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➤ BY VICTOR M. CASSIDY


ATI Stellram

ATI Stellram's 4E geometry in grade SP0819 is for machining Inconel 718. The grade utilizes the obtuse 100° corner of a CNMG432A-4E insert, which the company says improves productivity and insert utilization.

Taming the 'Nastalloys'

Tips for turning nickel-base superalloys.

Sometimes you just can't win. Centuries ago, miners in Saxony discovered what they thought was a copper ore. Processing yielded a useless slag, so they concluded that the devil ("Old Nick") had bewitched the ore and decided to name it *kupfernickel,* or Old Nick's copper. When A.F. Cronstedt isolated nickel from this ore in 1751, he stuck the devil's name onto the new element. Nowadays we call nickel-base superalloys the "nasty" alloys because they're so difficult to machine.

Nickel has a high melting temperature (1,453° C) and a face-centered crystal structure, which makes it ductile. It alloys readily, and the major nickel-base alloying systems include nickel-copper, nickel-iron, nickel-chromium, nickel-molybdenum and nickel-iron-chromium.

Developed after World War II from the nickel-chromium system, nickel-base superalloys are more complex than other nickel alloys. They may contain as many as 10 metal components. For example, Inconel 625 contains seven: 61 percent nickel, 21.5 percent chromium, 9 percent molybdenum, 3.6 percent niobium, 0.2 percent titanium, 2.5 percent iron and 0.05 percent carbon. The most familiar nickel-base superalloys are Inconel, Hastelloy, Rene, Waspaloy and Alloy-X. Each of these names denotes an alloy family.

Nickel-base superalloys serve where high tensile strength, fatigue and thermal resistance are required in combination with corrosion resistance. They retain their strength and creep-rupture resistance up to a large fraction of their melting temperature.

The superalloys workharden rapidly. High pressures that accompany turning cause a hardening effect that slows further turning—and may also cause warping in small parts.

Nothing Comes Easy

CUTTING TOOL ENGINEERING talked to metalcutting professionals who work every day with nickel-base superalloys. All cautioned that turning nickel-base superalloys requires close attention to cutting speed, feed rate, DOC, tool geometry and coolant application.

What kinds of nickel-base superalloys are more difficult to turn? Inconel, Hastelloy, Rene, Waspaloy and Alloy-X are "all about the same," said Chuck

Schneider, turning manager for toolmaker Walter USA Inc., Waukesha, Wis., "but the higher the chromium content, the worse it becomes. All the Hastelloys are in the 60 to 65 percent nickel range, with 7 to 22 percent chrome."

However, progress is being made. "Not only us, but all of our competitors are making some great improvements in being able to attack the superalloys," he said.

According to Sean Holt, aerospace specialist for Sandvik Coromant Co., Fair Lawn, N.J., the biggest difference between nickel-base superalloys "is not necessarily the material, but the material condition." With Inconel 718, he said, "you could possibly get a range from 26 HRC up to 46 or even 48 HRC. So turning Inconel in the softer condition and the harder condition varies considerably." This affects tool life and the selection of tool inserts.

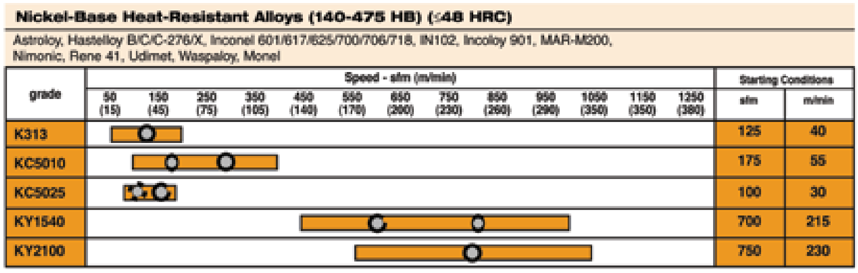
Holt added that nickel-base superalloys cause notch wear in inserts, which quickly breaks them down, so inserts must be monitored or the shop risks catastrophic failure. "If you can get 20 minutes of tool wear from an insert on roughing applications, that's pretty good," he said. "We get an average of 40 minutes for finishing applications."

Martin Gardner, global product manager—turning, threading and grooving, ATI Stellram, La Vergne, Tenn., said Inconel 625 is easier to machine than Rene 41. The degree of difficulty increases with Inconel 718 and continues with the Hastelloys and finally the Waspaloys. Nickel-base superalloys withstand high temperature and take longer to turn because they put extreme mechanical and thermal pressure on the cutting edge, forcing down cutting speeds and feeds.

With one cutting edge, a shop can remove up to 130 cu. in. of aluminum or 7.5 cu. in. of Inconel 718. "That gives you a relationship between where the material stands—one extreme to another," Gardner said.

Machining nickel-base superalloys generates built-up edge, workhardening, temperature diffusion and notching. They have "an aggressive abrasive effect on the carbide cutting edge, all excellent formulas for wearing out cutting tools fast," Gardner said. Tool

Kennametal



Speed recommendations for Kennametal positive inserts.

life can be as much as 245 percent less than when cutting aluminum or 90 percent less than when cutting steel.

What ideal recipe—a combination of cutting speed, feed rate, DOC, tool geometry and coolant—does each metalcutting professional recommend for machining these materials? "You have to generate a progressive cutting action with a positive rake angle to reduce cutting pressure," Gardner said. The edge doesn't have to be sharp, but the edge condition needs to be controlled to protect the cutting edge, which is under pressure during chip formation and material abrasion.

It's important to cut and not deform or push the material, Gardner added. If the cutting action is not perfect immediately, the machined component workhardens, which can affect the material's structure and mechanical properties. This can decrease the performance of the cutting edge, leading to BUE, chipping and notching.

Prepare the edge with care, Gardner continued. If you make it excessively sharp, the edge will be too weak. Heat generated with the material will burn the edge away very fast and create DOC notching. The wrong edge can cut turning productivity by half.

Cutting speed is a "sensitive parameter, which affects tool life," Gardner said. Increasing the cutting speed raises the cutting temperature, which can decrease tool life. For example, machining ATI's Alvac 718 (Inconel 718) with a cutting speed of 110 sfm and a feed rate of 0.005 ipr, a parts manufacturer can expect a tool life of around 30 minutes. When machining at the same feed rate and increasing the speed to 180 sfm, tool life will drop to about 10 minutes. Likewise, increasing the feed rate to 0.008 ipr while using a 110-sfm cutting speed, tool life drops to 15 minutes. A 0.008-ipr feed rate and a 180-sfm cutting speed drops tool life from about 10 minutes to 3 minutes.

To obtain a higher feed rate, it's necessary to use a low approach angle. This minimizes chip thickness and can have a dramatic effect on tool life. For example, when machining Alvac 718 using the new Stellram 4E geometry in grade SP0819 and standard CNMG inserts with a 95° approach angle, tool life is 17 minutes. When using the same type of inserts in an SMNG style with a 45° approach angle, tool life increases to 40 minutes.

Holt also has a recipe. "We always recommend our 1105 PVD-coated inserts for notch wear resistance rather than a CVD insert, so you're looking for a very thin coating and a very sharp geometry on the insert," he said. "That all helps [increase] notch wear resistance. With the right programming techniques, you could really optimize it with the sharp geometry and the PVD-coated insert. CVD-coated S05F inserts are utilized when there's plastic deformation on the insert."

Holt added that Sandvik Coromant "does a lot of work with ceramic inserts" and released two Sialon grades in 2007, which are designed for machining nickel alloys. These can operate at cutting speeds 10 to 15 times higher than those of carbide, according to the company. With a carbide insert, "you're around 165 sfm," Holt said. The ceramic insert can turn at about 1,000 sfm.

Schneider's recipe is "as positive a top geometry as you possibly can get and still maintain strength at the cutting edge, combined with heavy feed rates and moderate to low cutting speeds." The heavy feed is necessary because of workhardening characteristics and also because superalloys tend to cause BUE. "You want to get through them as quickly as possible," he said. "Too low a feed rate will keep the cutting edge in contact with the workpiece longer, exposing it to tremendous heat, ultimately accelerating flank wear."

Coatings Boost Productivity

Schneider added that Walter's WSM-30 turning insert has a micrograin substrate and a PVD aluminum-oxide coating. This "allows for sharper edge preparations on existing geometries and also the inclusion of some higher positive geometries that are on the drawing board," he said. Walter is now able to maintain a sharper edge preparation by going with the PVD coating vs. a medium-temperature CVD coating.


Sandvik Coromant

In 2007, Sandvik released two Sialon grades for machining nickel-base alloys.

Schneider said even when standard austenitic-type grades are used, sharp cutting edges can be maintained on Walter's medium-temperature CVD cutting inserts because the coating has "a matrix that binds the carbonitride layer and the Al_2O_3 layer like reinforcing bars in concrete." This matrix is a patented feature called the intermediate layer.

Before this coating became available, machinists often used round, or button-type, tools to rough some nickel-base superalloys. This was done to avoid notching, Schneider said, which is "very common in repeat cuts at uniform cutting depths." Notching happens because superalloys are so difficult to cut and shear that an insert will oxidize or vaporize and form cutting notches when used for repeated cuts.

Schneider said with the new coating and substrates, shops can employ conventional inserts, which are "a lot freer cutting … the freer you can cut these materials, the better off you are." Machinists can use conventional geometries with positive top geometries that cut through the material instead of plowing, he said, adding that the new PVD Al_2O_3coating is polished, which "helps in avoiding BUE."

Benefits of the new coatings and substrates include less horsepower draw, freer cutting, longer tool life and improved productivity.

The product was introduced in January, after extensive lab and field tests, which showed a 20 percent cycle time improvement, so Schneider thinks that at least 10 percent—and possibly more—should be achievable in the field. Tool life should improve 20 to 30 percent.

Coolants Make a Difference

Each company has a slightly different take on coolants. Schneider said "any coolant is fine if it has the lubricity to prevent BUE" in nickel-base superalloys. "You need a coolant that's going to give you lubricity without gunking up your machine," he added, "one that is applied in a volume and pressure suitable to flush chips and cool the cutting edge."

Gardner thinks that both the coolant and its flow are important. "For superalloys, there should always be a strong flow of coolant at the cutting point," he said. "It dissipates the heat produced by the chip, cleans the component and helps prevent the chip from being recut." It can also decrease the friction between the material being machined and the cutting edge and therefore reduce the cutting edge's temperature. "When we optimize the type and flow of coolant used," he said, "we can see tool life improvements of up to 40 percent and 20 percent in material-removal rates."

Coolant must be delivered to the cutting edge at high pressure, according to Holt. "This is optimized at 1,000 psi, but we have tooling solutions up to 4,000 psi [jet break]." Sandvik Coromant has introduced CoroTurn HP, a "range of high-pressure coolant tools that deliver a laminar flow directly to the cutting edge."

Holt described three benefits from CoroTurn HP when machining Inconel. The first is chip control. Nickel-base superalloys have long, stringy chips, but these can be broken if coolant is directed to the cutting edge at 1,000 psi. Second, high-pressure coolant allows between 20 and 30 percent greater cutting speed because the coolant is on the cutting edge. Third, surface integrity improves, which is important

Vast, tiny future for superalloys

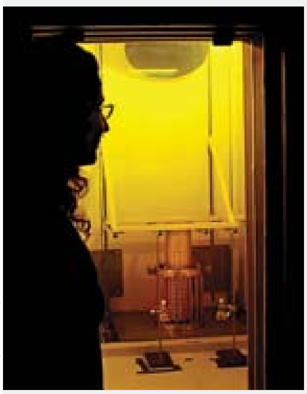
Sandia National Laboratories, Albuquerque, N.M., is pioneering the future of nickel-base and other superalloys by advancing the science behind the way that superalloys are made. As part of Sandia's nanoscale research, a group of scientists designed a series of experiments to study the creation of metal and alloy nanoparticles.

The research has vast implications, said Tina Nenoff, project lead. The lightweight, corrosion-resistant materials that the team is creating would be suitable for weapons casings, gas turbine engines, satellites, aircraft and power generating plants.

In the past, superalloy development depended on chemical and technological innovations and was driven primarily by the aerospace and power generation industries. Sandia is studying manufacture via a method of radiation, known as radiolysis, that involves synthesis of nanoparticles.

According to Nenoff, radiolysis could become a universal method of nanoparticle formation. Once Sandia scientists understand how superalloy materials are formed at the nanoparticle level, they'll be able to research nickel-base superalloys. They hope to eventually develop entirely new materials for use in low-polluting engines and power generation systems of unprecedented thermal efficiency. For details, visit www.sandia.gov/news/resources/releases/2007/nanopart.html.

—*V. Cassidy*



Randy Montoya

Tina Nenoff, Sandia National Laboratories, observes an experiment to create superalloy nanoparticles in a testing cell at the SNL Gamma Irradiation Facility.

to aerospace customers.

Tips from the Trenches

Steve Weitz is president and owner of K.L. Steven Co. Inc., Rio Rancho, N.M., which does custom precision machining of parts for numerous industries. The firm routinely machines nickel-base superalloys.

A shop must plan the machining process carefully. Weitz said: "Set up a strategy. Coordinate roughing and finishing. Check the diameter after roughing. Watch chip formation. Don't expect to work at high speed."

When it machines nickel-base superalloys, K.L. Steven uses cutting oil. "It does the job for us," Weitz said, "even though many guys complain about the mess and extra work it creates. Many machine tool makers have grease injectors because they want to avoid costs of cleaning up oil." Weitz added that there's no pollution problem with his company's use of oil because it uses mist collectors and recycles the oil.

Also, working on nickel-base superalloys requires considerable preparation, even when the work is being done by an experienced machinist. "It's not routine work," Weitz said, "so we teach our best operators how to work with the metal, control chips and maintain tooling."

Regardless, nickel-base superalloys are still a challenge. "Hastelloy is really nasty stuff," Weitz concluded. △

Editor's Note: Additional information on turning aero-engine parts is available on www.ctemag.com. Click on "Interactive Reports" and choose "Taming the 'Nastalloys.'"

About the Author

Victor M. Cassidy is a Chicago-based freelance writer.

The following companies contributed to this report:

ATI Stellram
(800) 232-1200
www.atistellram.com

K.L. Steven Co. Inc.
(800) 739-9176
www.klsteven.com

Sandia National Laboratories
(505) 845-0011
www.sandia.gov

Sandvik Coromant Co.
(800) 726-3845
www.coromant.sandvik.com/us

Walter USA Inc.
(800) 945-5554
www.walter-tools.com