Wear it, launch it, drive it—the many shapes of carbon

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What is as thin as an eggshell, yet strong enough to withstand a space launch?

What has been used to make both car springs and artificial human heart valves?

What do burnt toast and diamonds have in common?

Answer: Carbon, and carbon-based materials.

Dr. Robert Meyer, head of the Materials Sciences Laboratory's Carbon and Polymers Department, discussed this versatile material at an Aerospace Colloquium recently.

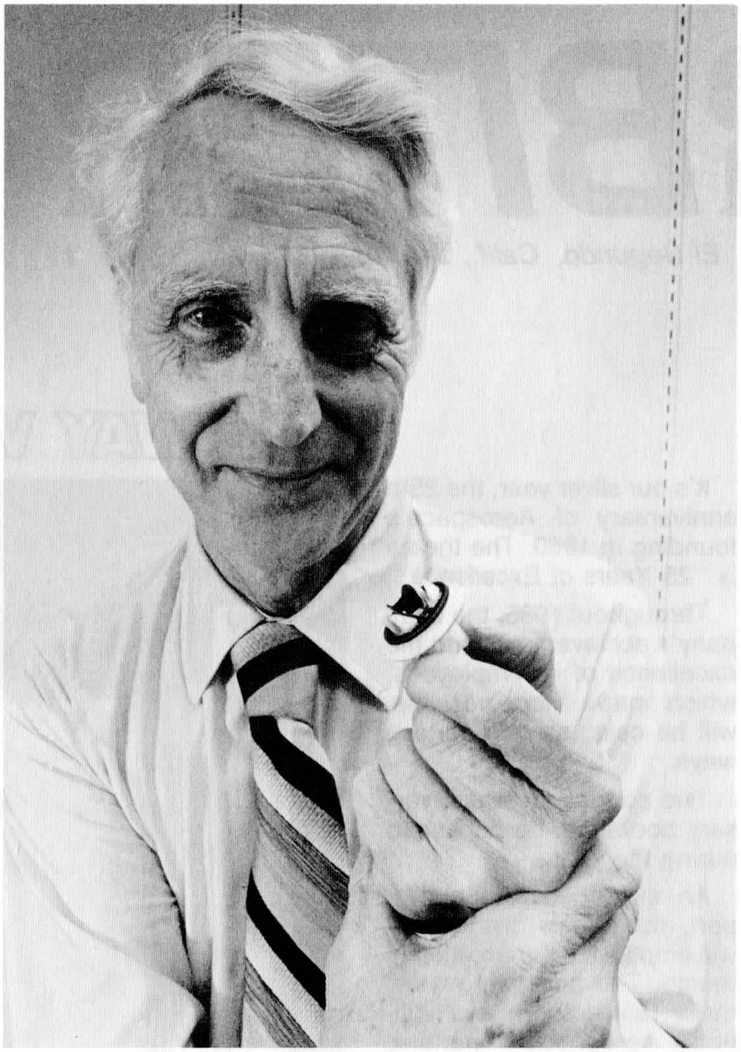
Carbon has a variety of forms and properties which make it useful in damaging environments like nuclear reactors and space vehicles. Dr. Meyer's career has been spent studying the many ways you can "beat upon" carbon without destroying it. He has also devoted time to understanding why carbon has such amazing properties and to develop useful things to do with this miraculous material.

"Carbon takes on different states depending on its raw material, temperature and pressure at the time it was formed," he said. "At relatively low temperatures and pressures it turns into the black stuff on burnt toast. At very high temperatures and pressures it becomes a diamond. Somewhere in between, it takes on the form of graphite, which constitutes the lead in your pencil.

"Graphite's unique properties result from its structure," Dr. Meyer continued. "Carbon atoms line up in flat planes, with very strong bonds between atoms. The planes are stacked, which creates weak bonding forces between planes. Planes can be perfectly stacked or they may be twisted or crosslinked. Different orientations of the stacked planes result in different material properties."

Graphite that is highly oriented, that is, with all the stacks lined up, comes in the form of fibers about 1/7 the thickness of a hair, he explained. These fibers are stronger than steel at very high temperatures. Also, for the same strength as steel, they weigh much less.

Carbon composites are made by embedding these fibers in a matrix. Different matrices produce materials that can be used in an immense variety of products. Carbon fibers in an organic matrix can be used for skis and other sports equipment. In a ceramic matrix, they can be used as reinforced concrete.



Dr. Robert Meyer and artificial human heart valve

John Gambrell photo

Carbon fibers in a carbon matrix, called carbon-carbon composites, are used in surgical implants, like heart valves, and space applications, like reentry vehicle nosetips and exit cones.

"Carbon-carbon exit cones four feet in diameter and only 80 mils (0.08 inch) thick have survived more than 20 space launches," said Dr. Meyer. "Only two carbon-carbon cones failed on being launched from the shuttle. The failures were traced to a processing stage where the cone is graphitized, or heated to very high temperatures until graphite forms in the matrix between fibers."

Dr. Meyer and the Carbon and Polymers Department were asked to determine what caused the failure. Samples cut off of each cone after graphitization were tested for microstructural changes. Dr. Meyer found that since these particular cones were located near the furnace's bottom during graphitization, they didn't stay hot enough and/or long enough to produce a high percentage of graphite in the matrix.

"Those cones with more graphite in the matrix were more *plastic*," Dr. Meyer explained. "Under stress they tended to crack in numerous tiny branches, using up more energy, rather than storing up all the energy until a catastrophic crack occurred, resulting in a failure. This is similar to comparing the damage from several small earthquakes to one large one."

Dr. Meyer developed a method to determine if future exit cones will be graphitized enough. His scale for classifying the plasticity of samples is called the "Relative Plastic Index." The two failed cones had an index of around 0.7, while several others has an index of around 0.4.

Based on this research, Dr. Meyer selected the exit cones with a Relative Plastic Index very close to 0.4 to be used in the next launch after the failure. These cones survived. Dr. Meyer will continue his research to determine just how far away from 0.4 the indexes can go and remain failure-free.

Other uses of carbon and graphite in space include a boom for a space telescope and a FLTSATCOM antenna. According to Dr. Meyer, applications of these materials in space will continue to grow in the future.