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# Lightweight, impact-resistant honeycomb structures can sense when they have been damaged

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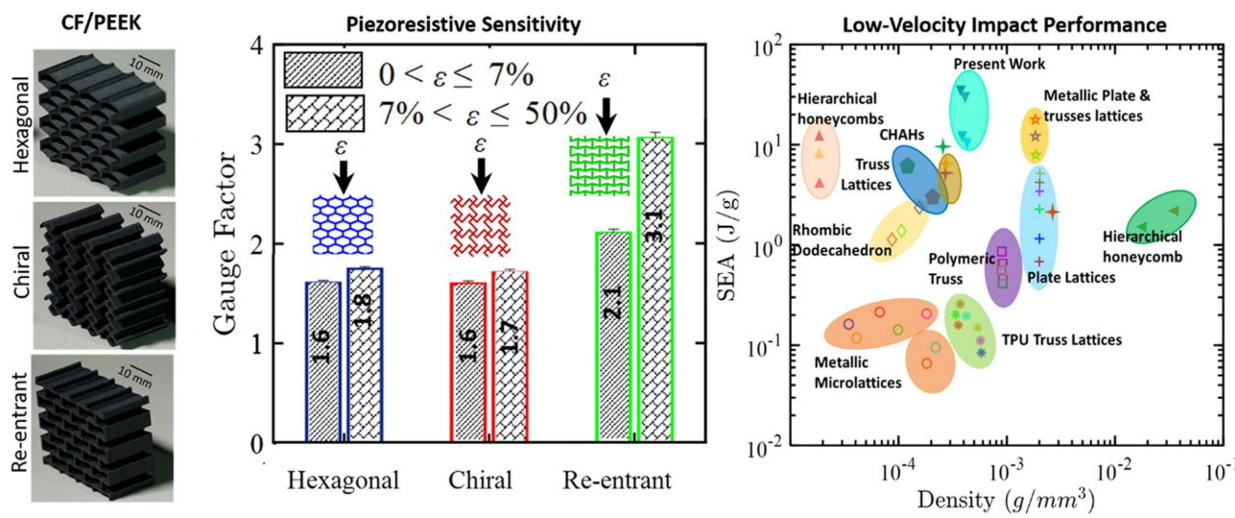


Graphical abstract. Credit: *Materials & Design* (2021). DOI: 10.1016/j.matdes.2021.109863

A new form of lightweight, impact-resistant plastic-based 'honeycomb' structures which can sense when they have been damaged could find use in new forms of 'smart' prosthetics and medical implants, its inventors suggest.

In a new paper published today in the journal *Materials & Design*, a University of Glasgow-led team of engineers describe how they have used 3D printing techniques to add new properties to a plastic known as polyether ether ketone, or PEEK.

PEEK's mechanical properties and resistance to high temperatures and chemicals have made it useful for a wide range of applications in the aerospace, automotive and oil and gas sectors.

The team added microscale carbon fibers to their cellular PEEK structures, giving the usually non-conductive material the ability to carry an electric charge throughout its structure.

They wanted to investigate whether damaging their electro-conductive cellular PEEK composite would affect its electrical resistance. If so, it could give the new material the ability to 'self-sense' – allowing a hip implant, for example, to report when its conductivity has changed, indicating that it has worn down and needs to be replaced.

To test their design's self-sensing ability, they used 3D printing to create three different honeycomb configurations—a hexagonal structure, a cross-shaped chiral structure, and a six-sided re-entrant design using both the carbon-fiber PEEK material and conventional PEEK.

Then, they subjected the cellular structures to two types of loadings to compare their respective abilities to absorb energy. In crush tests, where consistent pressure is applied until the structure collapses, each design of the carbon-fiber PEEK was outperformed by its conventional PEEK counterpart, which were able to withstand higher pressures.

However, in impact tests, where a weight is dropped from height onto the structures, the three carbon-fiber PEEK structures demonstrated greater resistance to damage. The hexagonal honeycomb configuration of the carbon-fiber PEEK had the best response, withstanding greater impacts than any of the others.

In the crushing tests, the researchers also measured the carbon-fiber PEEK cellular structure's resistance to an electric charge as the three different structures were strained. The change in resistance to applied strain—a measure of damage progression known as the piezoresistive sensitivity—decreased as the compressive strain increased, leading to a near complete loss of electrical resistance when the structures were completely crushed. The different gauge factors observed for different configurations is associated with their rate of damage growth in accordance with their ability to absorb energy, suggesting that the piezoresitivity of carbon-fiber PEEK could be of benefit in creating a new generation of smart lightweight multifunctional structures.

Dr. Shanmugam Kumar, of the University of Glasgow's James Watt School of Engineering, is the corresponding author of the paper. Colleagues from Khalifa University in the United Arab Emirates and the University of Cambridge in the UK also contributed to the research.

Dr. Kumar said: "The unique properties of PEEK have made it invaluable to many industrial sectors, and we hope that the carbon-fiber engineered PEEK cellular structures that we've been able to build via 3D printing will open up further possibilities.

"3D printing gives us a remarkable amount of control over the design and density of the cellular structure. That could allow us to build materials which more closely resemble the physiology of the native bone than the solid metal alloys traditionally used in medical implants like hip or knee replacements, potentially making them more comfortable and effective.

"We hope that these cellular forms of microengineered lightweight, self-sensing PEEK we've developed will find new applications in a wide range of fields, not just in prosthetics and other medical devices but also in automobile design, aerospace engineering, and the oil and gas sector."

The team's paper, titled "Energy absorption and self-sensing performance of 3D printed CF/PEEK cellular composites," is published in *Materials & Design*.

**More information:** J. Jefferson Andrew et al, Energy absorption and self-sensing performance of 3D printed CF/PEEK cellular composites, *Materials & Design* (2021). DOI: 10.1016/j.matdes.2021.109863

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