and Space Administration (NASA) use chemical force microscopy to produce detailed information about adhesion between single-walled carbon nanotubes (SWNTs) and molecules of polymers with different functional groups. Their goal is to combine carbon nanotubes with lightweight polymers to produce composite materials with properties attractive for use on future space vehicles.

"Our hypothesis is that the stronger the adhesive interaction between molecules and nanotubes, the more likely it is that the polymer will fully wet the nanotubes, break up aggregations of nanotubes, and form a mechanically sound composite," said Larry Bottomley, a professor in the Georgia Tech School of Chemistry and Biochemistry. "The intent is to come up with two or three chemical groups that will give us the strongest interaction, and then incorporate these onto polymers for further studies."

Instead of using atomic force microscopy to map a surface, the researchers used the cantilever beam and deflection measurement to study the adhesion force between alkanethiol molecules on the microscope tip and nanotubes on the surface. As reported on March 23 at the 225th American Chemical Society National Meeting in New Orleans, the researchers raised a surface composed of nanotube bundles until it contacted the tip. When the nanotubes on the surface contacted the alkanethiols on the tip, they adhered to it. When the surface was lowered, the adhesive force between nanotubes and polymer pulled the cantilever down.

"If there are no adhesive interactions between the tip and the sample surface, the cantilever tip just lets go cleanly when you lower the surface," Bottomley said. "If there is strong adhesive interaction, the adhesive interaction bends the cantilever down until the restoration force of the cantilever exceeds the adhesive force. That provides a direct measurement of the adhesion."

The adhesion forces they are measuring with this method are in the nano-Newton range. Instead of a three-dimensional map of the surface, the technique produces a force volume image showing adhesion force variations across a two-dimensional surface.

From that information, Bottomley and collaborators M.A. Poggi of Georgia Tech and P.T. Lillehei of NASA judge which polymers—and functional groups—provide the best adhesion to the nanotubes.

"We find dramatic differences in the adhesive interactions with subtle changes in the chemistry of the tip," Bottomley said. "You have the strongest interactions in the amine-terminated samples compared to the methyl-terminated, hydroxyl-terminated, and carboxyl-acid-terminated composites."

Carbon nanotubes tend to clump together into bundles, which can pose problems in composite manufacture. If the polymer does not interact with or "wet" the nanotubes individually, the result is a mechanical defect that will weaken the resulting composite, the researchers said.

Bottomley said, "The real challenge is distributing the nanotubes throughout the polymer in a proper orientation."

Silica-Reinforced Rubber Provides a Temperature-Resistant Mount

L. Reuvekamp from the University of Twente has mixed silica and rubber to produce a tire with a low rolling resistance, which will result in reduced fuel use for vehicles. Under a grant through the Netherlands Organization for Scientific Research, Reuvekamp mixed silica and rubber under the influence of organosilane. Tire manufacturers normally use carbon black instead of silica to strengthen the rubber of car tires. The organosilane used by Reuvekamp and colleagues acted as a coupling agent. It binds to the surface of silica and rubber, linking together two substances that can scarcely be coupled otherwise.

The ideal coupling temperature was determined experimentally. A temperature of at least 130°C is needed for the coupling agent to react with silica. The reaction temperature cannot go above 150°C or the rubber will vulcanize and become too hard for further processing.

The researchers discovered that zinc oxide, which is an essential part of the final tire, disrupts the coupling. However, they found that zinc oxide could be added after the coupling reaction without an adverse effect.

The researchers said that silica grain size influences the rolling resistance, and silica split into minute particles reduced this the most. The researchers have applied for a patent. □