Tiny Tubes Could Make Space Missions More Affordable and Productive

A Weighty Problem for NASA

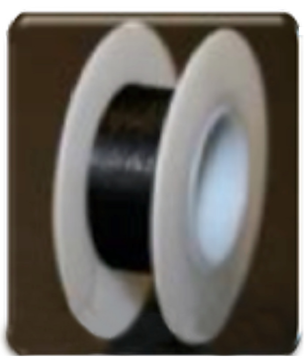
The more something weighs on Earth, the more it costs to launch it into space, so NASA needs materials that are very lightweight yet very strong. NASA's Nanotechnology Project is addressing this need by developing high-strength carbon nanotube (CNT) materials.

Strong, Lightweight Materials

CNTs are hollow carbon tubes with walls that are only one to a few carbon atoms thick, lengths that are less than 1 centimeter, and diameters of about 10 nanometers. Despite being about 100,000 times thinner than a human hair, CNTs are more than 50 times stronger than steel because of the strong chemical bonds between carbon atoms.

Replacing conventional, carbon-fiber-reinforced composites with 50-percent lighter composites that are reinforced with CNT tapes, fibers, and yarns could reduce the unfueled weight of space vehicles and structures by up to 30 percent. NASA's goals are to develop CNT reinforcements with twice the strength of conventional aerospace carbon fiber and to demonstrate the benefits of their use in reducing the weight and improving the durability of aerospace structures, such as composite overwrap pressure vessels.

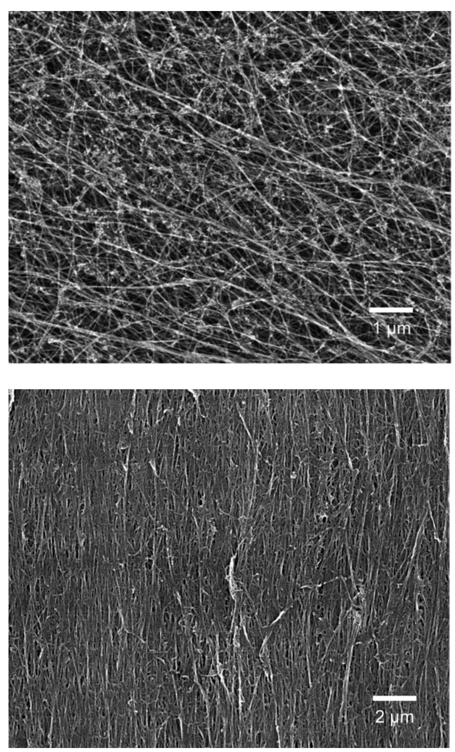
CNT yarns, sheets, and tapes have been produced commercially, but these materials have a tensile strength (resistance to damage during pulling or stretching) that is only half that of conventional carbon fibers. Fiber strength depends on how the nanotubes are aligned and packed; how straight, pure, and free from defects they are; and the attractive forces between them. For maximum strength, nanotubes should be aligned parallel to the fiber length. In current CNT fibers, only about 40 to 50 percent of the nanotubes are aligned. Tensile strength also suffers because of poor attractive forces (van der Waals forces) between nanotubes, which allow the CNTs to slide against each other easily during pulling.



CNT yarn.

NASA Solutions

The Nanotechnology Project team, led by the NASA Glenn Research Center, includes six NASA centers, two universities, and two CNT manufacturers. The project, which is funded by NASA's Game Changing Development Program, also collaborates with researchers supported by other Federal agencies. The team is working to increase the tensile strength of commercially available CNT materials by finding ways to produce longer, higher quality, purer nanotubes and by developing chemical treatments that tie the nanotubes together (cross-linking). Longer, better aligned nanotubes increase van der Waals forces



Magnified images of CNTs before (top) and after (bottom) stretching and infiltrating with a polymer.

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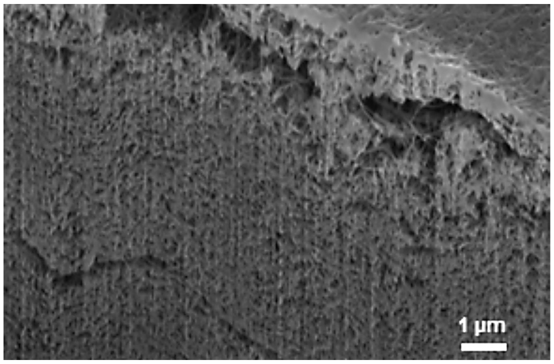

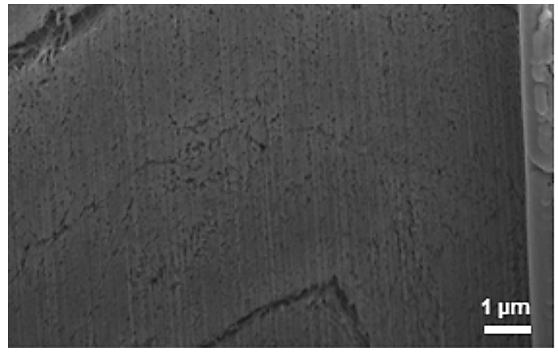

Scanning electron microscope images of cross sections of CNT yarns before and after irradiation with an electron beam.

and lead to greater strength. One approach to improving alignment is to stretch the nanotube materials. For example, stretching CNT sheets increases their specific strength and modulus by more than 300 percent because of better alignment and smaller gaps between nanotubes.

Modeling and simulation studies suggest that cross-linking could result in CNT fibers with tensile strengths as much as 5 times higher than those of conventional aerospace carbon fibers. Several methods are being explored to cross-link nanotubes, including the use of electron beam irradiation and reactive molecules. Early experimental results from these studies show that cross-linking could triple the specific tensile strength of CNT materials. Further increases in tensile strength are possible by cross-linking stretched sheets.

The team is working on developing techniques to characterize the effects of different cross-linking treatments on the structure of CNT reinforcements. One method uses an ion beam to machine a slit into a CNT yarn to reveal a cross section of the material so that it can be imaged in an electron microscope. Using this advanced technique, NASA scientists have observed that the distances between the CNTs in the yarn become smaller when the yarn is irradiated with electron beams. This is due to the formation of chemical bonds between the CNTs that tie them together into tighter, stronger bundles.

Processing methods are being developed to incorporate these reinforcements into composites. Processing of composites with CNT reinforcements can be challenging because of the low surface activity of the nanotubes. This can lead to poor-quality composites that have high porosity and incomplete polymer distribution. These defects can weaken the composite and cause premature failure. To counteract this, NASA scientists have developed a processing method that heats the CNT reinforcements with an electric current during composite processing to cause the polymers to better flow into the reinforcements. This produces composites with more than twice the specific strength of the CNT reinforcement.

In fiscal year 2014 and 2015, the team plans to

- Scale up production of CNT fibers, tapes, and sheets
- Test CNT-reinforced composites in different forms (strands, panels, and cylinders) under use conditions similar to those of composite overwrap pressure vessels
- Design, build, and test a subscale CNT-reinforced composite overwrap pressure vessel
- Perform a sounding rocket flight test on a subscale CNT-reinforced composite overwrap pressure vessel to assess its durability during launch and landing

Future CNT Materials

Someday, NASA could use CNT-reinforced composites as structural materials in launch vehicles, habitats, satellites, and rovers. These materials could also be used in commercial and military aircraft, automobiles and transportation systems, and blades for wind turbines.

The Game Changing Development (GCD) Program investigates ideas and approaches that could solve significant technological problems and revolutionize future space endeavors. GCD projects develop technologies through component and subsystem testing on Earth to prepare them for future use in space. GCD is part of NASA's Space Technology Mission Directorate.

For more information about GCD, please visit
http://gameon.nasa.gov/