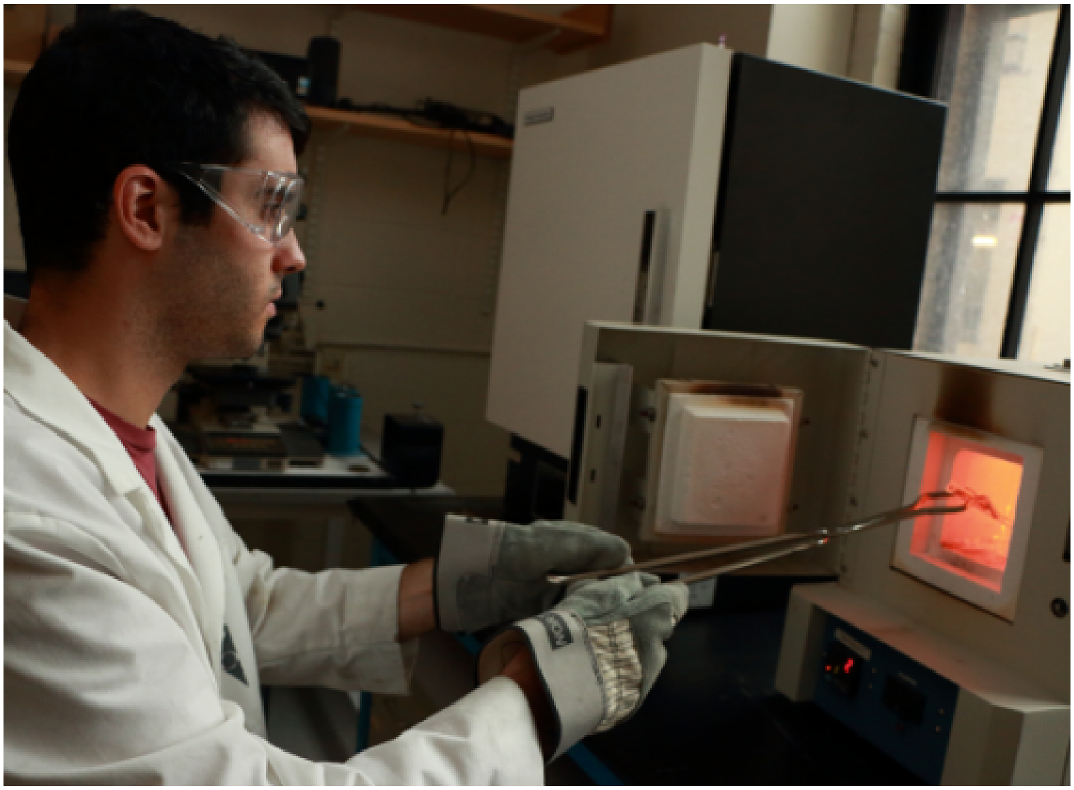
Deforming and compacting chromium-tungsten powders to create stronger metals

December 3 2014, by Denis Paiste



MIT graduate student Zack Cordero removes a vacuum-sealed glass ampoule from a box furnace operating at 1,100 degrees Celsius that is used to anneal metal powders. Credit: Denis Paiste/Materials Processing Center

New tungsten alloys being developed in the Schuh Group at MIT could potentially replace depleted uranium in armor-piercing projectiles. Fourth-year materials science and engineering graduate student Zachary

C. Cordero is working on low-toxicity, high-strength, high-density material for replacing depleted uranium in structural military applications. Depleted uranium poses a potential health hazard to soldiers and civilians. "That's the motivation for trying to replace it," Cordero says.

Normal tungsten would mushroom or blunt on impact, the worst possible performance. So the challenge is to develop an alloy that can match the performance of depleted uranium, which becomes self-sharpening as it shears off material and maintains a sharp nose at the penetrator-target interface. "Tungsten by itself is exceptionally strong and hard. We put in other alloying elements to make it so that we can consolidate it into this bulk object," Cordero says.

A tungsten alloy with chromium and iron (W-7Cr-9Fe) was significantly stronger than commercial tungsten alloys, Cordero reported in a paper with senior author and Department of Materials Science and Engineering head Christopher A. Schuh and colleagues in the journal *Metallurgical and Materials Transactions A*. The improvement was achieved by compacting metal powders in a field-assisted sintering hot press, with the best result, measured by the fine grain structure and highest hardness, achieved at a processing time of 1 minute at 1,200 degrees Celsius. Longer processing times and higher temperatures led to coarser grains and weaker mechanical performance. Co-authors included MIT engineering and materials science graduate student Mansoo Park, Oak Ridge postdoctoral fellow Emily L. Huskins, Boise State Associate Professor Megan Frary and graduate student Steven Livers, and Army Research Laboratory mechanical engineer and team leader Brian E. Schuster. Sub-scale ballistic tests of the tungsten-chromium-iron alloy have also been performed.

"If you can make either nanostructured or amorphous bulk tungsten (alloy), it should really be an ideal ballistic material," Cordero says.

Cordero, a native of Bridgewater, N.J., received a National Defense Science and Engineering (NDSEG) Fellowship in 2012 through the Air Force Office of Scientific Research. His research is funded by the U.S. Defense Threat Reduction Agency.

Ultrafine grain structure

"The way that I make my materials is with powder processing where first we make nanocrystalline powder and then we consolidate it into a bulk object. But the challenge is that consolidation requires exposing the material to higher temperatures," Cordero says. Heating the alloys to high temperatures can cause the grains, or individual crystalline domains, within the metal to enlarge, which weakens them. Cordero was able to achieve ultrafine grain structure of about 130 nanometers in the W-7Cr-9Fe compact, confirmed by electron micrographs. "Using this powder processing route, we can make big samples up to 2 centimeters in diameter, or we could go bigger, with dynamic compressive strengths of 4 GPa (gigapascals). The fact that we can make these materials using a scalable process is maybe even more impressive," Cordero says.

MIT graduate student Zack Cordero demonstrates a uniaxial press used for consolidating loose powder into a pellet. Working under Materials Science and Engineering Department chair Christopher A. Schuh, Cordero has developed extremely hard, finely grained tungsten alloy powders and compacts. Credit: Denis Paiste/Materials Processing Center

"What we're trying to do as a group is to make bulk things with fine nanostructures. The reason we want to that is because these materials have very interesting properties that are of potential use in many applications," adds Cordero.

Not found in nature

Cordero also examined the strength of metal alloy powders with nanoscale microstructures in an Acta Materialia journal paper. Cordero, with senior author Schuh, used both computational simulations and laboratory experiments to show that alloys of metals such as tungsten and chromium with similar initial strengths tended to homogenize and produce a stronger end product, whereas combinations of metals with a large initial strength mismatch such as tungsten and zirconium tended to produce a weaker alloy with more than one phase present.

"The process of high-energy ball milling is one example of a larger family of processes in which you deform the heck out of material to drive its microstructure into a weird non-equilibrium state. There isn't a good framework really for predicting the microstructure that comes out, so a lot of times this is trial and error. We were trying to remove the empiricism from designing alloys that will form a metastable solid solution, which is one example of a non-equilibrium phase," Cordero explains.

"You produce these non-equilibrium phases, things you wouldn't normally see in the world around you, in nature, using these really extreme deformation processes," he says. The process of high-energy ball milling involves repeated shearing of the metal powders with the shearing driving the alloying elements to intermix while competing, thermally-activated recovery processes allow the alloy to return to its equilibrium state, which in many cases is to phase separate. "So there is this competition between these two processes," Cordero explains. His paper proposed a simple model to predict chemistries in a given alloy that will form a solid solution and validated it with experiments. "The as-milled powders are some of the hardest metals that people have seen," Cordero says, noting tests showed the tungsten-chromium alloy has a nanoindentation hardness of 21 GPa. That makes them about double the nanoindentation hardness of nanocrystalline iron-based alloys or coarse-grained tungsten.

Zack Cordero pours tungsten-chromium iron powder into a steel vial used to deform the metal in a high-energy ball mill. The deformation process, which involves repeated shearing of the metal powders, drives the alloying elements to intermix creating an exceptionally strong nanostructure. Credit: Denis Paiste/Materials Processing Center

Metallurgy requires flexibility

In the ultrafine grain tungsten-chromium-iron alloy compacts he studied, the alloys picked up the iron from abrasion of the steel grinding media and vial during high-energy ball milling. "But it turns out that can also be kind of a good thing, because it looks like it accelerates densification at low temperatures, which reduces the amount of time you have to spend at those high temperatures that could lead to bad changes in microstructure," Cordero explains. "The big thing is being flexible and recognizing opportunities in metallurgy."

A compacted metal alloy pellet sits next to as-milled tungsten-chromium iron metal powders in a boat used for weighing the metals. The steel balls are used to deform the metals in a high-energy ball mill. Credit: Denis Paiste/Materials Processing Center

Cordero graduated from MIT in 2010 with a bachelor's in physics and worked for a year at Lawrence Berkeley National Lab. There, he was inspired by the engineering staff who learned from an earlier generation of metallurgists that made special crucibles to hold plutonium for the Manhattan Project during World War II. "Hearing the kind of stuff that they were working on got me very excited and keen on metals processing. It's also just a lot of fun," Cordero says. In other materials science sub-disciplines, he says, "You don't get to open a furnace at 1,000 C, and see something glowing red hot. You don't get to heat-treat stuff." He expects to finish his PhD in 2015.

Although his current work is focused on structural applications, the kind of powder processing he's doing is also used to make magnetic materials. "A lot of the information and knowledge can be applied to other things," he says. "Even though this is traditional structural metallurgy, you can apply this old-school metallurgy to new-school materials."

More information: "Powder-Route Synthesis and Mechanical Testing of Ultrafine Grain Tungsten Alloys." *Metallurgical and Materials Transactions A*. link.springer.com/article/10.1007%2Fs11661-014-2286-1

This story is republished courtesy of MIT News (web.mit.edu/newsoffice/), a popular site that covers news about MIT research, innovation and teaching.

Provided by Massachusetts Institute of Technology

Citation: Deforming and compacting chromium-tungsten powders to create stronger metals (2014, December 3) retrieved 25 April 2024 from https://phys.org/news/2014-12-deforming-compacting-chromium-tungsten-powders-stronger.html