Frustration inspires new form of graphene

October 14 2011

They're the building block of graphite – ultra-thin sheets of carbon, just one atom thick, whose discovery was lauded in 2010 with a Nobel Prize in Physics.

The seemingly simple material is graphene, and many researchers believe it has great potential for many applications, from electronic devices to high-performance composite materials.

Graphene is extremely strong, an excellent conductor, and with no internal structure at all, it offers an abundance of surface area – much like a sheet of paper.

When it comes to producing and utilizing graphene on a large scale, however, researchers have come upon a major problem: the material's tendency to aggregate. Like paper, graphene sheets easily stack into piles, thus greatly reducing their surface area and making them unprocessable.

Researchers at Northwestern University have now developed a new form of graphene that does not stack. The new material – inspired by a trash can full of crumpled-up papers – is made by crumpling the graphene sheets into balls.

A paper describing the findings, "Compression and Aggregation-resistant Particles of Crumpled Soft Sheets," was published October 13 in the journal *ACS Nano*.

Graphene-based materials are very easily aggregated due to the strong interaction between the sheets, called "Van der Waals attraction." Therefore, common steps in materials processing, such as heating, solvent washing, compression, and mixing with other materials, can greatly affect how the sheets are stacked. When the paper-like sheets band together – picture a deck of cards – their surface area is lost; with just a fraction of its original surface area available, the material becomes less effective. Stacked graphene sheets also become rigid and lose their processability.

Some scientists have tried to physically keep the sheets apart by inserting non-carbon "spacers" between them, but that changes the chemical composition of the material. When graphene is crumpled into balls, however, its surface area remains available and the material remains pure.

"If you imagine a trash can filled with paper crumples, you really get the idea," says Jiaxing Huang, Morris E. Fine Junior Professor in Materials and Manufacturing, the lead researcher of the study. "The balls can stack up into a tight structure. You can crumple them as hard as you want, but their surface area won't be eliminated, unlike face-to-face stacking."

"Crumpled paper balls usually express an emotion of frustration, a quite common experience in research," Huang says, "However, here 'frustration' quite appropriately describes why these particles are resistant to aggregation – because their uneven surface frustrates or prevents tight face-to-face packing no matter how you process them."

To make crumpled graphene balls, Huang and his team created freely suspended water droplets containing graphene-based sheets, then used a carrier gas to blow the aerosol droplets through a furnace. As the water quickly evaporated, the thin sheets were compressed by capillary force into near-spherical particles.

The resulting crumpled graphene particles have the same electrical properties as the flat sheets but are more useful for applications that require large amounts of the material. The ridges formed in the crumpling process render the particles a strain-hardening property; the harder you compress them, the stronger they become. Therefore, the crumpled graphene balls are remarkably stable against mechanical deformation, Huang said.

"We expect this to serve as a new graphene platform to investigate application in energy storage and energy conversion," Huang said.

Provided by Northwestern University