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**Surface and Volume Resistivity Test for
ESD and Power Cable Semicon Compounds**

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This method describes the procedure used to measure the resistivity of both Electrostatic Discharge (ESD) and power cable semi-conductive plastics containing carbon black at loadings varying between 10% and 50%.

The conductive performance of a carbon black is intrinsically a function of the type of carbon black and the quality of its dispersion.

Dispersion is in turn influenced by the compounding process.

The carbon black loading has a critical influence on the conductivity, resulting in higher conductivity with increasing loading (Figure 1).

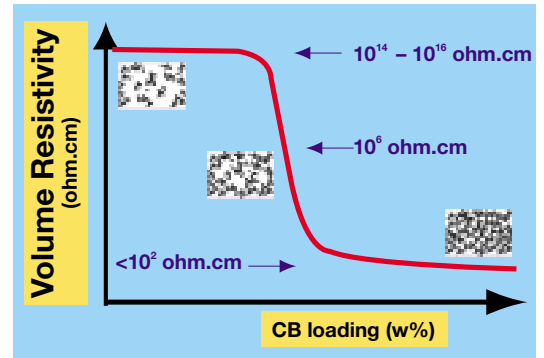


Figure 1: Percolation Curve for Volume Resistivity

Though high shear during the mixing can result in a better dispersion, loss of conductivity can result if an optimal value is exceeded.

Conductivity is also influenced by the processing step leading to the product to be tested.

Resistivity tests measure the sum of these effects.

Depending on the conductive features, carbon black compounds can be used in different applications. The range of resistivity obtainable with an ESD or semicon compound is shown in Figure 2.

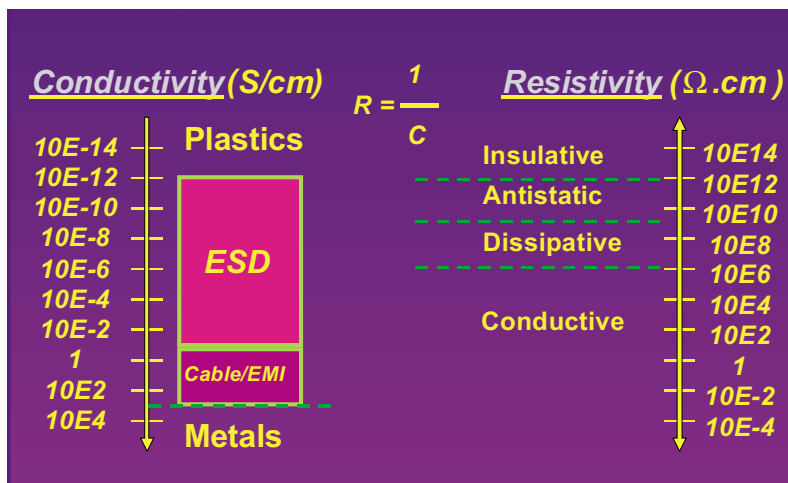


Figure 2: Range of conductivity/resistivity for the different carbon black compounds in conductive applications

Principle

When a potential difference is applied between two electrodes, a displacement of charges is observed, creating a current. The material offers a resistance to the flow of charges, governed by the Ohm law (Figure 3).

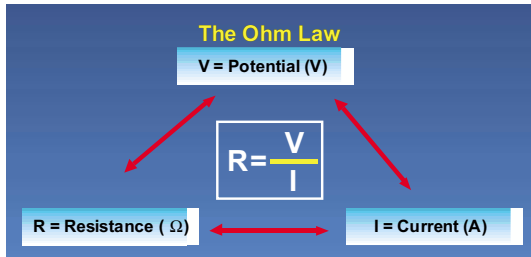


Figure 3: Ohm Law

V = Potential Difference (Volt) between the electrodes
I = Current (Ampere) = displacement of charges between electrodes
R = Resistance (Ohm) of the material to the flow of charges

Depending on the position of the electrodes, the current can be mainly in volume or along the surface of the specimen. However, in each case, both contributions are present (Figure 4).

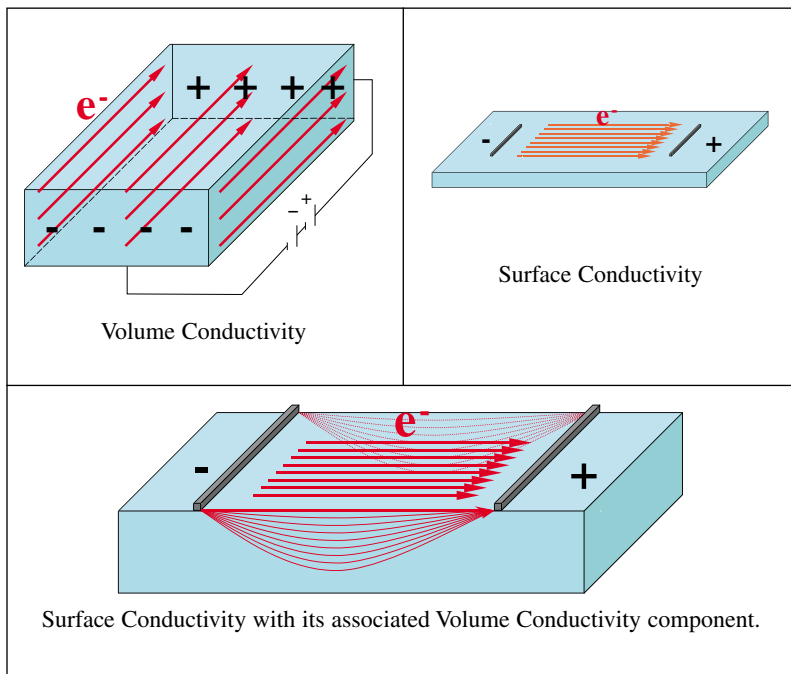


Figure 4: Differences between surface and volume electric current

Resistance (Ohm) depends on sample size, electrode type and electrode size. To obtain an intrinsic characteristic of the material, resistance is multiplied by a conversion factor leading to a value of resistivity.

Two different types of resistivity can be defined for ESD applications and power cable semicons:

- Surface Resistivity (SR) in Ohm/sq (Figure 5)
- Volume Resistivity (VR) in Ohm.cm (Figure 6 and Figure 8).

Cabot Surface Resistivity (SR) Test Description for ESD Compounds

Surface resistivity is measured according to Cabot Test Method (CMT) E042, based on the norm IEC167 (Figure 5).

Sample Preparation

Measurements are carried out on test samples prepared by injection molding, compression molding or extrusion, or directly on the final manufactured product.

Conditioning Procedure

Before testing, the samples are conditioned at 23°C, 50% RH for 4 hours.

Surface Resistivity (SR) Measurement

Two parallel electrodes of silver paint are applied, using an adhesive mask. Measurements are carried out at 23°C, 50% RH. The electrical resistance (Ohm) developed between the electrodes is measured.

SR is calculated, taking into account the geometry of the electrodes, with Equation 1.

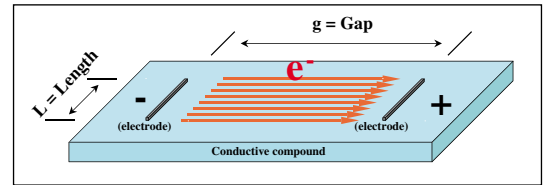


Figure 5: Surface Resistivity Test

Equation 1

$$SR = R * L / g$$

SR = surface resistivity (Ohm/sq)

R = resistance of the material to the flow of charge (Ohm)

L = length of the electrode (cm)

g = distance between the electrodes (cm)

Cabot Volume Resistivity (VR) Test Description for ESD Compounds (two-point method)

Volume resistivity is measured according to Cabot Test Method (CTM) E043, based on ASTM D4496 (Figure 6).

Sample Preparation

As for the SR, measurements are carried out on test samples or directly on the final manufactured product.

Conditioning Procedure

Before testing, the samples are conditioned at 23°C, 50% RH for 4 hours.

Volume Resistivity (VR) Measurement

Silver paint is applied to the opposite ends of the sample.

Measurements are carried out at 23°C, 50% RH. The electrical resistance (Ohm) developed between the electrodes is measured. VR is calculated, taking into account the geometry of the electrodes, with Equation 2.

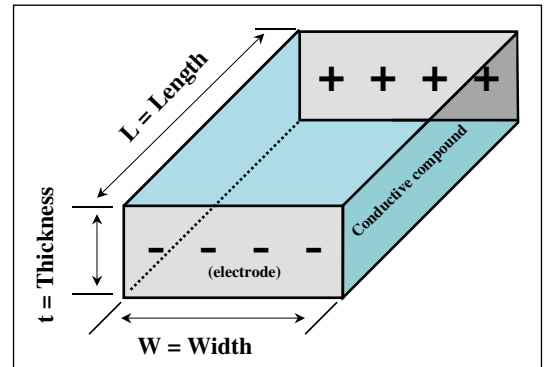


Figure 6: Two-point Volume Resistivity Test

Equation 2

$$VR = R * S / L$$

VR = volume resistivity (Ohm.cm)

R = resistance of the material to the flow of charge (Ohm)

S = surface of the electrode (cm²), defined as S = W * t

L = distance between the electrodes (cm)

Cabot Volume Resistivity (VR) Test Description for Power Cable Semicon Compounds (four-point method)

VR is measured according to Cabot Test Method (CTM) E043E. It is based on ISO3915. This approach is widely accepted by the industry, even though the preparation of the sample is done in a static way. The method has a very good reproducibility on molded semicon specimens.

Sample Preparation and Standardization

- **Compounding:** the compounding technology and conditions can affect the dispersion level and the volume resistivity of the inspected materials. When comparative study between carbon black grades is required, the same polymer base, carbon black loading, compounding technology and conditions have to be fixed.
 - Compounding equipment can be any of the standards used for semicon compounds, i.e. Banbury®, Buss Ko-Kneader®, Kobelco mixer®, etc.
 - Carbon black loading from 19% up to 45%.
- **Molding:** the material is compressed into a molded plaque in one step in a Fontijne® press equipped with a microprocessor. The dimensions of the plaque are 160 X 160 X 3 mm. To ensure the complete filling of the mold, the following amount of compounds should be weighed accurately to take into account the differences in specific gravity due to different carbon black loading (Table 1).

The press is first preheated to 180°C with the platens in contact for thirty minutes to reach the desired temperature. When the temperature is reached, the door is opened and the plates are separated to fill them with the compounds.

In order to allow a homogeneous melt, the pellets of material are distributed throughout the surface of the mold with the exceptions of the edges to avoid the loss of material when the pressure will be applied.

Two sheets of Mylar® are inserted between the plaques to facilitate the de-molding of the material.

The molding cycle takes seventeen minutes. The compound in the platens is first heated at 180°C during 10 minutes, then cooled down to 50°C before being removed. At the end of the program, the platen goes down automatically. The plaques are removed from the press and introduced in a small press cooled with water for several minutes to complete the cooling step. After de-molding, the plaque is put in a desiccator until it is cut into six specimens for testing.

Nomenclature	%CB	Weight (g)
A	19	76
B	22	78
C	24	79
D	25	79
E	28	80
F	32	82
G	35	84
H	38	85
I	41	87
J	45	89

Table 1: Amount of material versus CB loading

Conditioning Procedure

The six specimens to be tested have a width of 10 mm, a length of 70 mm and a thickness of approximately 3 mm. They are cut from the compression molded plaques with a Ceast® die cutter equipped with the adequate tool.

After their preparation, they are conditioned in an oven at 1 atmosphere and $60 \pm 2^\circ\text{C}$ for 5 ± 0.5 hours (Figure 7).

When conditioned, they are stored in a desiccator for at least 12 hours. Before testing, silver electrodes are painted at the center of the specimens (with the adequate tape glued onto them) as well as at their ends. Typically, the solvent is evaporated after 10 minutes.



Figure 7: Conditioning oven

Volume Resistivity (VR) Measurement

The schematic diagram of the test circuit is given in Figure 8.

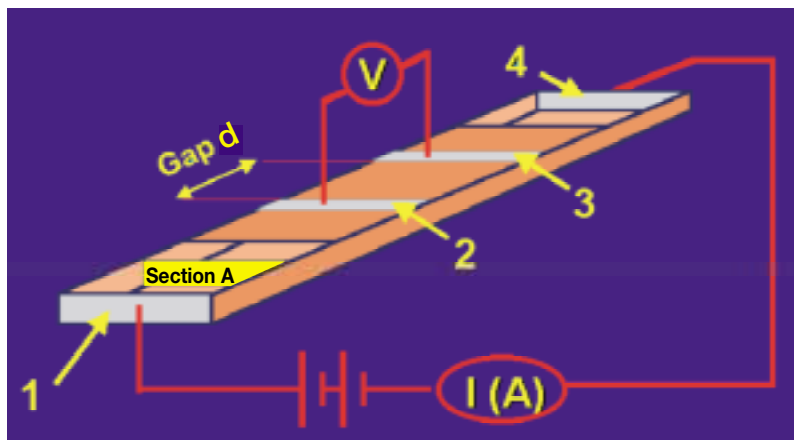


Figure 8: Four-Point Volume Resistivity Test

The potentiometric electrode system is placed on the silver lines at the middle of the specimen (the distance between them is 10 mm).

The current is therefore applied from the ends of the specimen, stabilized at 10.00 ± 0.01 mA and the voltage drop between the potentiometric electrodes is measured. The same procedure is repeated for the six specimens.

If the resistivity of the material is high, it is possible that the applied current will not reach 10.00 mA. In this case, the reading of the voltage drop can be done at 5.00 or 1.00 mA and will be taken into consideration during calculation of the volume resistivity.

Results

The resistivity is expressed in Ohm.cm and is calculated using Equation 3.

Equation 3

$$VR = V * A / (I * d)$$

V = potential difference between the potentiometric electrodes (Volts)

I = current through the specimen (Amperes)

A = cross-sectional area of the specimen perpendicular to the current flow (cm²), defined as $A = W.t$

d = distance between the potentiometric electrodes (cm)

W = width of the specimen

t = thickness of the specimen

In this procedure, the following parameters are kept constant.

Parameter	Setting
I	0.01A (10 mA)
d	1.0 cm
W	1.0 cm

Therefore, Equation 3 can be simplified as Equation 4.

Equation 4

$$VR = V * t * 100$$

If the resistivity of the specimen is too high, another current setting should to be used. Equation 4 can be modified

as: **VR = V*t*1000** if the current is 1 mA

or as: **VR = V*t*200** if the current is 5 mA.

This brochure provides general information relative to surface and volume resistivity tests fulfilled by Cabot to ensure the performance specifications of our products. Cabot representatives are available to provide any additional details related to the tests described in this brochure.

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