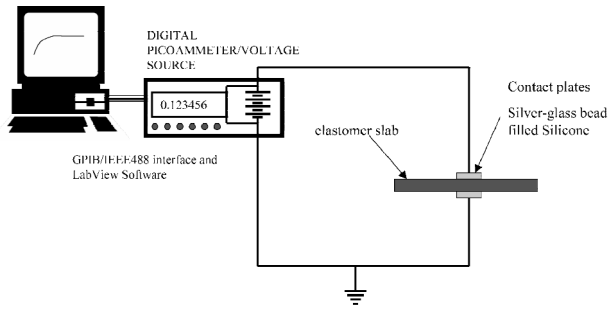

Figure 2. Volume Resistivity Testing, Slab Stock

Stationary Roller Volume Resistivity Testing

Among the most often used VR test methods (but least representative of actual functional use) is the "Stationary Roll" Volume Resistivity test. This method employs a flat, or inside radius, contact plate pressed against the roller to either a known force or known nip width. The surface contact area is either limited by the contact size, and therefore known, or it is calculated by the nip width x length. The method is similar to slab testing, only done on a roller.

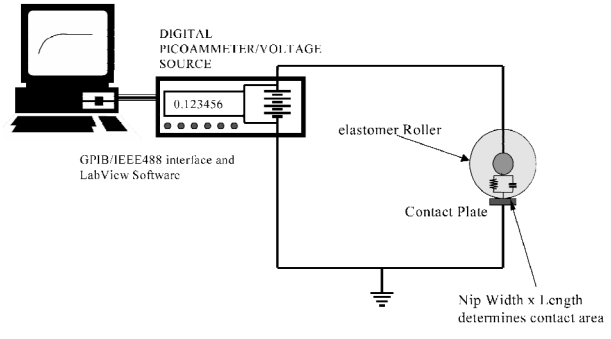

Figure 3. Stationary Roller Volume Resistivity Testing

Dynamic Roller Volume Resistivity Testing

In dynamic testing, a rotating contact roll is employed as the bottom contact. Volume resistivity is calculated utilizing Formula 1, where contact area is nip width x length of roller, and thickness is cross sectional wall thickness of the roller. Results of this testing can be captured and graphed over time and compared to the results of stationary roll testing or slab test results. A picture of the dynamic test fixture utilized in this study is contained in figure 4 below. This fixture utilizes a nickel-plated contact roller platen of 30 mm diameter. The subject roll under test is pressed into the contact roller platen using an air cylinder actuated engagement. Electrical contact to the test roller is made via a brass leaf contact in the vee-block of the fixture holding it. Contact to the platen roller is made in a similar fashion to platens datum journal. These brass leaf contacts are replaceable, as they will wear from use. The DC motor controller driving the system can control rotational speed of the fixture. All components are isolated from each other by utilizing UHMW or Nylon components to hold the rolls and as a base plate. Pressure on the test roller can be adjusted to achieve the desired contact area.

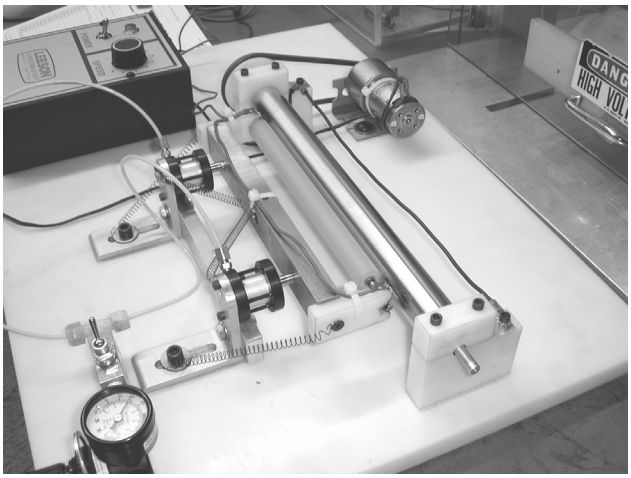

Figure 4. Photo of Dynamic roller Test Fixture

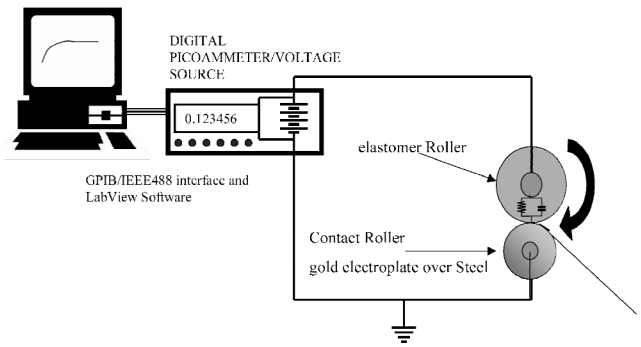

Figure 5. Schematic of Dynamic Roller Volume Resistivity Testing

It is hypothesized that dynamic testing will result in lower rate of increase of volume resistivity over time than static testing, and additionally that since "fresh" material volume is constantly being rotated through the nip, that the volume resistivity value should be lower in dynamic mode than in static and centered near where the static test value begins (i.e. the 1 second data value). This hypothesis was tested as follows. Rollers made of Winthane™D2683 and Winthane™D2718 were first tested in static mode utilizing the dynamic roll test fixture as described in figures 4 & 5, without rotation. The same rollers were then tested in the same fixture with rotation. The data detailing volume resistivity vs. time were collected in (x,y) pairs automatically by the test software. The graphs of that data are shown in Figures 6 and 7 below.

Observations

It was noted that the nip width of the D2718 material was smaller in dynamic rotation then it was at rest. This was not expected and resulted in the "calculated" volume resistivity of the dynamic test being higher than the static test. If we correct for this nip width change, the results are similar to the D2683 (volume resistivity is actually lower in dynamic mode than in static mode). For purposes of testing the hypothesis about the rate of increase however, the nominal was unimportant. This did not occur with the D2683 material because it is a harder material, the softer (Shore A 17) D2718 material, when at rest in the nip, continued to conform to the platen roll and increase in nip width. During rotation, it did not have a chance to relax into the nip and conform. This is the same physical effect that occurs in car tires (at rest, the footprint is larger than during rotation). This indicates the need to model or estimate the nip width dynamically prior to testing so the correct estimate of nip width can be used in calculating volume resistivity.

Results

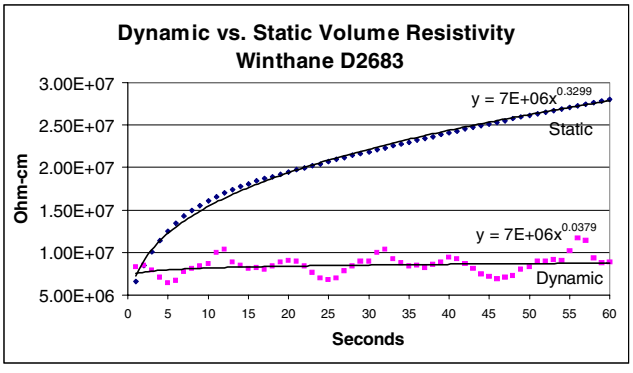

Figure 6. Comparison of Dynamic to Static Testing, D2683

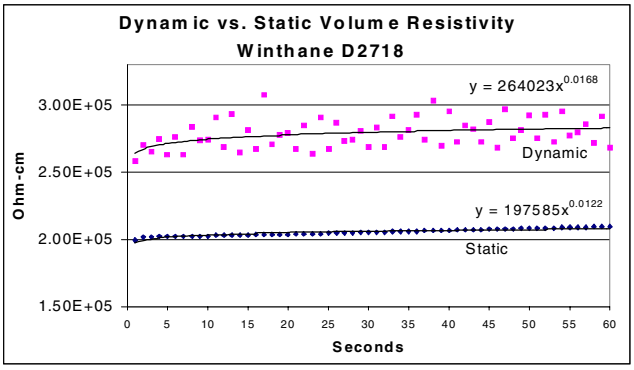

Figure 7. Comparison of Dynamic to Static Testing, D2718

From the data collected, it is possible to determine the rate of increase of volume resistivity and compare this rate of increase in the static mode to the dynamic mode. It is noted that the rate of increase in resistivity in static mode of the D2683 material was 10x that of dynamic mode. The rate of increase of the D2718 material, however, was essentially the same in either dynamic or static mode. The difference between the two materials is that they contain differing conductive agents and the D2718 is lower overall resistivity. This can be an important consideration with respect to test modeling and being able to predict "end of life" of a material when testing in the dynamic mode is not possible. "End-of-life" would be defined as an upper specification or functional limit of volume resistivity. Beyond that upper limit, the EP system may not function. In the case of a bias charge roller or paper transfer roller, reaching this limit would result in insufficient charge or transfer. The volume resistivity of the dynamic mode test was lower than during static mode testing. The calculated value of dynamic mode testing of the softer D2718 material was incorrect due to nip width changing (becoming smaller) while rotating than while at rest. In addition to the nip width changing, it may be important to consider that cross sectional thickness will also be different at rest than while rotating and different for differing test pressures. Because of this it would be important to standardize the pressure at which the test is taken and standardize the diameter of the test platen.

Conclusions

In specifying a value for volume resistivity of an ionic-conductive polyurethane roller, it appears to make sense to specify that the value be collected at the 1 or 2-second time-slice, if only static-mode testing is available. If dynamic mode testing is available, then some average value should be calculated and reported as dictated by mode of use of the roller, attempting to match rotational speed and duty cycle. If a time-slice of greater than 3 seconds is used during static testing, depending on the material under test, the difference in resultant measured volume resistivity during the static test and actual use conditions dynamically will increase. For instance, if in the case of the D2683 a 10 second value were

chosen during static mode testing, the volume resistivity would have been around 1.6 x 10E09 ohm-cm, while actual use condition at 10 seconds would have been around 9 x 10E06 ohm-cm.

Depending upon the type of conductive system chosen to dope the polyurethane with and or the nominal volume resistivity of the cured system, the rate of increase in volume resistivity could be similar to, or be different, when comparing dynamic to static testing. It would be important to verify this rate in both modes prior to determination of which mode will be used to conduct "end-of-life" predictive testing.

When dynamic roll testing cannot be performed, static testing can still be used to estimate effective roller "life". This should also hold true for initial "slab" testing during the development phase for the material chemistry. Dynamic testing will show cyclical patterns due to roller runout and alignment issues, and this can be minimized by proper roll and fixture design. The effect of speed and roll wall thickness on rate of increase in volume resistivity requires further investigation as does the effect of temperature, relative humidity, and conditioning or stabilization of the roller to environmental conditions prior to testing.

Acknowledgements

1. Special acknowledgement to Krishna Chaurasia, Manager of Research & Development, Winfield Industries, Inc. for recent development of D2683 and D2718, discussions regarding this type of testing, as well as for pointing out that differences in rate of decay as a result of the type of conductive agent used should be investigated. This lead to further investigation for this paper and changed the conclusions.
2. Tom Borczynski, Tony Mazurkiewicz & Jim Young for helping to machine and build the test fixture.
3. My wife, for proofreading.

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Biography

Charles Matteliano is currently Vice President of Product Development and Quality for Winfield Industries, Inc., Buffalo, NY. His responsibilities include directing materials, process and product development activities for polyurethane and silicone engineered components including imaging, film and EP process rollers. Charles holds a Graduate Degree in Applied Math and Statistics from RIT, and a Bachelors Degree in Industrial Technology from SUNY. Past experience includes Quality/Materials Manager with BIC SMD, Clearwater FL; Supervisor for Westinghouse Electrical Controls Division, Oldsmar, FL; Quality/Process Development Engineer with Buffalo China, Inc.; and Quality Manager at Winfield Industries, Inc. Charles and his wife Susan reside in Kenmore, NY with their three children.