QUICK-FREEZE METALS

'Instant' metals yield new materials and energy-saving products

BY IVARS PETERSON

What does a stereo phonograph cartridge have in common with the wall of a fusion reactor? The answer is that both may be applications of new materials resulting from freezing hot molten metal in less time than the blink of an eye. Using cooling rates as high as 1 million degrees Celsius per second, metallurgists are developing alloys with unusual magnetic properties, greater strength and more resistance to wear, corrosion and high temperatures than conventionally produced alloys.

Although scientists have been experimenting with rapidly cooled metals for about 30 years, they are only now realizing the wide range of potential applications of producing totally new alloys and improving the properties of old alloys.

An alloy starts out as a uniform mixture of two or more liquid metals. During solidification, however, crystals begin to form, and the various metals tend to separate from one another. Thus, most conventional alloys look like a patchwork quilt when viewed under a scanning electron microscope. But when a metal freezes quickly enough, the atoms have little time to arrange themselves into crystalline rank-and-file order. A rapidly solidified material looks more refined and uniform.

The trick in producing rapidly solidified alloys is to cool only very small amounts of the metal at a time. This involves the same principle that governs the faster cooling of a spoonful of soup compared to soup in a bowl. Spraying tiny droplets of liquid metal into high-speed jets of helium gas is one method of achieving fast cooling. The product is a fine crystalline powder. In another method, an elastic ribbon of metallic glass results when a thin column of liquid falls on a spinning, water-cooled wheel.

A surface layer of rapidly solidified alloy can be created by scanning an intense laser or electron beam across the surface of a metal part. This causes a thin layer of metal to melt, but the bulk metal beneath the melted portion draws away the heat, leaving a more uniform layer in place of the original alloy surface.

Much of the current flurry of research and development in rapid solidification technology is focused on solving particular materials problems. Researchers at the Massachusetts Institute of Technology are facing "the outstandingly difficult materials problem for the present period of time," says Otto K. Harling, director of the Nuclear Reactor Laboratory. He and Nicholas J. Grant of the materials science and engineering department are trying to demonstrate how well rapid solidification improves a material so it can withstand the tough mechanical, temperature, corrosion and radiation requirements of a fusion reactor.

"The material must withstand cyclic stresses, temperatures of up to half the absolute melting point, intense neutron damage and the effects of high gas production, especially helium," Harling says.

Compared to a fission reactor, a fusion reactor produces large amounts of helium. When helium seeps into a reactor's wall and migrates to grain boundaries within the material where it collects into bubbles, it can cause a lot of mischief and can make the wall mechanically weaker. The researchers' approach is to include a fine, dense dispersion of titanium carbide particles in the stainless steel alloy. They hope the helium will form many fine bubbles using these particles as nucleation sites rather than migrate to grain boundaries.

"What we can do better with rapid solidification than conventional technology is that we can put in a great deal more of these particles," Harling says.

The project is at the stage of examining the effect of radiation on the materials. The researchers already know that the new materials are mechanically tougher. They are also looking at other possible candidates for helium-trapping particles within the stainless steel.

"It's too early to tell how we are going to succeed," says Harling. "The time cycle for radiation testing is very long. In a few years, we should have a fair idea if this is a good approach."

Saving energy is one result of research at Allied Corp. in Morristown, N.J., on rapidly solidified metallic glasses. One major project is development of iron-based alloys for electric power applications. Metallic glasses can be magnetized easily and have remarkably low magnetic losses.

The iron cores of distribution transformers, like those found on top of telephone poles, are magnetized, then demagnetized, 60 times a second, 24 hours a day, every day, for up to 30 years. Each time the core goes through the magnetization cycle, a little energy is lost. This was not really appreciated in the past when energy was cheap, but now metallic glasses, with much lower energy losses per cycle, are a preferable material for transformer cores. Allied researchers are working with transformer manufacturers to incorporate the new material in their processes.

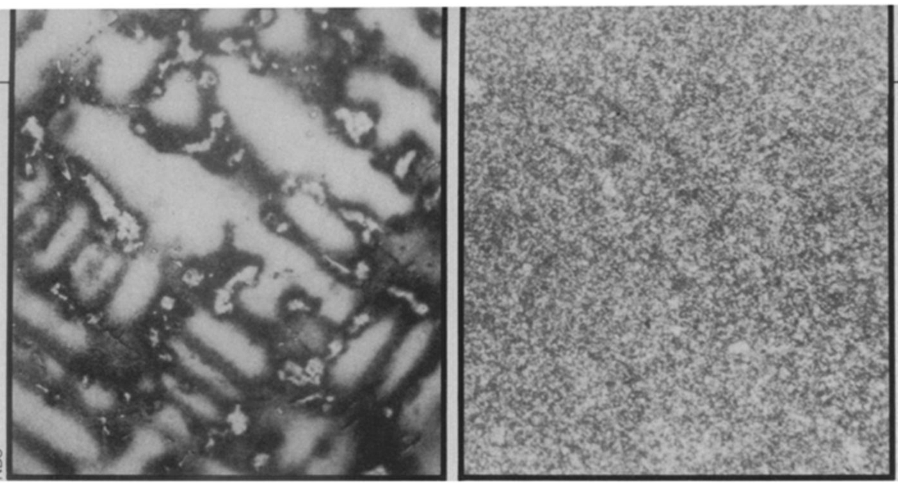
Donald Raskin, applications research and technical service manager for Allied Corp., says other properties of metallic glasses are also useful. Many iron-based alloys are highly sensitive to stress. Pulling along the length of a ribbon changes magnetic domain orientations so the material can be incorporated in devices for sensing pressure, for example.

Metallic glasses, because of their easy magnetization and mechanical ruggedness, are already being used for stereo phonograph cartridges, magnetic tape heads and ultra-sensitive magnetometers. Magnetic shielding fabrics, made of interwoven metallic glass ribbons, are commercially available. They can be cut to size with scissors and formed to the shape of any part requiring protection.

"There are probably as many phenomena in these materials that are not understood as there are ones that are understood," says Raskin. "A lot of our explanations is founded on a crystalline structure. On this basis, people said there would never be any ferromagnetic amorphous materials. That, of course, was determined not to be correct. This gives you an idea of how difficult it is to understand what's really going on in a material that doesn't have a crystalline structure."

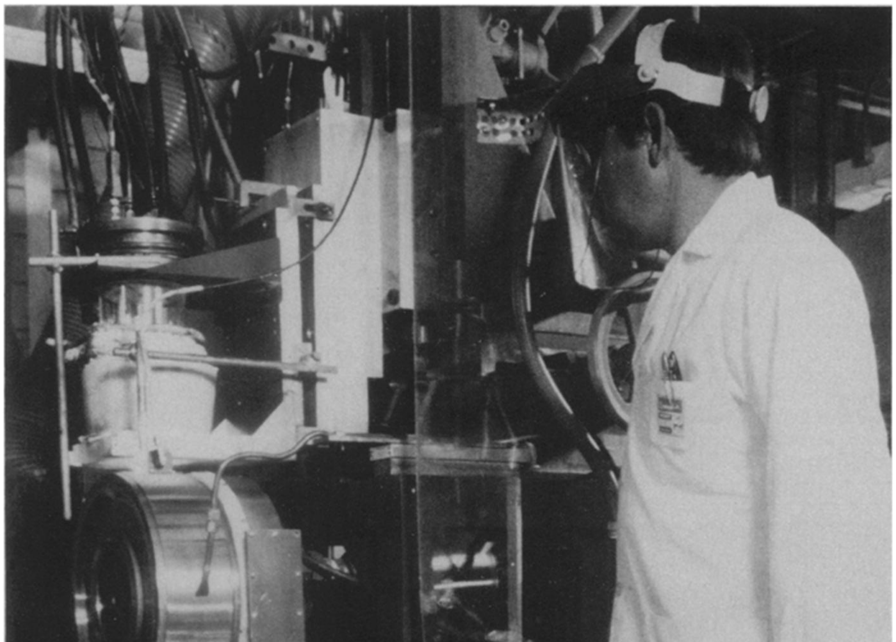
Robert Mehrabian, metallurgy division chief at the National Bureau of Standards, says, "The engineering advances in rapid solidification have been significant. On the other hand, our understanding of the basic phenomena at play is lagging

NBS



These scanning electron micrographs show the difference in microstructure between a conventionally cast alloy (left) and the same alloy made by rapid solidification. (Magnification of both micrographs is 100X.)

Allied Corp.



A molten stream of metal strikes a rotating, water-cooled wheel and freezes rapidly to form metallic glass ribbons that are spewed out at 30 meters per second.

behind. I think it's agreed that to fully exploit the opportunities open in this field in developing new microstructures and properties, we need to have predictive models that tell us, given a new alloy composition, what we have to do to get the structure we want."

One NBS program, developed in conjunction with the American Society for Metals, involves evaluating phase diagrams and putting the information into a computer system. A phase diagram is essentially a map that shows what alloy composition exists at a given temperature. Scientists can use this information to design new alloys and improve old ones.

Researchers at NBS are also doing fundamental studies in rapid solidification. For example, William Boettinger investigated how fast a liquid metal had to be frozen to get a particular structure. The apparatus he designed held a hollow glass rod filled with a liquid alloy and then plunged the tube into liquid gallium at various constant speeds. His experiments were among the first to establish precisely the critical velocity needed to produce a glassy structure for a particular alloy composition. These experiments also helped to show that the cooling speed was the most important factor determining the ultimate structure of an alloy.

Rapid solidification technology is also an important part of the government's strategic materials program because it allows the creation of totally new alloys. These alloys could reduce U.S. dependency on imports of cobalt, chromium, tantalum and other critical elements. Because glassy metals contribute to corrosion resistance, one possibility is coating steel with a low-chromium alloy rather than with pure chromium. A laser beam would create the glassy coating by melting and transforming just the surface.

The Defense Advanced Research Projects Agency funds a major effort to produce new alloys for higher efficiency, more durable, lighter weight gas turbine engines. A new rapidly cooled aluminum alloy with high lithium content may result in lighter, more fuel efficient aircraft.

Quick-freeze metals are rapidly solidifying into significant new products. □