Researchers create paracrystallized aluminosilicate glass with supreme toughness

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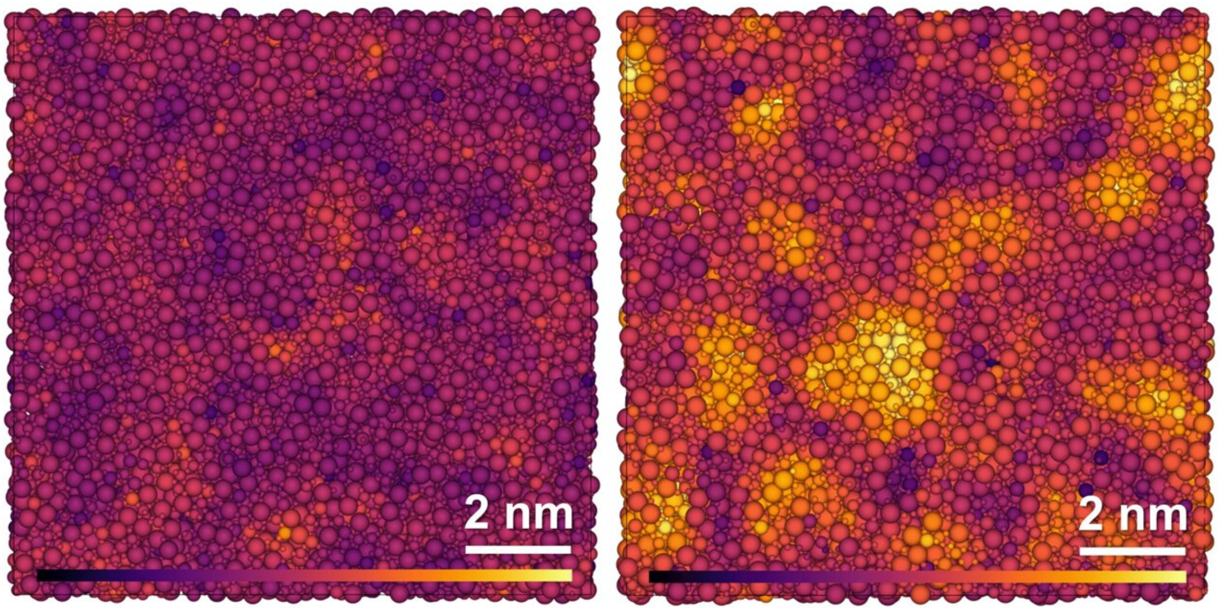

Simulated structure of glassy (left) and paracrystalline (right) grossular. The atoms of the elements oxygen, silicon, aluminum and calcium (from small to large) are coloured lighter the higher the degree of order in the surrounding structure. Credit: Hu Tang

Researchers at the University of Bayreuth, together with partners in China and the U.S., have produced an oxide glass with unprecedented toughness. Under high pressures and temperatures, they succeeded in paracrystallizing an aluminosilicate glass: The resulting crystal-like structures create a highly damage-tolerant material.

In many respects, glass is an attractive material for modern technologies. However, its brittleness, which easily leads to cracks and fractures, limits its potential applications. Research approaches to greatly increase the toughness of glass while retaining its advantageous properties have largely failed to produce the desired results.

The new approach presented in *Nature Materials* starts with oxide glasses that have a rather disordered internal structure and are the most widely commercially utilized glass materials. Using aluminosilicate, which contains silicon, aluminum, boron and oxygen, the research team has created a new structure by employing high-pressure and high-temperature technologies at the Bavarian Research Institute of Experimental Geochemistry and Geophysics (BGI) of the University of Bayreuth.

At pressures between 10 and 15 gigapascals and a temperature of around 1,000°C, the silicon, aluminum, boron and oxygen atoms grouped together to form crystal-like structures. These structures are called "paracrystalline" because they differ significantly from a completely irregular structure, but they do not approach the clear regular structure of crystals.

Both empirical analyses using spectroscopic techniques and theoretical calculations clearly showed this intermediate state between crystal structures and amorphous irregularity. Even after a drop in pressure and temperature to normal ambient conditions, the paracrystalline structures in the aluminosilicate glass remain.

The penetration of the glass with these structures results in the toughness of the glass being many times higher than before paracrystallization. It now reaches a value of up to 1,99 ± 0,06 MPa $(m)^{1}/^{2}$. This is a toughness never before measured for oxide glasses. At the same time, the transparency of the glass is not seriously affected by the paracrystalline structures.

The researchers explain the extraordinary strengthening of the glass by the fact that forces acting on the glass from outside, which would normally lead to breakage or internal cracks, are now primarily directed against the paracrystalline structures. They dissolve areas of these structures and transform them back into an amorphous, random state. In this way, the glass as a whole acquires greater internal plasticity, so that it does not break or crack when it is exposed to these or even to stronger forces.

"Our discovery highlights an effective strategy for developing highly damage-tolerant glass materials, which we plan to pursue with our research in the coming years," said Dr. Hu Tang, first author of the new study.

"The increase in toughness due to paracrystallization shows that structural changes at the atomic level can have a significant impact on the properties of oxide glasses. At this level, there is great potential for optimizing glass as a material that is far from being exhausted," adds Prof. Dr. Tomoo Katsura of the Bavarian Research Institute of Experimental Geochemistry and Geophysics.

More information: Hu Tang et al, Toughening oxide glasses through paracrystallization, *Nature Materials* (2023). DOI: 10.1038/s41563-023-01625-x

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