Tripp Cook, Machine Specialties Inc., monitors finishing operations performed on a Ti 10-2-3 workpiece. Correct work flow and processing techniques are part of an overall system for hard-metal machining.

Cut the Tough Stuff

The magic moment arrives when four key ingredients are mixed according to the right formula

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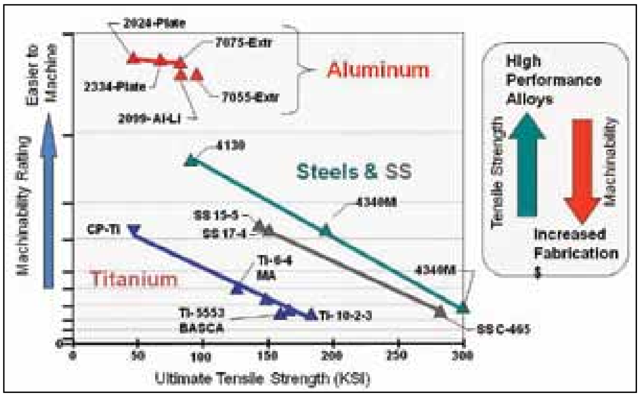
Unlike the "Sorting Hat" in the Harry Potter book series that made decisions quickly and intuitively, sorting out the best ways to cut tough materials has taken a few years of chips soaring, spindles smoking, tools exploding, and brains frying.

While that sounds like a spell gone wrong, that's the kind of magic we conjure in the metalworking industry.

Aerospace OEMs and their parts suppliers have been grappling with the influx of hard, difficult-to-machine materials, such as titanium 5553 and tough stainless steel grades. These materials have grown quickly in application because they are strong, flexible, light in weight, corrosion-resistant, and can take the heat. These characteristics are carrying over into the jet engines where the rotating parts can run hotter and be made smaller, and into such skeletal parts as struts, floor ribs, window frames, door hinges, and engine mounts to enhance structural integrity. Thanks to these challenging materials, all of these new components ultimately assemble into aircraft that require lower fuel costs to fly. The newer generation materials make up 15% of the weight of the latest jet fleets, such as the Boeing 787 Dreamliner. In each airplane there will be about 21,000 lb (9.5 t) of these heavy metal parts that will be machined out of 240,000 lb (1090 t) of raw stock. The volume of titanium used in aircraft in 2012 was projected to be at 100 million lb (45,360 t). Remarkably, this represents only 35% of total titanium consumption.



Source: Mitsui Seiki USA

The influx of titanium and hard stainless material grades spurred by demand of the aerospace and power generation industries for fuel efficiency, have been a machining challenge, as shown here.

Our crystal ball shows the flurry of activity for new aircraft orders will continue for five years. However, even when the boom in the commercial aerospace sector was just a hint on the horizon, forward-looking manufacturers began seeking the best methods for machining these demanding parts. Our company was involved at the start with Boeing's research engineers to develop technology designed specifically to cut these hard materials. We published and presented this research as the data unfolded, and it's time for an update. Manufacturers and technology providers have learned more about the nature of the materials and what is required to turn them into parts, profitably. Further, advancements in cutting tool technology have caught up with the machine tool designs, providing users with a complete, viable system.

The crux of the matter for optimum hard-metal part production lies in the ability of the system to perform low-frequency machining without chatter, hold tools tightly with heavy-duty tool tapers, increase machine stiffness construction, and deliver the power necessary.

Turn the Frequency Dial Down

Machining moderately complex titanium parts up to 1 m in length, which includes three-, four- and five-axis simultaneous machining, requires machine tools with the proper structural design to machine at low amplitude ranges in less than 350 Hz (especially at the 20, 90, and 320 Hz ranges). In hard-metal machining, all of the materials in the machine tool structure must stay within a specific range of stiffness and resiliency so that when cutting the spring memory of the machine is very repeatable. This repeatability is paramount for tightly controlling the cutting edge as the tools pass through the materials. A 1" (25.4-mm) diameter, four-flute end mill, for example, would be run at about 90 rpm. Each time a cutting edge engages with the material, it sends a shock wave into the machine. As each cutting edge “hits” the metal in a consistent, repetitive sequence it creates a low-frequency wave into the machine.

One of the misconceptions about machining titanium and similar grade materials is that general-purpose machines can handle these parts. That class of machine, while ideal for many applications, has a tendency to chatter at low frequencies. This negatively affects both the quality of the part and tool life. Tooling costs can be astronomical. A machine designed specifically for low-frequency machining dramatically reduces chatter at the necessary low rpm that the cutting tools must run to cut these materials. Logic follows that eliminating chatter significantly increases tool life and cost savings.

Ti5553 is a material that exhibits superior linear-elastic behavior. However, when machining these types of materials this behavior dramatically increases cutting forces and generates tremendous heat directly at the cutting edge shear location.
In aerospace components, tool lengths are long, axial cuts are deeper, and many application engineering hours are dedicated to process development. Unlike conventional machines that are designed for a wide range of materials, material-specific machine tools allow engineers a wider range of process opportunities in the specific cutting ranges needed. This dramatically contributes to longer tool life, chatter control, part finish quality, and predictable process control for FMS operations. Our company has application-specific machines that have structural modifications to reduce the amplitudes of the excitation frequencies in the low-frequency ranges. We have paid attention to requirements for handling the low-frequency stresses such

as height-to-width ratios on columns and tables to accommodate high moment loads, and optimal ballscrew locations for axes stability. Skilled craftsmen hand scrape surfaces throughout to provide the high accuracy needed to make quality parts in these materials.

Turn Up the Torque

To cut heavy metals, the machining system needs ample torque. The spindles should produce 2000 ft-lb (2711 N•m) of torque at 100 rpm and large servomotor drives on fine-pitch lead ballscrews. Ti5553 is about four times more difficult to machine than the well-established Ti6A14V in terms of tool life, stock-removal rate, and the required resiliency of the machine structure to push a cutting tool through the metal. At a depth of cut 1 ¼" diameter × $^3/_8$" (31.75 × 9.5 mm) in triple nickel titanium, the tool starts to separate from the taper at about 8500 in.-lb (960 N•m) of moment load on general-purpose machines with a BT/Cat 50 taper. A 7" (178-mm) long, 1" diameter four-flute cutter will remove about 1.2 in.^{3}/min of material from Ti5553 before the tool separates from the spindle taper. If the radial depth-of-cut is increased to remove more stock, the 8500 in.-lb limit will be exceeded. Latest generation machines feature tool taper interfaces, such as Kennametal's KM4X, that can handle up to 35,000 in.-lb (3955 N•m) of tool taper moment loads to accommodate long tools cutting highly resilient materials with an HMC. These elements provide the advantages to push the tool through these tough materials. These power mechanisms are designed so as not to influence the low-frequency excitation conditions.

The 'Titanium Triangle'

Other "must haves" include adequate chip control, high-pressure coolant, and the right cutting tools. There are some massive triple-spindle, high-horsepower vertical machines that have been in use for 25 years, making hard-metal components fairly successfully. However, they are using cobalt-coated carbide cutting tools that require maintenance and regrinding. Further, since they are cutting in the vertical mode, the chips are often remachined. Plus the work area is wide open; high-pressure coolant application is out of the question.

New machines specifically designed for hard-metal parts have a horizontal spindle orientation. The chips fall to the bottom of the machine, and the work area is completely enclosed to flush coolant through the spindles at high pressures. Adequate flooding aimed at the cutting edge contributes significantly to long tool life. Also, cobalt tools are being replaced by new generation indexable carbide cutters, which offer high stock removal rates and eliminate regrinding maintenance.

The combination of a precise, low-frequency, horizontal machine tool, new milling cutters, and high-pressure coolant is the "titanium triangle" required for optimal, cost-effective hard-metal machining. Other considerations are work flow and CNC toolpath creation. All aspects of the hard-metal machining process must be taken into account when considering the ideal system for cutting these new part materials.

Cost versus Profits

Stiffer machine tool materials simply cost more, so the machine tool technology costs more, too—up front. However the definition of "cost" as it relates to "profit" is worth consideration. If companies would profit by cutting deeper, faster, and with better quality, then they may be losing money by not doing so. The roughly 25% extra up-front cost, after scrutiny, could be miniscule by comparison to what might be lost. Further, general-purpose machines last about 20,000 hrs versus the 75,000 hrs that application-specific machines provide.

Difficult-to-machine workpieces, typically the newest titanium grades, Inconels, high-strength stainless steel and other alloys have forced greater design discipline on machine builders and suppliers of cutting tools, toolholders, coolant systems, and controls. They comprise a system and are necessary for successful results. Seek out experts who understand what it takes. As the "Sorting Hat" at Hogwarts School of Witchcraft & Wizardry might say, "Do your homework." **ME**