Surface vs. Volume Resistivity

Understanding the two methods and why they matter

PURPOSE

The purpose is to give an overview of the two methods used by Parker Chomerics to measure the resistance of a material, and hence its resistivity, and from that how to calculate volume resistivity.

INTRODUCTION

To measure the resistance of an elastomeric material, Parker Chomerics uses two kinds of probes that connect to a multimeter. The first is the Pressure Probe and the second is the Surface Probe, or CHO-POBE as it is commonly called. Each has a different application and this will be explained. For either one, once the resistivity is known the volume resistivity can be calculated. For coatings or thin films, only the surface probe is used for determining the resulting surface resistivity. Volume resistivity is not applicable.

So how are the probes used to measure a material's resistance? To answer this, it will help to give a brief overview of some basic electronics principles.

OHM'S LAW

Ohm's Law is a key building block of circuit analysis. Simply stated, it expresses the relationship between the voltage across a resistor when current passes through it. The expression is:

$$V = IR$$

Where

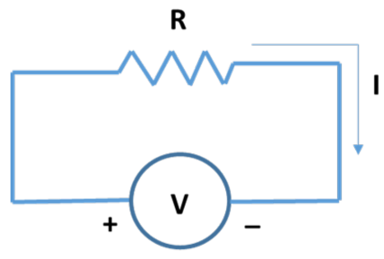
V = Voltage (like a battery); expressed as V

I = Current (electrons flowing); expressed in Amps (A)

R = Resistance (component resisting electron flow); expressed in ohms (Ω)

Note: "Resistivity" is the property of a material whereas "resistance" is what is measured.

The basic wire circuit representation is:

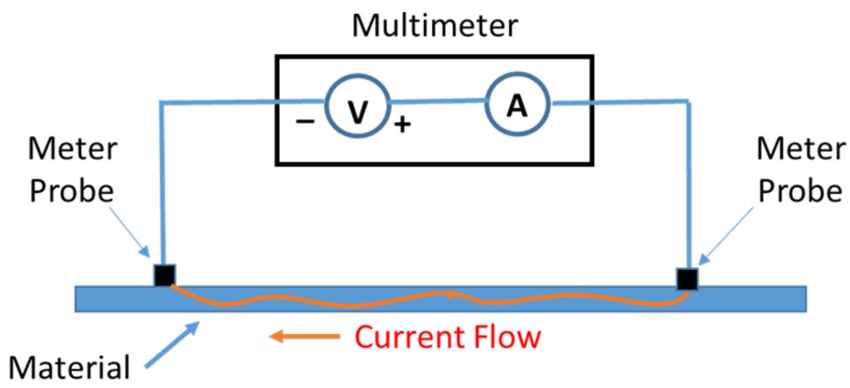


With this equation, it's possible to determine voltage, or current, or resistance if the other 2 terms are known.

For example:

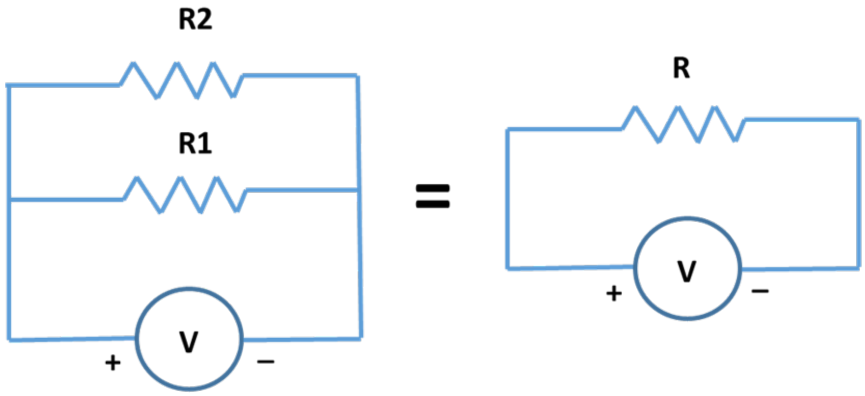
If $V = 10\,V$ and $I = 2\,A$, Then $R = V/I = 10/2 = 5\,\Omega$

Instruments such as multimeters operate on this principle. To determine the resistance, or "resistivity," of a material the meter will create a voltage between the two test probes. This will induce a current in the material.



Since the voltage is a known constant value, the resistance will be proportional to resulting current. The meter is calibrated to give the correct reading; it doesn't really "calculate" resistance.
Building on this basic principle are two equations that will prove useful in understanding your measurement results. These deal with one voltage across multiple resistors in a wire circuit.

a) Consider the diagrams shown below with two resistors in parallel. For analysis purposes the value of the two resistors can be combined into a single resistor:



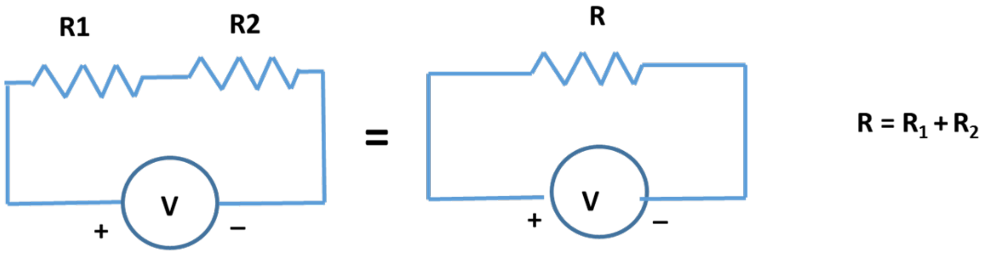
$$R = \frac{(R_1)\,(R_2)}{R_1 + R_2}$$

Sample Calculations:

1. If R1 = R2 = 4 Ω, then R = (4) (4) / 4 + 4 = 16/8 = 2 Ω
2. If R1 = 1000 Ω, and R2 = 0.1 Ω, then R = (1000) (0.1) / 1000 + 0.1 = ~0.1 Ω

The current will always find the least resistive path in the circuit. If the resistors are equal then the current will equally split and the resulting resistance will be ½ the original value as shown in (#1). If one resistor is much smaller than the other, most of the current will flow through that one and the total resistance will be approximately equal to the smaller value as shown in (#2). For an analogy, think of placing the meter probes on top of a conductive material. The current will flow all throughout the material like resistors in parallel. The thicker the material, the lower the resistance, or resistivity.

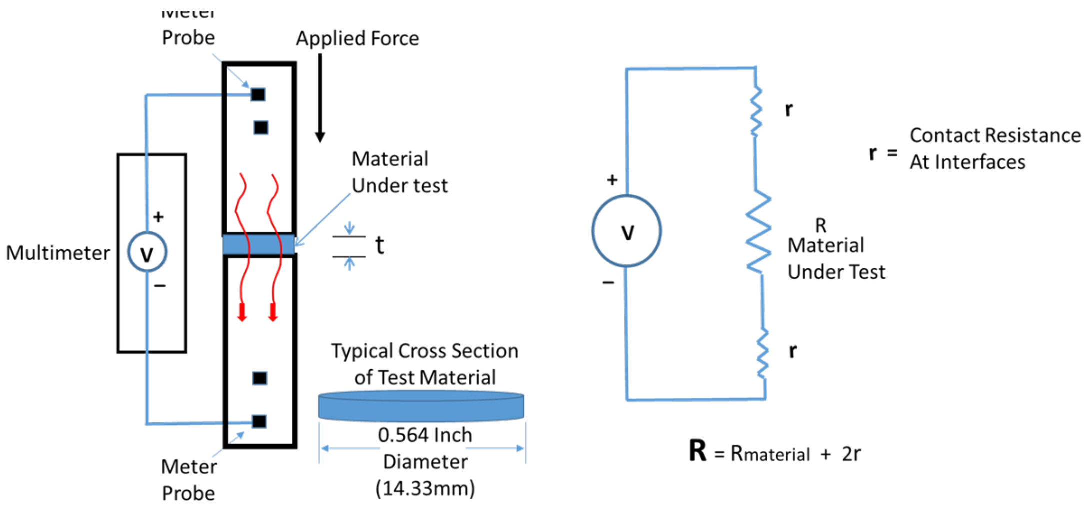
b) Now suppose the resistors are in series. For analysis purposes the value of the two resistors can be combined into a single resistor:



The resulting resistance is just the sum of the two. Think of placing the meter probes on top of a conductive material again. The resistance, or resistivity, will increase as the distance between the probes increases just like adding resistors in series.

PRESSURE PROBE

This test fixture is only used on small elastomer samples and is not use for thin films or coatings. Below is a blowup view of the pressure probe and test sample with red lines representing the current path. A simplified equivalent circuit is also drawn to show the different resistances.



Here, the meter creates voltage (V) between the top and bottom of the test specimen, which induces a current (I) up and down. The resistance R total is then measured, and is called the material's resistivity.

The volume resistivity p is then calculated from the equation:

$$p = RA/t$$

where

p = Volume Resistivity (Ω-cm)
R = Resistivity (Ω)
A = Surface Area (cm2)
t = thickness (cm)

Sample calculations using the typical specimen diameter = 1.433 cm:

a) To find the Volume Resistivity knowing: R = 0.02 Ω, A = 1.61 cm2, t = 0.50 cm,

Volume Resistivity p = RA/t = 0.02 Ω x 1.61 cm2/0.50 cm = 0.06 Ω-cm

b) To convert back to Resistivity:

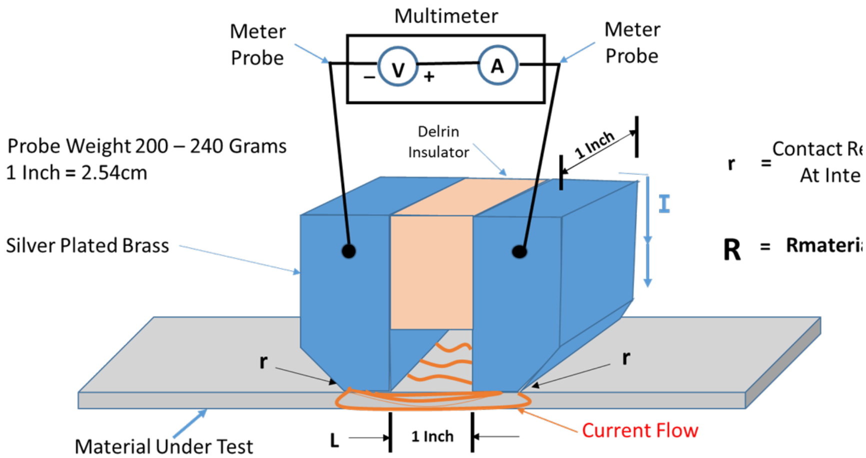
R = p t/A = 0.06 Ω-cm x 0.50 cm/1.61 cm2 = 0.02 Ω

Here are some takeaways based on the construction of the probe and how the current passes through the test specimen:

1. Because the test sample has a disk shape the same size as the electrode surface area, the
2. current path is very direct. Negligible current "bends" outside of the test area.
3. Controlled pressure over the entire electrode surface area reduces contact resistance and
4. error. Electrodes are coated with a silver layer to minimize oxidation.
5. This test directs current perpendicular to the material cross-section, which is atypical during normal shielding applications where the current flows parallel to the surface.
6. If you were to increase the material thickness, you would start to see the resulting resistivity increase just like 2 resistors in series. The calculated volume resistivity, however, will remain the same.

SURFACE PROBE (CHO-PROBE)

This test fixture is used on elastomers of all sizes as well as thin films and coatings. A blown-up view of the test specimen is sketched below with the induced current paths highlighted.



The circuit diagram would look the same as for the Pressure Probe, but the current path through the material is different. The meter creates a voltage at the probe terminals which induces a current parallel to the surface of the material. Current flow through the cross-section is what primarily occurs in shielding applications. The resistance through the material is then measured, and is called the material's resistivity. The volume resistivity is calculated using the equation:

p = RA/L

Where

p = Volume Resistivity (Ω-cm)

R = Resistance (Ω)

A = Cross-sectional area of the material = Thickness x Width (cm2)

L = Distance between the Probe Electrodes (cm)

Calculations are performed in the same manner as for the Pressure Probe, taking into consideration the different meaning of the area A for the Surface Probe.

Sample calculations using the actual probe dimensions of 1" x 1":

a) To find the Volume Resistivity knowing:

R = 0.02 Ω, A = 2.54 cm probe width x 0.50 cm material thickness, L = 2.54 cm,
Volume Resistivity p = RA/L = 0.02 Ω x 1.27 cm2/2.54 cm = 0.01 Ω-cm

b) To convert back to Resistivity:
R = p L/A = 0.01 Ω-cm x 2.54 cm/1.27 cm2= 0.02 Ω

A NOTE ABOUT THE SURFACE RESISTIVITY OF THIN MATERIALS
The resistance measurement procedure is the same as for elastomers. The current flow through the coating is the same. Varying the thickness, however, has a negligible impact on the results, and as such only the surface resistivity is of interest for very thin materials. It is a property of the material, and is expressed in ohms per square. The surface resistivity does not change as long as the measurement is performed using a probe with square dimensions.

For example, say you measure a resistance of 0.04 Ω using the 1" x 1" surface probe. The coating would have a resistivity of 0.04 Ω per square. If you then take another measurement using a 1m x 1m surface probe, the result will still be 0.04 Ω. This assumes of course that all other variables stay constant.

Here are some takeaways based on the construction of the probe and how the current passes through a test specimen:

1. The surface probe is a small, portable device and can be readily connected to a basic ohmmeter.
2. A fair amount of surface resistance between the probe and specimen can be a factor. Varying the contact pressure will change the measured resistance substantially. The electrodes are coated with a silver layer to reduce the contact resistance, but it wears unevenly over time due to the uneven application of pressure.
3. For materials extending beyond the probe contact surface area, stray current paths also exist beyond the probe. The effects are usually negligible but it is a factor.
4. The surface probe can be used on gaskets with narrow cross-sections. Simply use the actual material cross-section in the calculations.
5. This method of measurement creates current paths parallel to the surface of the material, which is more representative of how shielding gaskets actually work.
6. Increasing the material thickness by an appreciable amount will begin to reduce the resistivity, just like resistors in parallel. The calculated volume resistivity, however, stays the same.

CONCLUSION
It is helpful to have a basic understanding of the mechanisms involved in determining the resistivity of materials and the theory behind it. Care should be taken to account for contact resistance at the probe to material interface, and dimensions need to be accurately measured to obtain the correct results.

Parker Hannifin Corporation
Chomerics Division
77 Dragon Ct.
Woburn, MA, 01888
phone +1-781-935-4850
fax +781-933-4318