What If Ceramics were Ductile?

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In the 1900s it was discovered that ceramic materials, at least in principle, can be permanently deformed without fracture at room temperature. Since then, materials researchers have dreamed of making ceramics that can be bent, pulled, and hammered without fracture. In his article Dr. Erkka J. Frankberg comments on recent research results on ductile ceramics and ponders whether they could be scaled for commercial use.

Making of ductile ceramics is a hard task. Plasticity in ceramics is rarely observed and typically requires special conditions such as extreme temperatures to be plausible. Therefore, instead on denting, your ceramic coffee mug will fracture into pieces when dropped on a hard floor.

In his article, Dr. Erkka J. Frankberg, a Finland based expert on plasticity of ceramics, comments some of the latest findings regarding room temperature plasticity in ceramics, reported by J. Zhang et al. in the Science 378, 371 (2022). In his commentary, Frankberg paints a broader view on the potential benefits if such ductile ceramics could be made possible and scaled for commercial use, possibly ushering in a new stone age.

Why would it be important to discover ceramics that are ductile at room temperature? It is due to the atoms themselves and the bonding between them. Ceramics have ionic and covalent bonding between the atoms that significantly differ from, for example, bonds in metal alloys. One major difference is that the ionic and covalent atom bonds are among the strongest we know. As a result, in theory, ceramics should be among the strongest engineering materials that exist.

“The catch is this: while the bonds are strong, they also prevent atoms from easily moving around in the material, and this movement is needed to create plasticity, or in other words, a permanent change in the perceived shape of the material. Without plasticity, unfortunately, ceramics fracture well below their theoretical strength and, in practice, often have lower ultimate strength than many metal alloys commonly used in engineering," Frankberg says.

As a demonstration of the potential of ductile ceramics, Zhang et al. show that if silicon nitride (Si3N4), a ceramic material, is engineered to exhibit plasticity, it can exhibit a whopping ultimate strength of ~11 GPa prior to fracture. This is around 10 times stronger than some common grades of high strength steel!

What could ultra-strong ductile ceramics give us?

"Higher strength means less material needed to build moving machines such as vehicles and robots. Less material means lower inertia, meaning lower energy consumption and higher efficiency for all moving machinery. Higher wear and corrosion resistance of ceramics would allow higher up-time in these applications, which enables economic benefits," Frankberg points out.

Humanity has a constant need for ever stronger engineering materials, because of the large cross-cutting impact it would have in improving the energy efficiency of society.

"Because of the softer bonding, there is a hard limit to how strong materials we can create from metals. To reach the next level in strength, ceramics are a good candidate," he states.

While the results of Zhang et al. are spectacular demonstration of the potential of ductile ceramics, the results are demonstrated at the nanoscale, such as most similar results in the field. Therefore, a long and winding road is still ahead to realize the dream of flexible ceramics, which essentially needs that these results are repeated in a bulkier material.

"But every discovery of a new room temperature plasticity mechanism, such as that presented by Zhang et al., keeps us holding on to the dream of flexible ceramics," Erkka J. Frankberg sums up.

Read the original article on Tampere University.