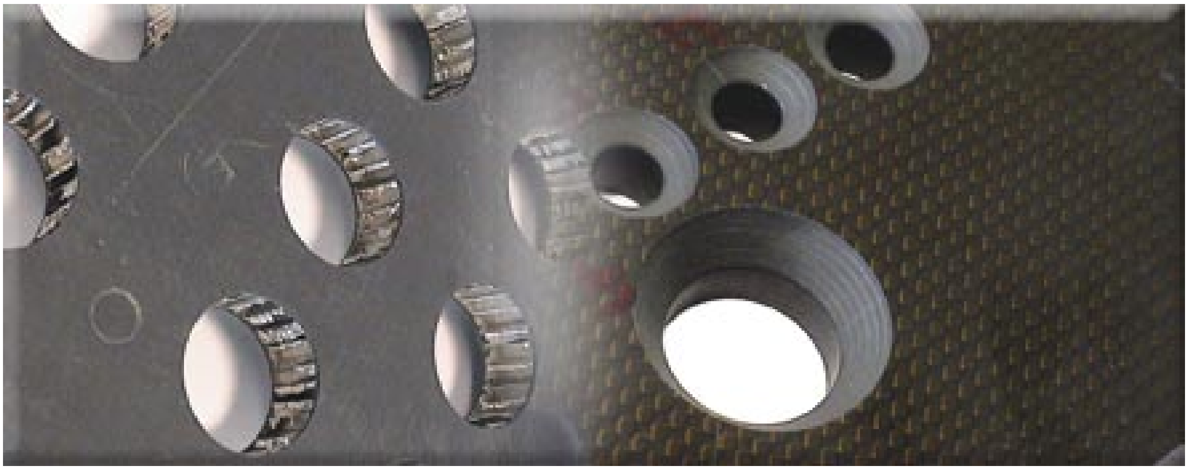
➤ BY DANIEL MARGOLIS, ASSOCIATE EDITOR



Stacked material: Novator

Stacking the Odds

Machining titanium-composite stacks requires patience and perseverance.

When the Boeing 787 enters service in 2008, it will be the first major airliner to use composite materials—including stacked materials consisting of a composite and titanium—for most of its construction.

Stacking composites and titanium is not new. The material combination has been around for at least 15 years. Initially seen on military aircraft, it has migrated to commercial aircraft, replacing titanium or aluminum assemblies in high-stress wing areas, such as where the wings join the fuselage.

Titanium-composite stacks have a high strength-to-weight ratio—with a yield strength as high as 120,000 psi and a density of roughly 4 g/cm^3—and provide corrosion and heat resistance. They're also reliably flexible, owing to the titanium reinforcement of the composite.

"Titanium has a lot of memory," said Mike Gadzinski, technical seminars and training manager for Iscar Metals Inc., Arlington, Texas. "It'll stretch and bend without distorting."

The makeup of titanium is well known, but just what is the composite in a titanium-composite stack? No one will say for sure, since aerospace companies jealously guard the material makeup of their aircraft components. "They can be a lot of different things," Gadzinski said. "A lot of it's actually fairly guarded."

The composite isn't the only aspect of titanium-composite stacks shrouded in secrecy. The companies that CUTTING TOOL ENGINEERING spoke with in connection with this article were generally tight-lipped about certain details surrounding the material, such as exact technical specifications for tool geometries, cutting parameters, hole widths and tolerances. They all have nondisclosure agreements with the aerospace companies they provide tools for and recommend cutting processes to.

The National Center for Defense Manufacturing & Machining, Latrobe, Pa., assists suppliers working with the U.S. Department of Defense and with aerospace manufacturers, helping them reduce the manufacturing cost of components. As part of its research, the organization takes on "problem projects"; it is given difficult workpiece materials and develops processes or tools to efficiently machine the materials.

NCDMM has been machining titanium-composite stacks for the past 18 months. Glenn Sheffler, the center's business development manager, explained that these tests are so secretive that sometimes the staff is not told what they are machining: "We know it's titanium, but what type of titanium? We're not sure. What kind of composite is it? We're not sure." Sheffler added that knowing this would be useful, as it would narrow what tools NCDMM considered in approaching the workpiece.

Various sources confirm that the composite is generally carbon-fiber-reinforced plastic, though it can also be a graphite-epoxy or a metal-matrix composite. Whatever the composite, in stack production it is formed, laid-out and cured, with the titanium CNC-machined separately. The composite layer is cast near-net shape. The two are then laminated to produce a workpiece that is generally about ½" thick, with the composite on top most of the time. From there, the main task is drilling, reaming and countersinking the workpiece in preparation for aircraft assembly. This is not exactly where the fun begins.

The Biggest Problem

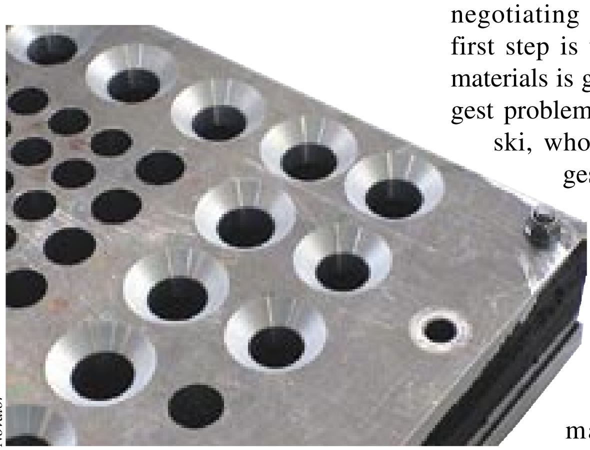
According to Ed Francis, vice president of Crystallume Engineered Diamond Products, Santa Cruz, Calif., one of the biggest problems aerospace manufacturers face currently is how to drill this workpiece material. "There is no 'this is the answer to it' solution at this point," Francis said.

Crystallume has worked with Lockheed Martin, Boeing and the Dutch aircraft manufacturer Stork Aerospace Group to produce drills for machining titanium-composite stacks. Like NCDMM, Crystallume is routinely given stacks to machine by its customers with the goal of developing improved processes or tools.

Finish inside of a titanium composite stack hole drilled with an uncoated carbide drill.

Crystallume

Finish inside of a titanium-composite stack hole drilled with a diamond-coated carbide drill.



Novator

Stacked material drilled with countersunk holes.

To illustrate the challenges of this machining operation, Francis used the analogy of wood over steel. "You can [easily] drill through the wood, but the minute you hit the steel and the hot chips start coming up, those hot chips burn and destroy the hole," Francis said. The same can happen when drilling composite over titanium.

The material theoretically calls for two different tools, one that fits the attributes of a composite and a different one that fits the attributes of the titanium. But only one type of tool can be used in each pass through the hole.

Composites are extremely abrasive, making PCD-coated drills the preferred choice. However, PCD doesn't last long when drilling titanium, which creates a great deal of heat. On the other hand, what works in titanium, such as carbide, doesn't last long in composites. Machinists generally end up selecting carbide drills, as wearing out PCD drills in titanium is expensive.

Iscar has a three-step program for negotiating this predicament. "The first step is to identify which of the materials is going to give you the biggest problem and why," said Gadzinski, who explained that the biggest concern in a titanium-composite stack is titanium's high tensile strength. "The second step is to select your cutting tool geometries based on the worst-case scenario," or worst-case material property. This means a sharp cutting edge with a positive rake angle.

"The third step is to identify the wear characteristics you're getting on your tooling," Gadzinski said. "That will give a good indication whether you're going too fast or too slow."

NCDMM uses dynamometers—machines used to measure torque and rotational speed—mounted on its machines to check the level of force being applied to the workpiece and the drill. This lets its researchers know what kind of wear characteristics they're getting during machining. "If your horsepower is increasing as you're going on, the tool's starting to wear," said Joe Slusarcyk, project engineer for NCDMM.

John Winebrenner, NCDMM's manager of technology assessment and advancement, added, "If you think it should last longer than what you're getting, you could try slowing it down, but then you've got to see if you're putting more stresses into the workpiece and causing delamination."

The composite's abrasiveness shortens tool life, but that's just the nature of the beast. Most resort to multiple passes with drills of increasingly larger diameter, going from ³⁄₁₆" to ¼" to ⅜", for example. "What in aluminum or a composite structure could be done with a single tool in a single pass is taking three to five passes in a titanium and composite structure—drilling it [multiple times] and then running some form of reamer with a countersink," Francis said. "A lot of people are looking for a tool that'll put the hole in with the countersink in one pass, and it's still a question whether that's even going to be possible."

Coolant Conundrums

Onsrud Cutter LP, Libertyville, Ill., is a cutting tool manufacturer that works onsite with those who drill, countersink and ream titanium-composite stacks. These processes create holes for permanent-attach or removable fasteners to assemble these bimaterial components.

According to Tom Cornwell, sales and application specialist for Onsrud, one of the biggest challenges a manufacturer faces when machining titanium-composite stacks is whether or not to use coolant, and, if so, how to apply it effectively. "In a lot of cases, coolant is an absolute no-no, because the composite materials being cut will absorb the moisture and that's something you don't want to happen," Cornwell said.

He explained that absorbed moisture can creates issues when the parts are exposed to different temperatures once in use. An aircraft part might experience a 200° F temperature swing in a matter of minutes, from 160° F on the runway to -40° F once it is 10,000' in the air. In this situation, absorbed moisture could freeze and contract, then expand and evaporate, leading to part failure.

Because of this, most people machine titanium-composite stacks dry or near-dry, applying coolant only in a fine mist or drip. This means effective chip evacuation is paramount.

However, manufacturers don't produce "sixes and nines" when cutting composites. Drilling the composite layer produces fine, dust-like chips that, in some cases, can be toxic when inhaled. This requires machining in a closed environment, and some manufacturers resort to a vacuum system to combat the dust.

A different problem arises once the drill reaches the titanium layer. The titanium forms typical-shaped chips that have sharp edges and are hot. "Those chips will actually scar the [composite's] sidewalls when they're evacuated by the flutes of the drill," Cornwell said. Furthermore, the titanium chips may wander into any gap between the two materials, which is also unacceptable.

In this situation, coolant-through drills come in handy even when machining dry. "Even if we're not using coolant, we can force air through [the drill] to assist in chip removal," Cornwell said.

NCDMM's Winebrenner explained how the right drill geometry makes chips proceed up the flute and out of the hole without damaging the composite. "You want a flute with a tight spiral, and then you want a very positive rake to the actual drill point, to curl the chip a lot faster and try to harness it inside the flute," he said.

Carefully setting production parameters and balancing speeds, feeds and DOC also helps with chip evacuation and with preserving workpiece integrity. Machinists have the most flexibility in setting speeds. "Those parameters are wide open," Cornwell said. "In general terms, let's say a ¼"-dia. drill is a popular drill size. In most cases, that's going to be running at about 3,500 rpm."

Gadzinski explained the reasoning behind running at relatively high speeds.

"The biggest thing is getting as much rigidity into the part as you possibly can, which is why high-speed machining techniques are very often used here, because you typically are taking light depths of cut, light feed rates and don't impart an awful lot of pressure back into the workpiece," he said. "Therefore, there's less likelihood of moving it or distorting it during the cutting process."

Gadzinski added that feed rates have increased conservatively as methods to machine this material have improved. "You're getting, in some cases, up into the 300 to 400 sfm range." Others, such as Crystallume's Francis, place maximum feeds at 200 sfm, drilling holes between ³⁄₁₆" and ⅜" in diameter.

All this cautiousness—multiple passes with different-size tools, light DOC, light feed rates, machining dry or near-dry in a closed environment—makes it difficult to achieve high productivity when machining titanium-composite stacks. But, as Gadzinski pointed out, productivity is not as important when machining aerospace parts. "They're going to build 700 or 800 [airplanes], compared to how many millions of engine blocks that are machined," he said.

A New Hope

While tool manufacturers consider developing tools specifically to machine titanium-composite stacks, most shops are making do with standard tools or "modified specials."

That may be about to change though. Last September, Kennametal made a go-to-market agreement with orbital drilling machine builder Novator AB, Spånga, Sweden. The companies plan to combine Novator's orbital drilling equipment and techniques with Kennametal tools. This agreement is focused on drilling aerospace materials such as titanium-composite stacks.

Orbital drilling technology combines the spinning of a tool on its own axis with a mechanical spindle that rotates eccentrically around a principal axis. These dual, high-speed rotations have the effect of feeding the drill through the material rather than pushing it.

"This process is uniquely suited to composite stacks, because it has the benefit of mitigating the heat generated by the titanium cutting," said Francois Gau, global segment manager for the

The following companies contributed to this report:

Crystallume Engineered Diamond Products
(800) 789-4322
www.crystallume.com

Iscar Metals Inc.
(877) BY-ISCAR
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Kennametal Inc.
(800) 446-7738
www.kennametal.com

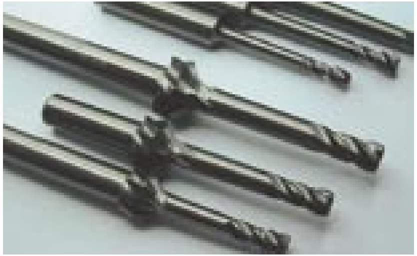
The National Center for Defense Manufacturing & Machining
(724) 539-6125
www.ncdmm.org

Onsrud Cutter LP
(800) 234-1560

aerospace and defense industry for Kennametal, Latrobe, Pa.

The tool's cutting edge is only partially and intermittently engaged with the material surface, so heat buildup is minimal. Orbital motion also allows the tool diameter to be smaller than the specified hole diameter, which makes for efficient chip and heat extraction.

Gau ticked off the advantages of this method: "I [the user] am flexible with the geometry of the tool. I have less time in cut for the cutting edge. I have intermittent contact so I can cool my tool much more efficiently. I don't have chip issues, [due to] the vacuum system we put in place. I don't have abrasion. I don't have delamination."



Kennametal

These tools are being combined with orbital drilling equipment and techniques to drill aerospace materials such as titanium-composite stacks.

For now, this seems like the best hope for more efficient drilling of titanium-composite stacks, though Onsrud's Cornwell speculated that tools may soon make further adaptive leaps to contend with the material. "[With] machinery today, the sensing capabilities that they have on some of these spindles, it's quite feasible that in the future the tool will actually sense what material it's cutting by the amount of load on the end of the tool," Cornwell said, "and, hopefully, we could control spindle speed and feed rates based upon whatever the spindle's sensing at the time."

Until then, machinists of titanium-composite stacks will have to continue to compromise. △