Metalworking

Machining Metals: Techniques and Tools to Tackle Hastelloy

Kip Hanson | Oct 25, 2022

Metallurgists have long known that small amounts of chromium, molybdenum, nickel and tungsten make steel stronger and more heat-resistant. The nickel-based superalloy known as Hastelloy contains all four, with a bit of cobalt and vanadium to boot. It's tough stuff.

It's also been around for a long time. Inventor and entrepreneur Elwood Haynes obtained the first patent on Hastelloy A in 1921. The superchargers that gave World War II military aircraft more power at higher altitudes contained Hastelloy B turbine blades, while nozzle skirts and heat exchangers made of Hastelloy C helped bring the Apollo 11 astronauts to the moon.

Those alloys are still in use today. So are Hastelloy X and numerous letter-and number-designated variants in between, all registered to Haynes International. The workhorse of the group is probably Hastelloy C-276, a heat-resistant superalloy (HRSA) known for its exceptional resistance to cracking and pitting in the presence of acids, chlorides and oxidizing salts.

These attributes make Hastelloy C-276 the top dog for a wide range of chemical, oil and gas, pharmaceutical and waste-treatment applications, even at temperatures up to 1900°F (1038°C).

Hastelloy variants remain popular in the aerospace industry, too, where they are widely used in gas turbine components.

'Have to Get Everything Just Right'

The strength that makes Hastelloy appealing simultaneously makes machining it more challenging, as Mike Restall is well aware.

A senior CAM programmer and application specialist at the Sandvik Coromant Center in Mebane, North Carolina, Restall spends his days developing effective machining strategies for such alloys.

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"For aerospace use, the most common is Hastelloy X, which has a machinability rating just 16 percent that of 1112 steel," he says. "It's easier to cut than Inconel 718, but not by much."

Many of the parts Restall is tasked with turning are forged. Here, he typically begins with a 3/4-inch round ceramic insert such as Sandvik Coromant's 670 grade (a whisker-reinforced ceramic) to "peel away the nasty, scaly outer surface," followed by a smaller 6160-grade ceramic insert to rough the balance of the workpiece.

Restall might begin the finishing process—which he defines as removal of the final 1 millimeter of material—with a CNMG or DNMG-style insert, depending on the part's geometry. He says an S205 CVD-coated carbide works well, although notching at the depth-of-cut line can be expected (as with all superalloys).

One productive alternative to carbide is a 7014 cubic boron nitride (CBN) finishing insert, which Restall suggests can run at speeds up to 900 surface feet per minute (SFM), more than twice that of carbide.

A similar approach applies with milling. Radial depths of cut during roughing are light—between 5 percent and 15 percent of the cutter diameter, using high axial engagement.

With ceramic tooling, machining is always performed dry. Otherwise, high-pressure coolant (HPC) should be used with carbide tools. Trochoidal toolpaths that leverage the chip-thinning effect and maintain constant chip loads are advisable, as is a rigid machine tool with plenty of horsepower.

"With Hastelloy and other heat-resistant superalloys, it's crucial to develop a repeatable, secure process, particularly if the part needs to be certified for aerospace use," Restall says. "That's because once you're locked in, it's very difficult to change anything without first going back to the customer for approval. This is why I strongly recommend that shops engage with their cutting tool provider early on. You have to get everything just right with these tough materials."

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> Mike Restall
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Greg Sage, regional product manager for turning at Kennametal, says Hastelloy tends to be gummier and more abrasive than some of the other superalloys, which changes the machining approach.

"For instance, I'd probably go in with one of our SiAlON ceramic turning grades on an Inconel but use a KY4300 whisker-reinforced ceramic on Hastelloy," he says. "It's tougher than a pure ceramic and deals with that gummy abrasiveness better."

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That equation begins to change as parts get smaller. For anything under an inch or so in diameter, ceramic tools often generate too much cutting force and should be exchanged for a single-sided, positive-rake carbide insert.

Yes, tool life and productivity will suffer compared with performance using ceramic, but since less material is being removed on smaller parts, the trade-off is minimal. "That's true as well for interrupted cuts, as ceramic is more prone to mechanical and thermal shock than carbide," Sage says.

'Really Tough Stainless'

Hastelloy is much like Inconel, cobalt chrome (CoCr), and A286 (an iron-based superalloy), agrees Keith Hoover, the regional product manager for holemaking and hole-finishing tools at Kennametal.

“They’re all extremely tough and heat-resistant, which is what they’re designed for, but they’re also extremely abrasive,” he says. “That means wear will be one of the main failure modes.”

Think of it as a “really tough stainless,” he adds, which calls for an up-sharp edge and a durable coating with high hot hardness and low friction coefficient. At Kennametal, that means an AlTiN coating.

Like most cutting tool experts, Hoover also recommends using application-specific grades and geometries for the demanding materials, but he offers a surprising counterpoint: Don’t discount the GOdrill.

“It’s considered a general-purpose solid carbide drill but has a really robust point and does a pretty good job in some of these superalloys,” he says.

Tony McClain offers additional advice, much of it focused on troubleshooting and process development. A regional product marketing manager at Kennametal, McClain has visited many shops experiencing tool life issues that have nothing to do with the cutting tool.

“A lot of times, people go into aerospace materials with a machine tool that’s not up to the task,” he says. “Does it have sufficient power and torque? Is the spindle connection rigid enough? Are the toolholders the right ones for the job? How about the fixturing and how well it grips the workpiece?”

Those are important considerations with any job and even more so with tough alloys such as Hastelloy. Whatever the problem, he says, it’s critical that shops take a scientific approach to fixing it.

Change one variable at a time and document the results, he recommends. Otherwise, you’ll never figure out what actually corrected it.

The Heat Is On

Machining Hastelloy isn’t all that different than other nickel-based superalloys—use dynamic toolpaths with light radial stepovers, don’t bury the tool in corners, and avoid work-hardening at all costs, say M.A. Ford Research & Development Manager Derek Nading and his colleague Dirk Dietsch, regional business manager for the Great Lakes region.

“This last part means keeping the feed rate fairly high, and if you’re drilling, don’t peck,” Dietsch says. “Of course, you’ll need a coolant-fed tool to do that, like one of our Cyclone XD solid carbide drills.”

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A positive geometry cutter and a sharp edge to shear the material are best for finishing, Nading adds.

“Find a tool with a very slight hone, just enough to break the cutting edge,” he says. “The other thing to look for would be a good heat-resistant coating, something with good oxidation resistance—a premium TiAlSiN, for instance, or even an AlTiN, along with a very tough substrate.”

Heat buildup is a significant problem with Hastelloy, he notes. For those using water-soluble, emulsion-type cutting fluids (as most shops do), proper maintenance is key.

Coolant should be filtered, free of tramp oil, and kept at a 10 percent to 12 percent concentration level. A high-quality neat oil designed for nickel-based alloys is another option, although a chiller unit should be used to keep temperatures low.

“Oils are quite lubricious, so they help to reduce built-up edge,” Dietsch says. “Another thing that helps is to keep as many teeth in the cut as possible. For example, our TuffCut 380 series 9-flute end mill was specifically designed for dynamic milling in heat-resistant superalloys; we often find that when it comes to tool life and cycle time, having the proper chip load and consistent chip thickness is even more important than the cutting speeds."