Solutions

INNOVATION

Hyperion Catalysis

THE LEADER IN NANOTUBE TECHNOLOGY

Preservation of Physical Properties in Molded Parts Using Compounds with **FIBRIL™ Nanotubes**

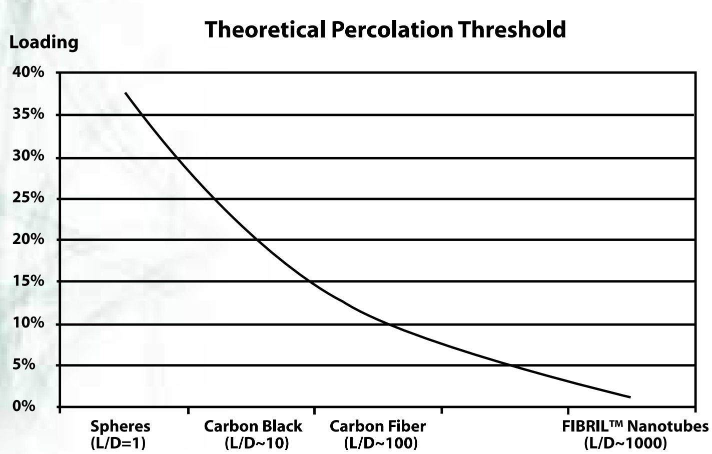
NANOTUBES' SMALL SIZE & HIGH ASPECT RATIO YIELD MULTIPLE BENEFITS

FIBRIL™ nanotubes from Hyperion bring electrical, mechanical, and aesthetic benefits to applications that require precisely controlled electrical conductivity and maintenance of maximum properties of the neat resin. FIBRIL™ nanotubes accomplish this primarily through their small size and high aspect ratio, which enable them to form a highly efficient conductive network when properly dispersed in a polymer matrix.

FIBRIL™ Nanotube Attributes	Feature	Benefit
Small Size & High Aspect Ratio	• Approximately 10-12 nm in diameter & 10-15 µm long • Size and shape form highly efficient electrical network within the volume of a part	• Minimal effect on surface quality • Isotropic dispersion for uniform conductivity and mold shrinkage • Lower loadings to meet electrical specification (resistivity, conductivity, etc.) compared with alternatives – Minimal change to neat resin's mechanical properties – Minimal increase in melt viscosity for easy processing

LOWER LOADING LEVELS VS. ALTERNATIVE CONDUCTIVE ADDITIVES

FIBRIL™ nanotubes exhibit high conductivity thanks to their graphitic carbon structure, nanoscale size, and high aspect ratio (length/diameter (L/D)).



The graph at left illustrates the calculated relationship between aspect ratio and filler level required to achieve percolation threshold in plastics. At the 1-5% loadings of FIBRIL™ nanotubes typically required to achieve electrical conductivity in plastics, there is a higher preservation of the base resin's physical, mechanical, aesthetic, and processing properties, such as toughness, surface smoothness, and low viscosity.

INDEPENDENT STUDY VERIFIES NANOTUBES HAVE LEAST IMPACT ON BASE RESIN PROPERTIES

An independent study – conducted by the Centre de Recherches Scientifiques et Techniques de L'Industrie des Fabrications Metalliques (CRIF) in Belgium – evaluated three commercially available grades of conductive PC/ABS compounds made from FIBRIL™ nanotubes, carbon black, and carbon fiber. Each compound was formulated to achieve roughly comparable surface resistivity levels needed for ESD performance.

Additive	Loading (Wt-%)	Volume Resistivity (Ω-cm)	Surface Resistivity (Ω/sq)
None	0	$1x10^{16}$	Not Available
FIBRIL™ Nanotubes	7.3	$1x10^{1}$ to $1x10^{3}$	$1x10^{4}$ to $1x10^{6}$
Carbon Black	16.7	$<1x10^{3}$	$<1x10^{6}$
Carbon Fiber	13.7	$<1x10^{3}$	$<1x10^{6}$

In actual practice, the recommended FIBRIL™ nanotube loading is generally less than half that of the 7.3% evaluated in the CRIF study. Even at the relatively high loading used in this study, FIBRIL™ nanotubes provided the best performance vs. carbon fiber and carbon black.

BETTER PROPERTIES = BETTER MOLDED-PART PERFORMANCE

Higher Base Resin Ductility. Use of particulate additives with most resins causes a decrease in resin ductility, especially at low temperatures. Although coupling treatments lessen this effect, they are rarely used with conductive formulations because they reduce conductive efficiency and can cause other problems in applications requiring chemical cleanliness. FIBRIL™ nanotubes, which are both extremely small and also free of coupling agents and other surface treatments, have measurably less effect on resin ductility than other conductive alternatives. The following table shows the results from the CRIF study. Note the dramatic difference in elongation at break vs. both alternatives, and the large gain in unnotched Izod strength exhibited by nanotubes compared to carbon fiber.

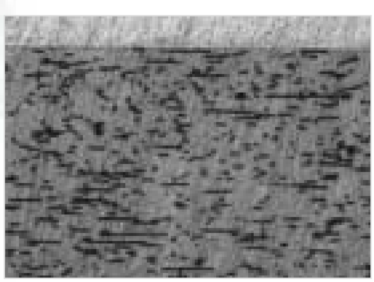
Additive	Loading (Wt-%)	Elongation at Break (%)	Unnotched Izod (ft-lb)	(Nm)
None	0	100	No Break	No Break
FIBRIL™ Nanotubes	7.3	10+	30	40
Carbon Black	16.7	3	10	14
Carbon Fiber	13.7	1 to 3	4	5

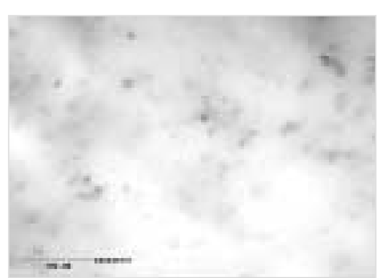
Smoother Surface Finish. Yet another benefit of using FIBRIL™ nanotubes is superiority of surface finish – both in terms of low particle sloughing and high part aesthetics. An area critical to many applications, part smoothness, is measurably better with FIBRIL™ nanotubes than with alternative conductive additives. Not only are loading levels lower with FIBRIL™ nanotubes, but also the extremely small size of these particles results in far less change to the molded part surface. In the CRIF study, a surface profilometer was used to measure average surface roughness (R_a) on plaques produced using a mirror-surface mold. The following table summarizes the results.

Additive	Loading (Wt-%)	R_a (µm)
None	0	0.019
FIBRIL™ Nanotubes	7.3	0.025
Carbon Black	16.7	0.035
Carbon Fiber	13.7	0.426

In addition, photomicrographs of a numeral 5 machined into a test plaque shows that the nanotube compound yields much sharper moldings. The tangential segments that make up the curve on the 5, clear on the nanotube molding (left frame), begin to soften and fade on plaques molded from the carbon black compounds (middle frame), and are almost totally absent on the plaques containing carbon fiber (right frame). The milling passes on the background are similarly distinct on the nanotube plaque, but begin to degrade in quality with carbon black and, especially, carbon fiber compounds.

Uniform Additive Distribution within a Part. Uneven distribution of conductive additives in a molded part can cause differing levels of conductivity, particularly at corners, openings, or other three-dimensional details. FIBRIL™ nanotubes are randomly aligned because their small size makes them relatively shear-insensitive. Random orientation of FIBRIL™ nanotubes helps ensure a uniform level of conductivity in complex parts as well as large parts with multiple gates. The figures below – the left, a light transmission photomicrograph of a microtomed section of a carbon-fiber-filled injection molded bar; the right, a transmission electron micrograph (TEM) of an ultramicrotomed section of a nanotube-filled injection molded bar – illustrate the random (isotropic) distribution of FIBRIL™ nanotubes in the polymer matrix vs. the more oriented (anisotropic) configuration of carbon fiber. The more isotropic the fiber orientation, the more balanced the dimensional stability, shrinkage, and other properties in the X, Y, and Z axes of a part.

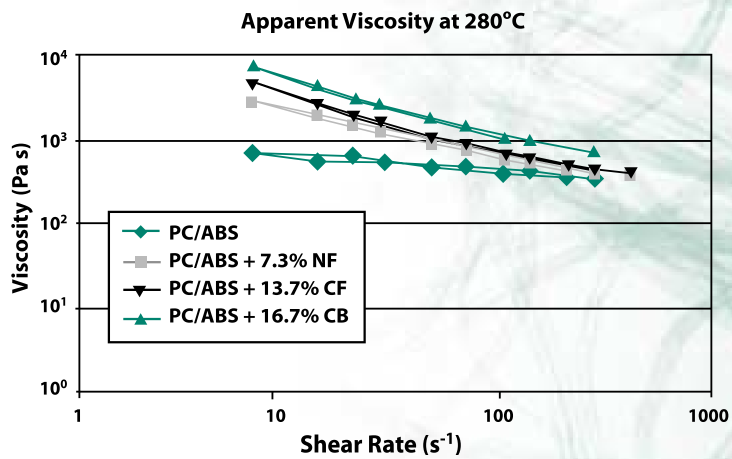




Relative dimensional stability (measured as differential shrinkage, the ratio of shrinkage in the flow vs. cross-flow direction) was also evaluated in the CRIF study. Because of their random orientation in molded parts, differential shrinkage for the very-high aspect ratio nanotubes was almost the same as that for nearly spherical carbon black, and much lower than that for carbon fiber.

Additive	Loading (Wt-%)	Differential Shrinkage[(a)]
None	0	1.03
FIBRIL™ Nanotubes	7.3	0.96
Carbon Black	16.7	0.97
Carbon Fiber	13.7	0.92

[(a)] *Ratio of shrinkage in flow direction divided by shrinkage in transverse direction*

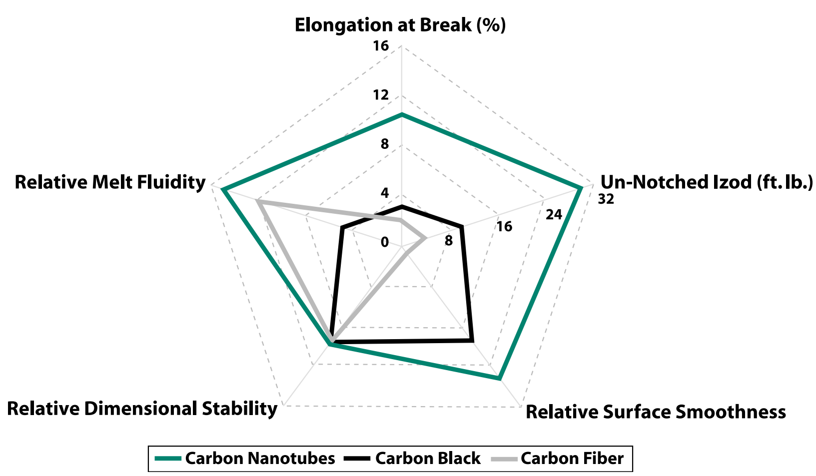


Better Retention of Neat Resin Melt Fluidity.
Compounds containing nanotubes have a relative melt fluidity - expressed as apparent viscosity - that is more like that of the neat resin. This means easier processing for thin-wall or long-flow parts. The chart above shows apparent viscosity of the test materials at 280°C.

BETTER PERFORMANCE, BETTER PARTS

FIBRIL™ nanotubes offer significantly better compound performance and aesthetics than carbon black or carbon fiber because nanotubes are more efficient at building a conductive network. Better preservation of neat resin performance means better parts and more successful applications.

The spider chart below summarizes the data discussed, comparing five important resin properties - elongation at break, unnotched Izod, relative surface smoothness, relative dimensional stability, and relative melt fluidity - of compounds containing FIBRIL™ nanotubes, carbon black, and carbon fiber.



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