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TECHNICAL BULLETIN

Electrical Conductivity

Concerns over the conductivity of rubber compounds loaded with high levels of carbon black have arisen due to various forms of degradation reported in products such as automotive radiator hose. Electrical current through the hose due to direct contact with clamps and other metallic parts is believed to be the cause of cracking and fluid absorption.

The quantity and grade of carbon black used are key factors determining the conductivity of a rubber compound. In general, conductivity increases with carbon black loading, but at a decreasing rate as the loading reaches higher levels.

Electrical properties of carbon black are typically expressed as volume resistivity in ohm.cm units. The ohm is the basic unit f resistance and Ohm's law expresses the following relationship:

I = E/R
where,
I = Current in amperes
E = Potential in volts
R = Resistance in ohms

If a 1 volt potential is impressed across 1 ohm of resistance, 1 ampere of current will flow. Where resistance values are high, it is frequently convenient to use 1,000,000 ohms as the unit. This is called the megohm, whereby on megohm equals 1,000,000 ohms or 10^6 ohms.[1]

Three basic properties of carbon black are considered to affect the level of conductivity in rubber compounds. These are the particle size (or surface area), the degree of structure and the corresponding amount of void space between those particles, and finally porosity.

Small particle furnace blacks, with their high degree of chain-like structure or aggregation, and less void space between the particles, have higher levels of conductivity than thermal carbon blacks, which have large particles and more space between the particles due to the low degree of aggregation. The greater amount of structure acts to reduce the distance between particles or aggregates, thereby allowing electrical flow to pass easily through along the molecular chains. Thus, an inverse relationship exists between both surface area and structure and the level of resistivity.

Finally, with relatively more porosity than large particle carbon blacks, small particle size carbon blacks yield more particles per unit weight than compact solid spheres. This reduces the interparticle distance and promotes flow amongst particle chains.[2]

Other factors play a role in determining conductivity but not to the extent of the above noted properties. These are volatile type and content, moisture and extractable matters, all of which may act to inhibit or disrupt electron flow.

In addition to carbon blacks, other fillers may affect the inherent electrical properties of elastomers. Any one filler, however, may not affect the electrical properties of all elastomers to the same degree. The following base formula for a natural rubber compound is used to show the effect of various fillers on volume resistivity.[3]

Pale Creep NR	**100**
Stearic Acid	**2**
Zinc Oxide	**5**
Sulphur	**3**
Altax (accelerator)	**1**
Methyl Zimate (accelerator)	**0.1**
	111.1

Press cures: 15 minutes at 143°C

[1]John D. Hogan, "Wire and Cable" in the Vanderbilt Rubber Handbook, 13th ed., p. 704
2Corry, Brian R., "Carbon Black", in Katz, Harry S. and Milewski, Jon V., eds., Handbook of Fillers for Plastics, Van Nostrand Reinhold Company, New York, 1987, p. 406
3Hogan, Ibid., p. 717

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Effects of Fillers on Volume Resistivity (NR Compound) Ohm.cm

Loadings	Immersion Days at 70°C	Volume Resistivity
No Filler	0	4.4×10^{16}
	7	3.3×10^{16}
	14	1.4×10^{16}
Dixie Clay 50 phr	0	3.6×10^{15}
	7	2.2×10^{14}
	14	1.7×10^{14}
Calcined Clay 50 phr	0	4.3×10^{15}
	7	2.1×10^{14}
	14	2.1×10^{14}
Whiting (water ground) 50 phr	0	8.4×10^{15}
	7	1.9×10^{15}
	14	1.4×10^{15}
Thermax® N990 25 phr	**0**	$\mathbf{1.5 \times 10^{16}}$
	7	$\mathbf{1.9 \times 10^{16}}$
	14	$\mathbf{1.1 \times 10^{16}}$
Thermax® N990 50 phr	**0**	$\mathbf{2.5 \times 10^{10}}$
	7	$\mathbf{3.7 \times 10^{12}}$
	14	$\mathbf{4.1 \times 10^{12}}$
SRF Black N765 25 phr	0	9.1×10^{10}
	7	3.6×10^{13}
	14	9.5×10^{13}

Certain carbon blacks are being marketed as "low conductivity" blacks. The following is a comparison between a low conductivity carbon black (LCCB) that is made in Japan and Thermax® N990. Although essentially an FEF type of black with properties similar to an N550 grade, the comparative LCCB black is marketed to applications requiring high resistivity and reinforcement, such as automotive radiator hose.

Comparison of Thermax® N990 to Low Conductivity Carbon Black

Property	Thermax® N990	LCCB
Ash Content (%)	0.1	0.2
Heat Loss (%)	0	0.1
Sieve Residue 325 mesh (ppm)	3	27
Toluene Extract (%)	0.18	0.16
N_2 Surface Area (m^2/m)	9.5	26.6
Oil Absorption Number (cc/100 g)	38	123
pH	10	6.4

The data provides a comparison of the low conductivity carbon black and Thermax® N990 in EPDM compound.

Electrical Properties

Although testing was initially carried out to ASTM D257 at the normal 500 volts and at 100 volts, electrical readings were not obtainable. Using fresh samples, the voltage was reduced to 12 volts and comparative results were obtained.

Anti-static compounds are generally considered to have resistivities in the range of 10^8 to 10^4. At 12 volts, the Thermax® N990 compound gave volume and surface resistivities in the order of 10^7, which places the compound near the top of the anti-static range. On the other hand, the compound containing the low conductivity carbon black with resistivities of 10^4 is at the low end of this classification, below which it would actually become a conductive material.

Compound Properties

The LCCB provided a mooney viscosity which was too high to measure on the standard large rotor. Measurement using a smaller rotor showed a very high viscosity of 96, compared to the Thermax® compound viscosity of 77. Rheometer torque was substantially higher for the LCCB and curing time was four to five minutes shorter.

Vulcanizate Properties

As expected from an FEF type black, the LCCB gave a very stiff compound with hardness and tensile properties much higher than given by the Thermax®.

Accordingly, the ultimate elongation for the Thermax® compound is far higher than the LCCB compound. The LCCB has strong reinforcing characteristics, unlike the thermal carbon blacks, which are essentially non-reinforcing. Consequently, Thermax® could not be substituted directly for the LCCB without serious reduction in the physical property levels. This can be countered by blending small amounts of a FEF black with the Thermax® N990. Adequate green strength, for example, can typically be obtained by blending in 50 phr of FEF black.

Conclusion

Compared to general carbon blacks, the large particle, low structure thermal carbon blacks impart less conductivity to rubber compounds. Thermax® N990 was found to have lower conductivity (higher resistivity) than the low conductivity FEF type black currently marketed. However, as this LCCB grade has improved resistivity over conventional furnace blacks, there is potential for Thermax® N990 to be blended with it in order to provide highly loaded compounds having good processing and physical properties, without sacrificing resistivity properties in applications such as radiator hose. The high loading should provide sufficient economic justification.

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Low Conductivity FEF Carbon Black vs. Thermax® N990 in EPDM Compound

Formulation		
Vistalon 7000 EPDM	100	100
Stearic Acid	1	1
Zinc Oxide	5	5
Sunpar 2280	30	30
Thermax® N990	**160**	-
LC FEF Carbon Black	-	160
Sulphur	0.2	0.2
TMTD	1.5	1.5
TMTM	1.5	1.5
Butyl Zimate	1.5	1.5
Sulfasan R	2	2
Compound Properties		
Compound Viscosity @ 100°C	77.7	96.4
(M_L 1 + 4)		(small rotor)
Mooney Scorch Time @ 125°C		
Minutes to 5 pt. rise	26.43	19.38
		(small rotor)
Monsanto Rheometer @ 166°C (3° arc, 0 preheat, 100 range)		
Maximum Torque M_H (dNm)	100.75	148.37
Minimum Torque M_L (dNm)	10.61	38.89
Delta Torque	90.14	109.48
t_c50 (min)	8.62	5.03
t_c90 (min)	11.71	7.41
t_s2 (min)	3.48	2.49
Vulcanizate Properties		
Cure Time (Min @ 166°C)	14	9
Shore A Hardness	79	87
Modulus @ 100% Elongation (MPa)	3.5	12.3
Modulus @ 300% Elongation (MPa)	5.9	-
Modulus @ 500% Elongation (MPa)	9.2	-
Tensile Strength (MPa)	11.2	18.2
Ultimate Elongation (%)	575	195
Electrical Testing (Tested @ 12 volts)		
Volume Resistivity (ohm.cm)	45000000	23000
Surface Resistivity (ohm.cm)	240000000	49000