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Like Superman, titanium has amazing strength. But is it kryptonite on the lathe?

cover story ➤ BY BILL KENNEDY, CONTRIBUTING EDITOR

Turning tips for a 'Supermaterial'

B. Kennedy

Titanium has "special powers" that allow it to save the day in a growing number of applications. The metal's high strength-to-weight ratio, toughness and superb corrosion resistance dictate its use in products from medical implants to golf club heads to military armor.

However, when it's time to turn those parts, some machinists look at titanium like Superman looks at kryptonite. They assume that as a metal's performance properties become more extreme, so does the challenge of machining it, to the detriment of their machining "powers." This assumption is true with titanium, but only to a certain extent.

This article explores turning strategies that allow machinists to deal with this difficult-to-machine material, exotic titanium applications such as Indy car parts and scuba equipment, and new cutting technologies.

Tough Turning?

Bill Headland, senior project specialist at titanium producer RTI International Metals Inc., Niles, Ohio, said many shops assume titanium is "kryptonite" in regard to machinability. Actually, titanium includes “a broad category of alloys, and you need to know what family you are working with,” he said. “There are grades that are extremely difficult to machine and then there are grades that are very readily machinable.”

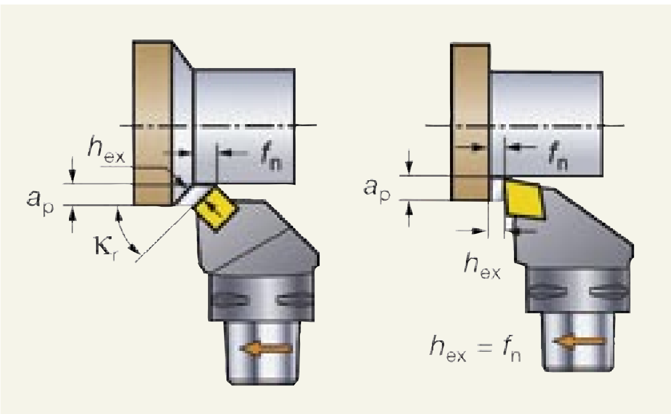
Commercially pure, or “CP,” titanium grades are unalloyed and used for making medical parts, heat exchangers and eyeglass frames. CP grades offer excellent corrosion resistance and are relatively easy to machine, but have low strength relative to other alloys. They are “very gummy and very soft, relatively speaking,” Headland said.

Alloy additions to pure titanium change its phase, or crystal structure, as well as its performance properties and machinability. Alpha and near-alpha titanium alloys include additions such as nickel, aluminum and vanadium. “These intermediate grades machine pretty well,” Headland noted.

Alpha-beta titanium grades may contain increased amounts of aluminum and vanadium. Industry’s workhorse titanium alloy, Ti6Al4V, is an alpha-beta grade containing about 6 percent aluminum and 4 percent vanadium. Ti6Al4V and its variations account for 50 to 70 percent of the titanium in use today.

Beta grades, which include additions of iron and chromium, are among the most difficult to machine titanium alloys. With high fracture toughness and excellent resistance to high cycle fatigue, “they are getting into machinabilities like Hastelloy and similar materials,” Headland said. As a typical beta alloy application, he cited lightweight springs used to activate the folding fins of a barrel-launched tactical missile.

Characterizing machinability across the various titanium alloys is somewhat arbitrary, but one shop owner said he generally assumes a Ti6Al4V workpiece will take three times as long to machine as a steel part, while another said a difficult-to-machine Ti5553 beta grade requires twice the machining time of Ti6Al4V.



Sandvik Coromant

Replacing an 80° insert applied at a -5° lead angle (right) with a square insert presented at a 45° lead angle (left) will produce a wider, thinner chip, reducing the concentration of heat on the cutting edge.

Turning Time

When it comes to turning, titanium’s most significant property is its poor heat conductivity. High temperatures developed when machining are concentrated in the tool’s cutting edge rather than being absorbed by the workpiece. Excessive heat catalyzes a chemical reaction between the cutting edge and the chip, producing crater wear.

Titanium also has a tendency to workharden, so removing metal through a shearing action, rather than pushing it away, is crucial. Further, although titanium has high strength, it has a relatively low modulus of elasticity. This means it is relatively resilient compared to other materials and moves away from the cutting edge, especially during lighter cuts. Together, these properties make a balance of speed, feed and DOC the key to successfully turning titanium.

Cutting speed is the biggest factor affecting heat development. Stefan Gyllengahm, now a turning specialist for Sandvik Coromant Co., Fair Lawn, N.J., previously spent 3½ years developing tool grades for the toolmaker. During that time, he conducted laboratory tests on Ti6Al4V that demonstrated the care required when setting cutting speeds. In some cases, he said, “when I turned the speed up 10 to 15 percent, tool life went from 40 passes to 6 passes. That’s how significant it is if you take a step too far.”

Gyllengahm also found that when turning at speeds that did not shorten tool life, raising the feed rate produced a critical temperature detrimental to tool life. “There is a window where you reach too much heat,” he said.

Tool geometry plays a key role in dissipating heat by controlling the chip’s shape. A wider, thinner chip enlarges the contact area between the chip being produced and the cutting edge, thereby reducing heat concentration. “If you have a thinner chip, you produce less heat, and you can go slightly faster,” Gyllengham said. For example, when roughing with a C-style (80˚ diamond) insert and a standard -5˚ lead angle, chip thickness is roughly equivalent to the feed rate. But applying a square insert set at a 45˚ lead angle spreads the metal being removed—and the heat of the cut—along a greater length of the cutting edge.

Round inserts theoretically take this concept to its extreme, “but only at lighter depths of cut,” Gyllengahm said. “Normally, with a round insert you have a very thin chip at a low depth of cut.” However, considering the case of a round insert with a ½" inscribed circle applied at a DOC of more than 0.080", “your effective lead angle is getting low. Then you might be better off with a square, because at that depth of cut, you still have a 45˚ lead,” he said.

Push and Pull

Bill Skoretz is manager of the machining division of Patriot Forge Co., Paris, Ontario, which maintains an inventory of raw materials ranging from low-alloy steels and stainless steels to specialty grades of aluminum and titanium. Skoretz occasionally machines titanium parts for Patriot’s customers. However, when discussing the challenges of turning titanium, he recalled an experience from a prior position when he turned nozzles for cooling sprays used in steel rolling mills. The corrosion-resistant grade of titanium “didn’t like parting with itself, and it was abrasive," he said.

Positive tool geometry was essential, but with emphasis on the shape of the tool's top, due to titanium's resilient nature. "If your bottom angle or rake angle underneath is a little too sharp, then you end up with more problems, because the tool starts to pull in." he said. "So you have to find the happy medium between a top geometry being positive and support underneath the cutting edge."

Skoretz described the situation from the historical perspective of cutting tool development. Before the development of carbide tools, HSS tools were traditionally ground sharp and "peeled the steel off," he said. The advent of hard carbide tools permitted the use of positive geometries, "which could just pound the steel off, but you had to have horsepower to do that." However, a negative geometry makes titanium "just fold and push. You'll not be able to remove the material." But "if you go with something too positive, the insert wants to pull into the material," he cautioned. "You have to find that happy medium between pushing and pulling."

The following companies contributed to this report:

Atomic Aquatics Inc.
(714) 375-1433
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Patriot Forge Co.
(519) 758-8100
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Rayco Machine Co. Inc.
(317) 271-7848
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RTI International Metals Inc.
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Sandvik Coromant Co.
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Sandvik Coromant

Turning a Ti6Al4V part typically requires cutting times three times longer than a steel part.

Skoretz noted that the inserts he employed in his previous position featured a slight T-land edge preparation of 0.004" or 0.005", "basically for edge security. You can't go right up to a sharp edge, because it won't last long." He also used an oil-based coolant, more for its lubricious characteristics than its cooling capabilities. Skoretz is sure other shops have different approaches to turning titanium. "As with any material-removal process, there are many, many ways to skin a cat."

Fast Turning at Indy

Making racecar parts is about 30 percent of Indianapolis-based Rayco Machine Co. Inc.'s business. Greg Cox, company president, noted that Rayco machines a lot of relatively pricey titanium, because the top racing teams are willing to spend extra for light, strong parts that allow them to keep their cars at the rule-regulated minimum weight but still maintain some control over how weight is distributed throughout the car. For example, reducing the weight of rotating and unsprung masses like wheel and brake parts can significantly enhance acceleration and handling. Among the titanium parts Rayco turns are bobbin inserts that go between the brake caliper and rotors.

Like Skoretz, Cox said successfully turning titanium requires a balanced approach. Regarding machining parameters, he said: "One of those things you just know, you're not going to push it. If you push it, it is going to workharden and hurt you more. We run around a standard of about 120-sfm speed and about a 0.005" to 0.008" feed."

DOC makes a difference as well. Again, moderation is the best course. "We don't bury it. I think the deepest depth of cut we ever take is 0.030" to 0.040," Cox said.

Production volumes at Rayco may run as high as 200 pieces, but the majority of runs are from five to 20 parts. Cox said the shop does pursue continuous improvement, but has to be somewhat cautious regarding cutting parameters because "titanium is so expensive you can't be so aggressive that you scrap a part." He said the price of titanium has risen rapidly, from $47 per lb. to $68 per lb. over the past year.

According to Cox, higher titanium prices also tightened his workpiece material inventory. "We are like a drive-through service for the racing industry; they literally call today and get parts tomorrow." When titanium prices were lower, he might have had 10 pieces to run of a particular part and, "I'd order a whole stick of titanium, just so I'd have a stick on the shelf," he said. "I have really pulled away from that, just because the cost per pound has gotten to be so expensive."

A Certain Recipe

Scott Holland, general manager of Atomica Research and Development, the R&D and manufacturing division of dive equipment company Atomic Aquatics Inc., Huntington Beach, Calif., said when machining scuba equipment from titanium, "we always try for continuous improvement, to find that extra few seconds, a couple more parts or more tool life." However, he said he resists the urge to go too far and "try and get one more part out. I can get that one more out and then snap, there goes the tool." He added that there is "a middle ground in there that we try to reach."

It's not all numbers and programs, however. Holland has been machining titanium for nearly a decade and said he relies on "what the part looks like, what the tool looks like and what the cut sounds like."

Machining titanium can be relatively simple. "Use sharp tools and change them when you are supposed to. You can only run titanium within a certain box," Holland said. "You can try things on your own, but it might not work out. There's a certain recipe for it, and if you stick to the recipe, everything is going to work out right!" △

Titanium-taming technology

The increasing use of titanium is driving development of cutting technologies focused on turning it more productively.

Chris Mills, senior manager for application management and support at Sandvik Coromant, Sandviken, Sweden, emphasized that chemical wear is the main failure mechanism when turning titanium and that high cutting temperatures accelerate that wear. As the hot chip slides over the tool's rake face, it is "actually pulling out cobalt from the insert," he said.

Mills described a two-step approach to reducing cutting temperature. The first step is using tool geometry to reduce chip thickness. Applying a square insert with a 45° lead angle or a round insert thins the chip, which will thereby reduce cutting temperatures and resultant crater wear, ultimately permitting higher feed rates and extending tool life.

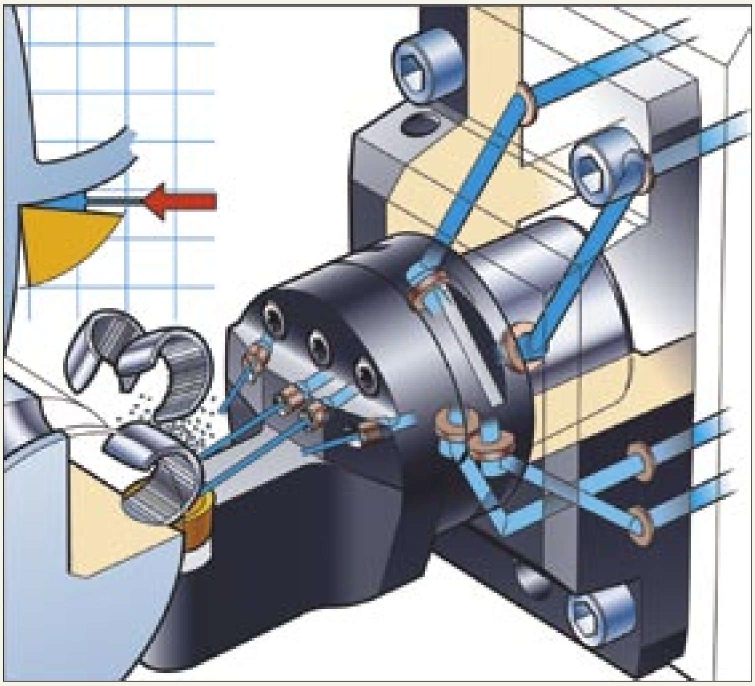
The second step involves application of a specific form of high-pressure coolant. According to Mills, the coolant is not only presented at high pressure, but is in the form of a "very accurate laminar flow jet, which produces a hydraulic wedge between the chip and the rake face of the insert. It lifts the chip up and doesn't have the same contact on the rake face, so you don't get the same crater wear."

Sandvik calls the system Jetbreak. It provides 0.050"-dia. jets at pressures from 1,000 to 3,000 psi. The system employs standard emulsion coolants, and, according to Mills, "it's the force of the jet lifting the chip up, not actually a cooling effect, which reduces the friction and the temperature between the chip and the face." He said use of the system can permit a 50 percent increase in cutting speed.

Mills described the effect of combining the two heat-reducing strategies. He proposed a basic situation of a CNMG insert employed at a -5° lead angle, run at optimized machining parameters of about 40 m/min. cutting speed and 0.3 mm/rev. feed rate, resulting in about 20 minutes of tool life. Substituting a round insert or a square insert with a 45° lead angle would enable the cutting speed to be increased to 50 to 60 m/min. and the feed to 0.4 mm/rev. Tool life would be similar.

"You remove a lot more material during the same time," Mills said. "Just by using a square insert you can pretty much say you've doubled your productivity. And then, if you apply the high-pressure coolant system, you can increase your cutting speed an extra 50 percent on top of that."

Mills said the high-pressure coolant must be routed through the machine spindle and not via external piping.



Sandvik Coromant

High-pressure coolant delivered in a small-diameter laminar flow jet produces a hydraulic wedge between the chip and the rake face of the insert, lifting the chip to minimize its contact on the insert rake face with the effect of reducing crater wear.

The coolant flows through a special adapter for the Sandvik Capto quick-change tooling coupling, engineered to handle the high pressures. The system is most easily implemented at the time the machine tool is installed.

For shops machining titanium on a daily basis—especially large, high-value aerospace components—the 50 percent increase in productivity makes it worthwhile to invest in special toolholders and a somewhat specialized machine, Mills said. The system offers unique advantages when turning titanium, because crater wear is not as prevalent in other workpiece materials.

—B. Kennedy