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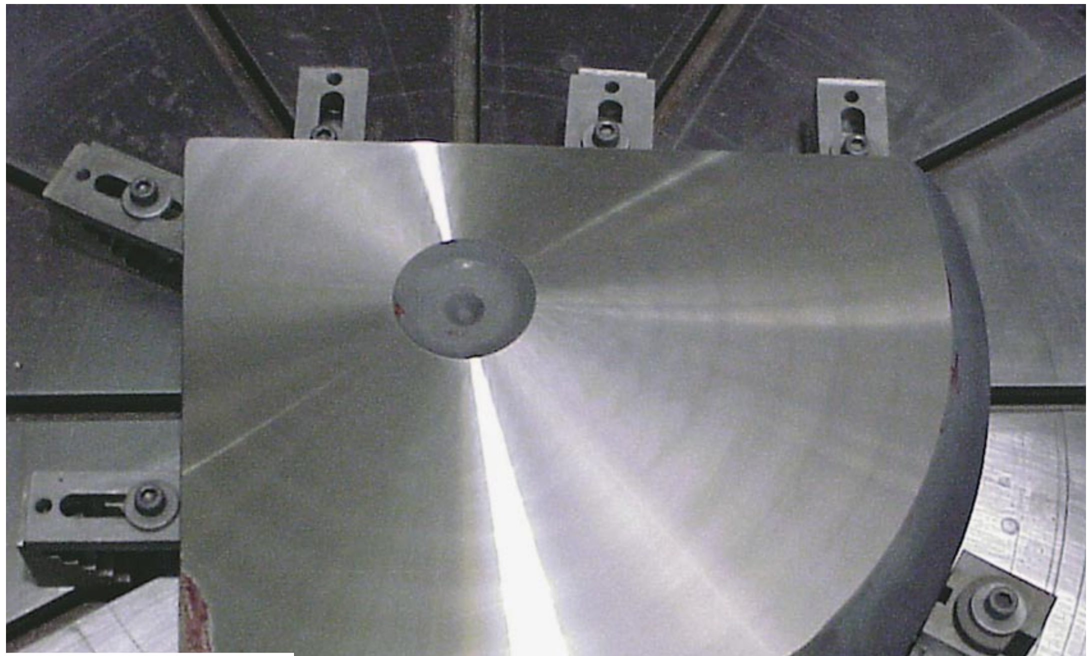
➤ BY DANIEL MARGOLIS, ASSISTANT EDITOR



Pratt & Whitney

A 28"-dia., 460-lb. gamma titanium-aluminide disc (below), commissioned by the U.S. Air Force to be machined into a compressor disc for a jet engine.

A quadrant of the 28"-dia. gamma titanium-aluminide disc (above), cut out to be subjected to stress and fatigue testing. Silicon-carbide wheels were used to grind the face to impart a surface finish from 10μin. to 14μin. R$_a$.

Intermetallic Wonder

Titanium aluminides hold potential as a parts material for the aerospace industry.

In 1944, in the song "Grand Coulee Dam," folk musician Woody Guthrie sang: "Now in Washington and Oregon you hear the factories hum, making chrome and making manganese and light aluminum. And there roars a mighty furnace now to fight for Uncle Sam, spawned upon the King Columbia by the big Grand Coulee Dam."

Guthrie was referring to how 2 years earlier, hydroelectric power generation projects such as the Grand Coulee Dam had given the U.S. the capacity to produce enough aluminum to manufacture 60,000 warplanes in 4 years. This was vital to U.S. efforts in World War II.

Increased focus on aluminum led post-World War II researchers to study it further during the next decade. This included combining it with other elements, such as titanium, and creating titanium aluminides, chemical compounds of aluminum and titanium. These compounds are ordered, which means their atomic elements sit on designated sites within a crystal lattice, a systematic, symmetrical network of atoms. Such compounds are known as intermetallics.

The original motivation for the development of titanium aluminides was the same as for the mass production of light aluminum: Use the material to make aerospace parts. This is because these intermetallics are strong, with a yield strength as high as 120,000 psi, three times that of a conventional stainless steel. At the same time, titanium aluminides are lightweight, weighing 4g/cm^3, roughly half that of conventional stainless steel.

The reduction in weight significantly improves fuel economy and aircraft engine performance.

"Titanium aluminides are extremely lightweight. I don't know of another material that is as stiff, hard and strong, with that density," said Don Graham, manager of turning products for Carboloy Inc., Warren, Mich.

Two classes of titanium aluminides have been studied extensively: alpha-2 (Ti$_3$Al) and gamma (TiAl). Alpha-2 has been abandoned for production applications because its high brittleness could cause aerospace components made from it to suffer catastrophic failure. This has led aerospace researchers to concentrate on gamma.

In addition to their attractive strength-to-weight ratio, gamma titanium aluminides have the ability to withstand high temperatures, maintaining structural integrity to 1,400º F and sometimes as high as 1,600º F.

"That is another attraction for the aerospace community," said Gopal Das, a materials scientist for Pratt & Whitney Aircraft, a division of United Technologies, East Hartford, Conn., who has been working primarily in the gamma titanium aluminides area for the last 10 years. "Titanium can go up to 1,000° F. Then, from 1,000° F to 1,400° F, there is no conventional material available, so people are forced into using [conventional] superalloys. We could replace [those] with gamma titanium aluminides."

Pratt & Whitney

A 17"-dia. gamma titanium-aluminide disc, turned on a conventional vertical turret lathe to impart a surface finish from 18μin. to 25μin. R$_a$.

In Development

Potential uses for gamma titanium aluminides in aircraft engines include valves, turbine blades, connecting rods and piston pins. In 1991, GE Aircraft Engines, Cincinnati, conducted its first successful test of a 747-class engine using turbine blades machined from gamma titanium aluminides. GEAE continues to machine and test aerospace parts, such as low-pressure turbine blades, structural circular rings and conventional air foils machined from titanium aluminides.

These parts are cast near-net shape, then machined within tolerance using a combination of turning, milling, electrochemical machining, EDMing and grinding. "It depends on what feature on the part we're machining," said Mike Weimer, general manager for the Materials and Process Engineering Department at GEAE. "We might use multiple techniques on a given part, similar to what we would do on a conventional superalloy used to make the same kind of a part."

In general, the most productive method of machining titanium aluminides is grinding, which yields precise, high-performance parts—free of critical defects—in an acceptable amount of time and at an acceptable cost. "Grinding is the most common [method used] on these aluminides," said Vinod Sikka, manager of R&D for Oak Ridge (Tenn.) National Laboratory's Metals & Ceramics Div. "Single-point machining puts a lot of point load [on the cutting tool], so the tool bit wears out rapidly. With grinding, you're applying the load over a larger area and are able to grind it successfully with higher feeds."

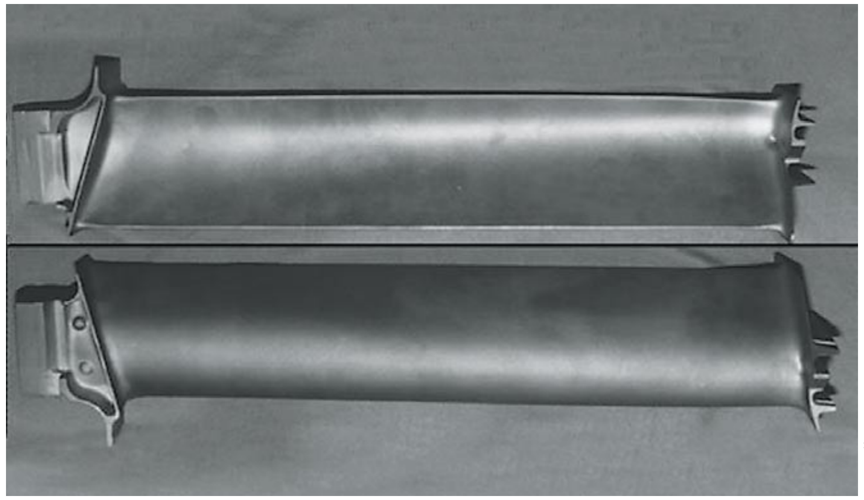
Applying the load over a larger area is preferable when machining titanium aluminides, due to their limited ductility. Intermetallics, in general, are difficult to machine. Titanium aluminides can be machined at low speeds, but tool life will be short. "People in the cutting tool industry talk about machinability ratings," Graham said. "A basic steel—a soft, easy-to-machine steel—is given a rating of 100. That's kind of the baseline. Titanium aluminides are about 8, maybe 10."

Weimer admits the potential for productivity when machining titanium aluminides is limited, but this is not outside of the norm when machining aerospace components. “It’s all relative productivity for us,” Weimer said. He added that alternate materials that GEAE uses for these applications allow for the same productivity in terms of speeds and feeds.

GEAE uses a titanium-aluminide alloy that is 48 atomic percent titanium, 48 atomic percent aluminum, 2 atomic percent chromium and 2 atomic percent niobium, with chromium and niobium serving as alloying elements. This, Weimer said, is an ordered balance of reasonable ductility. Although the alloy is 48 atomic percent aluminum, it’s 33 percent aluminum by weight.

It is the addition of alloying elements that allowed titanium aluminides to finally see parts testing in the early 1990s. “Over the last 15 to 20 years, people have begun to understand that, within realistic limits, you can mitigate titanium aluminides’ brittleness by alloying them with third and fourth elements, like chromium, niobium and tungsten,” said Jim Williams, a professor of materials in the Department of Materials Science and Engineering at Ohio State University and former general manager for the Materials and Process Engineering Department at GEAE.

Pratt & Whitney Aircraft uses a similar alloy for the test parts it produces. “What we use is called a ‘near gamma’ alloy, which is roughly half titanium and 45 to 48 percent aluminum,” Das said. “Then we alloy it with additions like chromium, niobium, manganese and tungsten, all of which impart a little bit of ductility.” He places this ductility at 2 percent or less elongation when pulled to failure at room temperature. He admits this makes the material difficult to design for, but not impossible.



A gamma titanium-aluminide turbine blade for a 747-class engine, pictured face-up (bottom) and face-down.

Jim Williams

From 1995 to 2000, Pratt & Whitney had a contract with NASA to develop titanium-aluminide aircraft engine parts intended for a small, economical version of a supersonic jet, similar to the Concorde. Though tests led to recommendation of titanium-aluminide aircraft engine parts by Pratt & Whitney, this program was cancelled in 1999.

Since 2000, Das has worked on Pratt & Whitney’s ongoing Air Force-sponsored program to develop and test titanium-aluminide compressor blades for rotors in military aircraft engines. These parts are cast near-net shape and then machined within tolerance, from ±0.005" to ±0.0005", using a combination of processes. The most common of these is surface grinding, at feed rates from 0.002 ipm to 1.3 ipm with a DOC around 0.1" or 0.2".

“This is a difficult material to machine,” Das said. “You can do just about everything you can do with nickel materials, but with gamma titanium aluminides, because of their low ductility, you have to be careful.” He explained that this means it’s essential to have sharp, balanced tooling customized for the application, precise workholding and use an oil-based, high-pressure coolant. “The problem with gamma titanium aluminides is that not too many people are familiar with them, so if you give them to somebody who is used to machining conventional materials like steel, they immediately make a mistake.”

Such a mistake would likely prove very costly. “If you were to do something untoward, like break a tool, the consequences with regard to being able to salvage a part would be substantially more than with a conventional titanium alloy,” Williams said. “These are high-value parts, so that becomes an issue.”

Sticker Shock

Parts machined in titanium aluminides are by definition “high value,” because the material is prohibitively expensive. “Stainless steel costs $5/lb. max, and that’s a worse-case scenario,” Oak Ridge’s Sikka said. “Nickel-based alloys may be running between $10 and $12/lb. Titanium aluminides are a $35 to $40/lb. material.”

The following companies contributed to this report:

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Oak Ridge National Laboratory, Metals & Ceramics Div.
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Ohio State University, Department of Materials Science and Engineering
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Pratt & Whitney Aircraft
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According to GEAE’s Weimer, titanium aluminides’ tendency to be 2 to 3 times more expensive than conventional superalloys is what limits their use, rather than any insurmountable issues in machining the material. “The challenge is to get the overall cost down, and then this material will see much more widespread usage. It’s a nice engineering material.”

According to Das, Pratt & Whitney is pushing to have titanium-aluminide components used in aircraft engines. “Everybody thinks that is a good idea, and people are spending money on R&D, trying to assess these parts in actual test conditions. But nobody has put any part in an engine [in a production application] as of yet.”

The company is concentrating on developing titanium aluminides for the Air Force, because military aircraft would be a vital proving ground. “Once people see gamma [titanium aluminides] used in a military aircraft engine, they’ll bring [them] to a civilian aircraft application,” Das said. “But right now, with the war going on, we’ve had a low period for funding. It might take several years.”

It seems that the “fight for Uncle Sam” that spawned mass production of aluminum is slowing the progress of its intermetallic derivative. △