

Rapidly strained metals strengthen when heated

In high-temperature microballistic experiments, rapidly strained copper is about as strong as steel.

Metals, when heated, soften and become easier to deform, and once cooled they harden again. As temperature rises, atomic defects move more readily through the crystal lattice and can break its atomic bonds. Things can get weird under extreme conditions—namely, under high rates of strain. When an object is rapidly deformed over a short time period, the atoms don't have a lot of time to rearrange around the defects. At the macroscopic scale, that means the metal doesn't soften. In a high-strain-rate regime, energetic crystal-lattice vibrations become the dominant obstacle for defects and oppose their motion around the crystal lattice. The less the defects move, the stronger the metal is.

Until recently, researchers had no way to test the theoretical research on how high strain rates affect a metal's strength. The typical approaches can measure strain rates of up to $10^4/s$. That means that the object would lengthen to 10 000 times its original length in one second. But in practice, the stress that's applied to a material in high-strain-rate experiments is sustained for just a few nanoseconds.

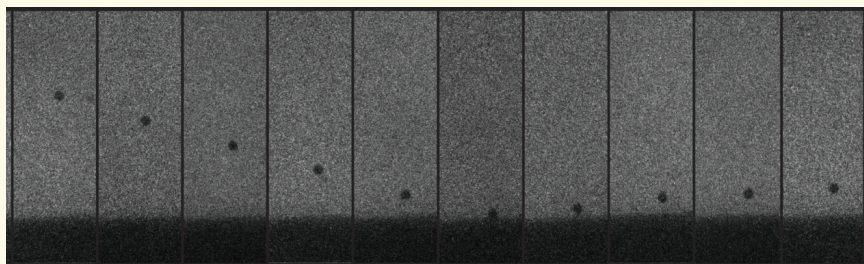
Although a strain rate of $10^4/s$ is high—on the order of what's experienced by an object impacted by a meteorite—it's still a few orders of magnitude below the range in which metals should start to behave counterintuitively. Now, because of advances in laser-driven microballistic systems, Christopher Schuh of Northwestern University and

graduate student Ian Dowding of MIT have experimentally confirmed that at the high strain rates of $10^6/s$ – $10^9/s$, copper and other metals strengthen as temperature increases.

In laser-driven microballistic experiments, fast-moving, micron-sized particles strike a metal target to generate high strain rates in the metal. With MIT post-doc Alain Reiser, Schuh designed a new testing setup that could withstand the high temperatures at which the unusual metal behavior can be observed. Starting at 0 °C and increasing the temperature of the metal by several hundred degrees, Dowding and Schuh measured a copper target's deformation and its strength—the applied stress necessary to deform it—as it was bombarded with 12 μ m particles of alumina.

The snapshots shown below, taken with a high-speed camera, illustrate a characteristic particle trajectory. In their experiment, Dowding and Schuh found the sought-after evidence: In a regime of high strain rates, the strength of copper increased by 30% for a 157 °C rise in temperature. The researchers found the same results in gold and titanium as they did in copper, and all pure metals should exhibit the effect. Many applications expose metals to high temperatures and high strain rates, so the findings may be relevant for various industrial processes, including high-speed metal machining, metal additive manufacturing, and sand-blasting. (I. Dowding, C. A. Schuh, *Nature* 630, 91, 2024.)

Alex Lopatka



A SIDE VIEW of the flight of a micron-sized particle impacting and rebounding from a copper target. The time between each image is 500 ns, and the particle's inbound velocity is 80 m/s. Using the particle's rebound velocity and the impact crater's volume, researchers determined that under certain conditions, rapidly strained copper strengthens as temperature increases. (Courtesy of Ian Dowding.)

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