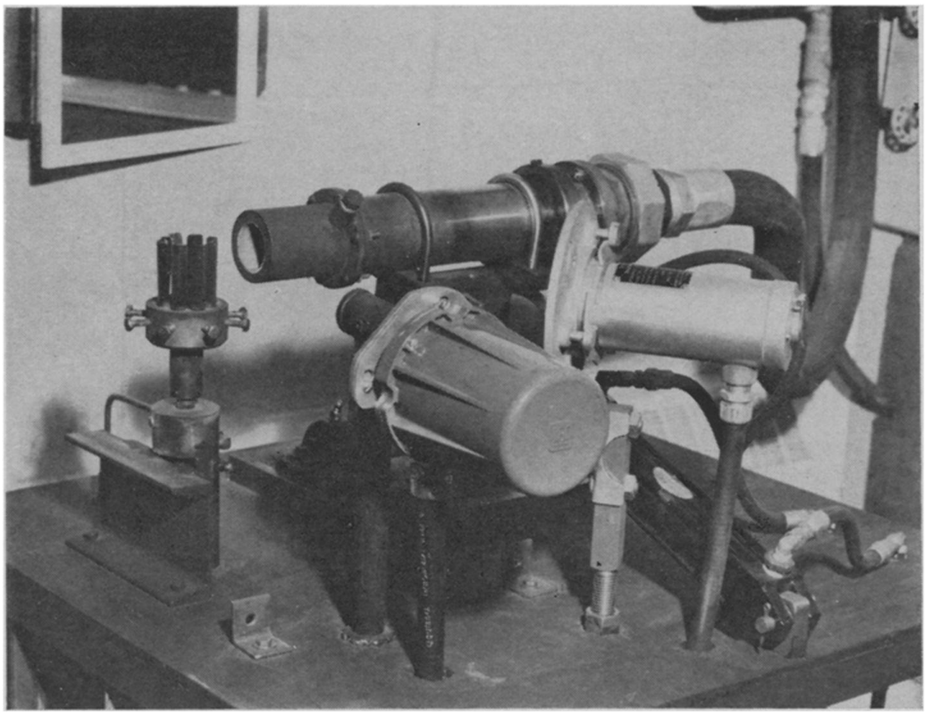
Alloys beyond superalloys

Dispersion-strengthened alloys are seen as the next generation of metals



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A dynamic oxidation rig for the testing of dispersion-strengthened alloys.

by Edward Gross

In the past decade, alloys have been developed that can withstand tremendous temperatures. But because of the increasing demands expected from aviation, nuclear and space technologies, even these so-called superalloys soon will be unable to fill the bill. Superalloys such as nickel- and cobalt-base alloys, even though some of them can withstand temperatures as high as 1,800 degrees F., will not hold up under the high-temperature requirements of upcoming jets, reactors and rockets.

What it will take to do the next decade's jobs may be entirely different types of alloys. And attention is now focusing on a kind called dispersion-strengthened alloys, the first major application of which will be in high-temperature jet engines. The National Aeronautics and Space Administration is also considering them for the skin material of space shuttle vehicles that will travel between orbiting space stations and the earth.

Some metallurgists see dispersion-strengthened alloys as the key material of the future. "They will be one of the most important high-temperature materials of the seventies and eighties," Eli Bradley, chief of materials engineering at Pratt & Whitney Aircraft, says. "They are the next generation."

Dispersion strengthening is not a new process; it has been around since 1948 when powdered aluminum was sintered (heated into a solid mass) and subsequently worked into a wrought form. It is, rather, a newly resurrected process that is just coming into its own now. The explanation lies in the demands of emerging technology.

"There hasn't been a strong enough need until recent years," says Neal T. Saunders, chief of the materials application branch at the NASA-Lewis Research Center in Cleveland. "Designers require materials with the ability to withstand higher temperatures and have high strength. Today's materials can't do the job."

Metals hardened by dispersion strengthening owe their strength to metal oxides that are stable at high temperatures. Such refractory metal oxides, which come under the heading of ceramics, are uniformly distributed throughout the matrix metal. They are the material of choice as dispersoids—the most popular of which right now is thorium oxide—not only because of their high-temperature stability but because they don't react with the matrix metal. As a result, dispersion-strengthened alloys can operate at temperatures up to about 2,100 degrees F., giving them a 250- to 300-degree edge over the superalloys.

In the typical dispersion-strengthening process, thorium oxide or another, refractory nonmetal is incorporated into a powder of ultrafine metal matrix particles. The trick is to get this oxide powder distributed uniformly throughout the matrix of the metal to be strengthened. This may be accomplished by precipitating the metal oxide and metal matrix oxide together out of a water slurry, drying the resulting composite powder and then reacting it with hydrogen to get rid of the oxygen, thus reducing the matrix metal oxide to a pure matrix metal.

An alternative after making the powder would be to precipitate a basic salt of the matrix metal in the presence of the oxide and reduce the slurry so formed with hydrogen under pressure in an autoclave to obtain the pure matrix metal.

In contrast, most of today's superalloys are strengthened by a process known as precipitation hardening, whereby a solid solution of a metallic compound dissolved in a complex alloy matrix is cooled, permitting submicroscopic particles of the metallic compound to precipitate and distribute themselves uniformly throughout the crystal lattice structure of the matrix alloy.

In both precipitation and dispersion strengthening, the key factor in alloy strength is the distribution of the fine particles. Metallurgists are not quite certain on an atomic level exactly how the distributed particles make a stronger, more heat-resistant alloy. Some say internal stresses are set up, others dispute this idea.

A generally accepted nonatomic theory for the dispersion process sets up a kind of friction principle with the particles in the grain boundaries, reducing the sliding of the grains one against the other.

The grain boundaries are naturally occurring irregularities in what would be an otherwise uniform crystal lattice structure. The irregularities run together to form a network of cracks, which under the microscope give a metal the appearance of being made up of grains. All metals have these cracks, and when subjected to stress, movement occurs along their interface.

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Dr. Evans: Structural uses for lead.

The ultrafine particles, it is theorized, prevent slippage by acting like sand grains clogging gears.

And while even the superalloys lose strength as they approach their melting point, dispersion-strengthened alloys do not. "Dispersion-strengthened materials retain their strength close to the melting point," says Dr. David J. I. Evans, director of the research and development division of Sherritt Gordon Mines Ltd. in Alberta, Canada. This means, he explains, that although a superalloy may have a melting point higher than 1,800 degrees F., its strength tends to fall off rapidly as that point is approached, because the precipitate redissolves in the matrix metal. Dispersion-strengthened alloys, on the other hand, do retain their strength up to their melting point since the dispersed oxide remains unchanged.

Since they are still in the experimental stage, few dispersion-strengthened alloys are available commercially. Pratt & Whitney is using them in experimental military jet engines, where higher temperatures are required for better fuel combustion.

There seems to be a technological law that says no advance is made without a trade off. And the dispersion-strengthened alloys are no exception. Although they have high-temperature strength, it is achieved at some expense in ductility. The result is a relatively brittle alloy with very little give: They can crack under localized stress. To avoid too much brittleness some strength must be sacrificed.

There are three other drawbacks to dispersion-strengthened alloys:

- They are difficult to work, making special welding and fabrication techniques necessary.
- When thorium oxide is used, the thorium emits some slight radioactivity.
- The alloy of nickel and thorium oxide, though it is among the best, may require a special chromium-aluminum coat for protection against oxidation at very high temperatures.

In addition to these technical problems, one other barrier stands in the way of commercialization: money. As with graphite fibers (SN: 6/21, p. 601), another frontier engineering material, the present cost of dispersion-strengthened alloys militates against commercial use. Graphite fibers can withstand higher temperatures (5,000 degrees F.), but they react with most metals, damage easily during processing and are more expensive.

Although nowhere near the $375 or so per pound that graphite fibers sell for, the price of $25 a pound for dispersion-strengthened nickel and $100 a pound for nickel-chromium are definite obstacles.

Still, scientists at Union Carbide, Battelle Memorial Institute and the University of Nottingham in England are looking ahead and contemplating a union of graphite fibers in combination with dispersion-strengthened nickel. Of all the metals, nickel is the least reactive with carbon, of which graphite is one form, and if an effective chemical reaction barrier can be developed, an even superior type of high-strength alloy will be possible.

The barrier would have to prevent the graphite from dissolving into the nickel. Without this protection, 30 to 50 percent of the theoretical strength is lost; the goal is to reduce the loss to as low as 10 percent.

But nickel or nickel-base alloy is still the most popular metal being considered. The DuPont Co. came out with the first dispersion-strengthened nickel alloy in 1962, and sold the rights to Fansteel, Inc., now the principal supplier. The original material was nickel and thorium oxide, which was eventually followed by a nickel-chromium alloy. Metallurgists hope eventually to make a dispersion-strengthened cobalt base alloy. Pratt & Whitney sees the present dispersion nickels as merely the pioneer, with other systems being developed in the nickel and cobalt family to supersede them.

One of the hottest prospects, outside of the nickel-cobalt group, is dispersion-strengthened lead. "Dispersion-strengthened lead has an interesting future," states Dr. Evans. "A potential application is in the lead-acid battery, where a lead-antimony alloy in the electrodes would be replaced by dispersion-strengthened lead to make a more efficient battery."

He even sees lead as a structural material: "Lead has never been used solely as a structural material because of its tendency to creep under load—even at room temperature. However, through dispersion hardening, lead can now be provided with significantly higher levels of tensile and creep strength, and can support loads of much larger magnitude than before." Though it is still in the pilot plant stage, he believes dispersion-strengthened lead will be available commercially in the near future.

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First commercial sheet of DS nickel.

The chief virtues of dispersion-strengthened lead are its creep resistance and corrosion resistance. Some specific uses Dr. Evans envisions for it, based on them, include linings for chemical processing vats, shielding for nuclear reactors, decorative weatherproofing for buildings, sheathing for electric cable and as more accurate bullets.

Dispersion-strengthened copper is another prospect, and although no practical applications for it have been tried as yet, it is regarded as potentially useful in high-temperature generators, high-temperature conductors in space vehicles or as electrical contact points where a big surge of power must be handled.

The present research thrust is to further strengthen the alloys to withstand temperatures as high as 2,400 degrees F. In October the International Nickel Co. announced it had taken a step in this direction by combining the dispersion and precipitation hardening processes into one. The new method, called mechanical alloying, is a high-energy process in which the ultrafine particles are uniformly distributed in the matrix. Inco has made some nickel-base alloys with the process and laboratory test results have shown them to have exceptional chemical and mechanical properties. The next step is to move up from the research stage to the pilot plant stage. □