

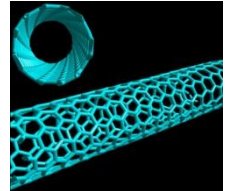


Specialty Multi-Walled (SMWTM) Carbon Nanotubes For Conductive and Anti-Static Plastics

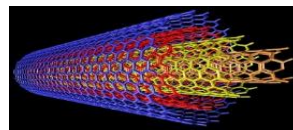
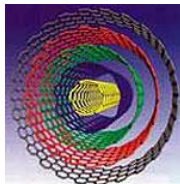
Over View: SMWTM100 Specialty Multi-Walled carbon nanotubes reduce electrical resistivity in the polymers studied at lower loadings than competitive products. They are morphologically more uniform and produce more uniform, consistent electrical conductivity. Advantages in compound physical and thermal properties are also observed.

Introduction:

Carbon nanotubes (CNTs) are a form of elemental carbon produced by one of a number of catalytic processes. They resemble graphite in that they consist of a network of carbon atoms arranged in six member rings. They can be thought of, in an oversimplification, as “rolled-up” sheets of graphite. A schematic of a section of a single-walled carbon nanotube (SWCNT) appears to the right. SWCNTs are on the order of one nanometer in diameter and one micron in length, corresponding to an aspect ratio (length/width) of about 1000. SWCNTs are expensive to produce and, currently, available in only small quantities, on the order of tens to hundreds of grams.



Multi-walled carbon nanotubes (MWCNTs) are produced in quantities of tens to hundreds of tons per year by a number of manufacturers and are available at much lower cost than single walls. As their name implies, MWCNTs exhibit a tube within a tube within a tube structure. See below.



In principle, both single and multi-walled CNTs can be used in plastic compounds to impart electrically conductive or anti-static properties. At present, high cost and lack of commercial quantities effectively rule out the use of single-walled tubes. Multi-walled tubes are used, but because conduction occurs along only the outermost wall, substantially higher loadings (weight %) are required, as compared to single-walled tubes. This can have adverse effects on the properties of the base polymer.

SouthWest Nano Technologies has bridged the performance gap between single and multi-walled CNTs with the introduction of a specialty multi-walled tube, SMWTM 100. SMWTM 100 tubes have fewer walls (3 to 7) compared to conventional multi-walls (10 to 20+). Since conduction occurs on only the outermost wall, SMWTM100 tubes have more conducting surfaces per unit weight than conventional multi-walled tubes. In effect, conventional multi-walled tubes are carrying the “dead weight” of a significantly larger number of internal, non-conducting tubes.

SMW™ 100 CNTs are also a high purity product and exhibit fewer wall defects than conventional MWCNTs. They also have a higher and a more precisely controlled aspect ratio than conventional MWCNTs. These properties promote more consistent and reproducible electrical results in conductive compounds.

Typical Properties of SMW™100 carbon nanotubes:

- Bulk Density: 0.22 gcm⁻³
- Number of Walls: 3 to 6
- Diameter: 6 to 9 nm
- Length: about 5 microns
- Carbon Content: 98%

Performance in Plastics:

SMW™100 nanotubes and competing MWCNTs from three suppliers were evaluated in Polycarbonate.

Chart 1 shows micrographs of the four nanotubes. The non-uniformity of tube diameters is particularly evident in samples “Competitor” A and B. Also shown – green line – are the results of thermo gravimetric analysis (TGA). The point at which this line flattens at the right of the graph indicates the residual (non-carbon) material in the tubes. The blue line is the derivative of the TGA curve. The temperature at its maximum is taken as the thermal stability of the material.

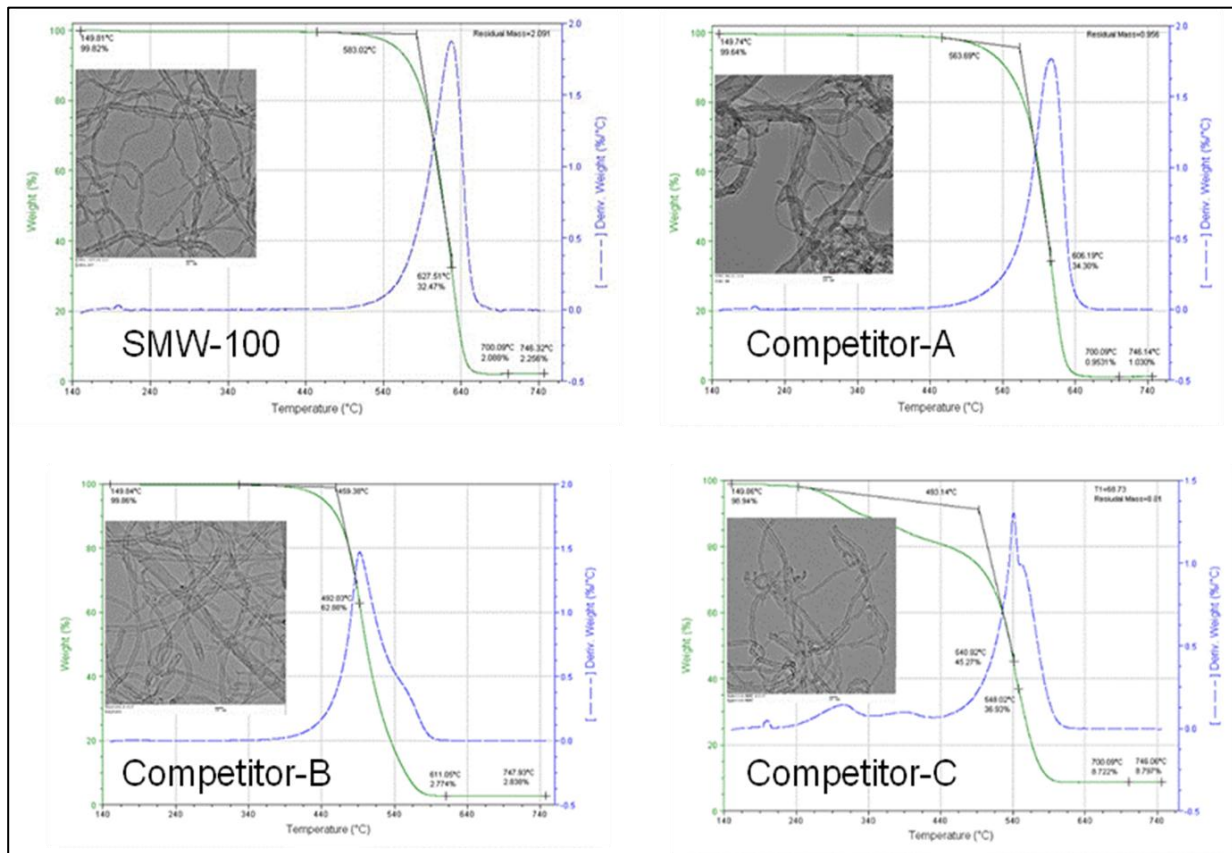
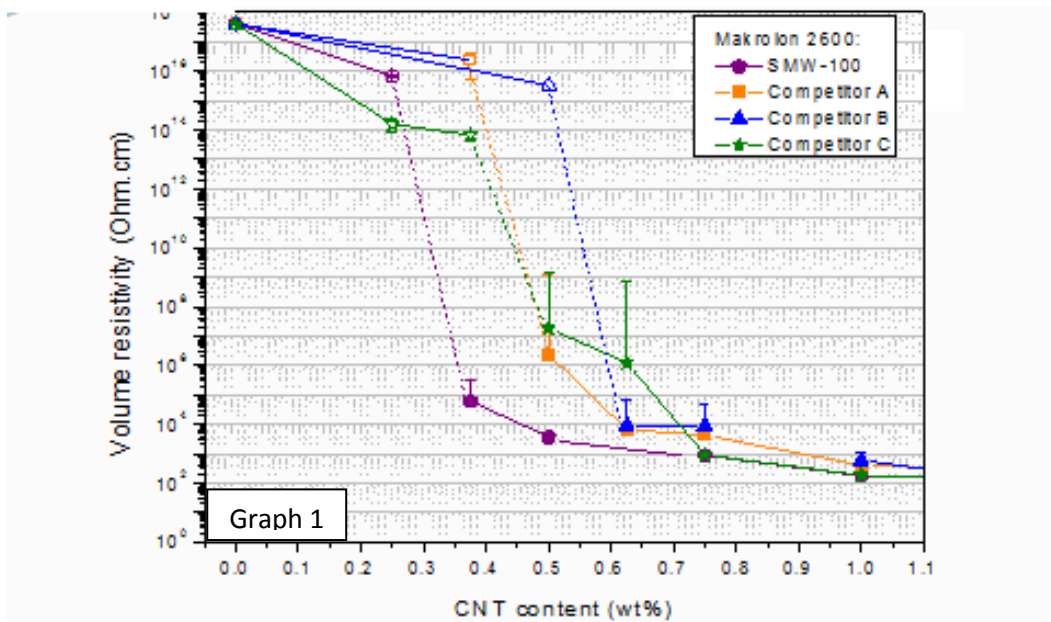


Chart 1

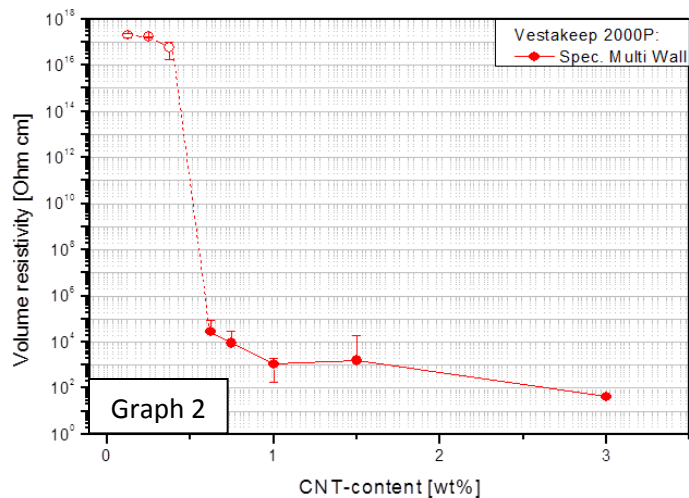
Table 1 shows electrical resistivity, thermal stability and residue data and Graph 1 depicts resistivities vs. weight % nanotube loading in polycarbonate. It is seen that lower loadings of SMW tubes are required to achieve percolation, the point at which a conductive network has been established and resistivity falls off rapidly. Lower loadings are also needed to reach specific values for volume resistivity. Additionally, the SMW compound is the most thermally stable.

Carbon Nanotube	Median Diameter (nm)	Percolation Threshold (wgt %)	Loading to achieve 10^4 (ohm/cm) Volume Resistivity (wgt %)	Loading to achieve 10^2 (ohm/cm) Volume Resistivity (wgt %)	Thermal Stability (degrees C)	Residual material (wgt %)
SMW-100	6.7	0.33	0.40	1.0	628	2.0
MWNT A	7.9	0.50	0.60	1.25	606	0.96
MWNT B	12.0	0.60	0.75	1.35	492	2.7
MWNT C	9.7	0.50	0.65	1.1	548	8.8

Table 1



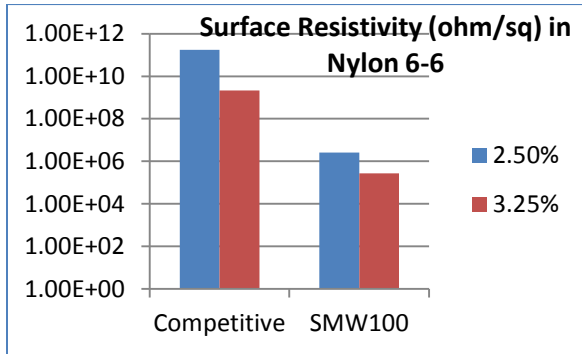
Graph 2 shows that SMWTM 100 also produces percolation below 0.5% loading in polyetheretherketone (PEEK), a thermoplastic with excellent chemical resistance, mechanical properties and high temperature performance. In independent studies



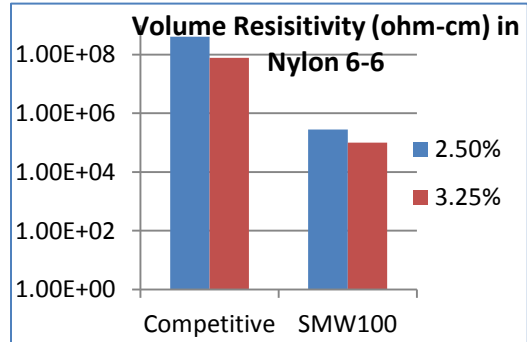
The data for Graphs 1 and 2 are used with the permission of Dr. Petra Potschke, Leibniz Institute of Polymer Research, Dresden, Germany

in nylon 6-6, SouthWest Nano Technology's SMW™ 100 carbon nanotubes were compared to a competitive product for volume and surface resistivity at 2.50 and 3.25 weight % loadings. In both instances, the resistance of the compound based of SMW100 tubes at 2.5% loading was lower than that of the compound based on competitive product at 3.25% loading by more than two orders of magnitude. (Graphs 3 and 4)

The study concluded, in part, that composites based on SMW 100 tubes also "...showed more uniform resistance values, with a narrower range of standard deviation..."

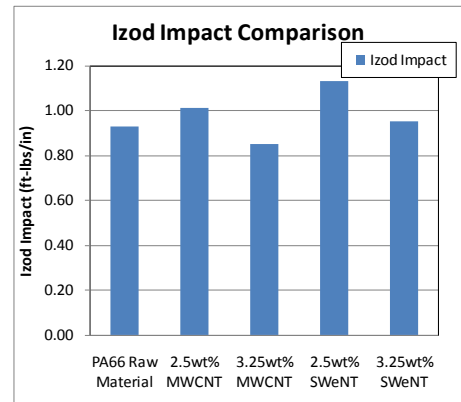


Graph 3



Graph 4

This same study also found that despite 2+ orders of magnitude lower resistivity, the SouthWest Nano Technology (SWeNT) based nanotube compound at 2.50% loading had a notched IZOD impact strength value nearly one third higher than the compound based on competitive nanotubes at the 3.25% loading. (Graph 5)



Graph 5



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