cover story

➤ BY BILL KENNEDY, CONTRIBUTING EDITOR

WATER WORKS

Advances in abrasive waterjet machining have encouraged a growing number of shops to adopt the technology.

Although a cycle time of 6 million years and tolerances of ±10 miles don't quite meet just-in-time or Six Sigma standards, the carving of the Grand Canyon clearly shows the cutting power of a stream of water. Try putting the water under pressure of 50,000-plus psi, sending it through a tiny opening so it accelerates to twice the speed of sound and adding hard, abrasive grit. The result is a precise erosive force that can cut virtually anything—and do it fast.

Abrasive waterjet (AWJ) machining is often considered an unconventional cutting technology best-suited for niche applications. However, an increasing number of general manufacturers and job shops are employing it. Advances in AWJ equipment and software have boosted the versatility and ease of use of this cutting technology.

A 30-Something Process

Compared to most other metalcutting processes, waterjet cutting is a youngster. Use of high-pressure waterjets as cutting tools began in the 1970s. Manufacturers found that a 0.005"-dia.

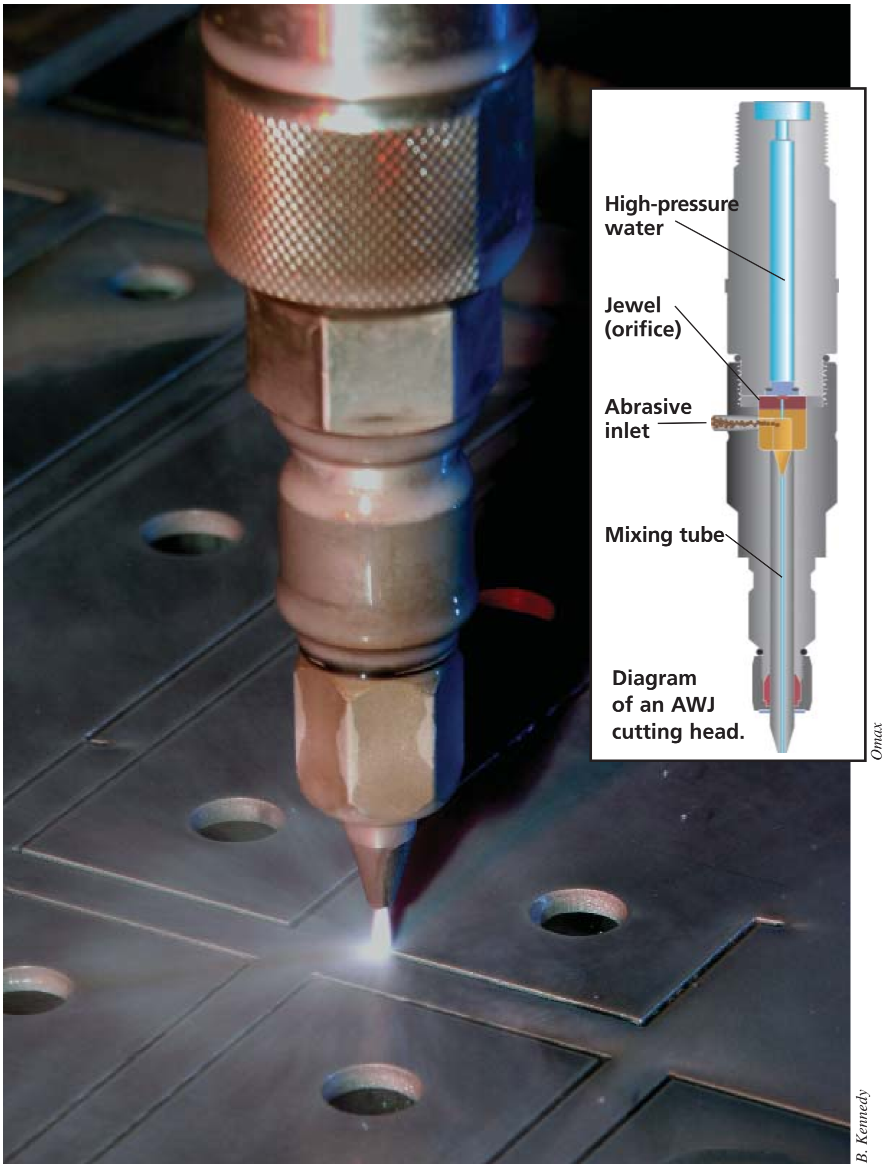

Diagram of an AWJ cutting head.

An AWJ cuts conveyor components out of stainless steel plate at Kutz Fabricating.

stream of plain water at a pressure of 40,000 to 60,000 psi could quickly and cleanly cut soft materials such as food products and disposable diapers.

In the early 1980s, Dr. Mohamed Hashish, now senior vice president of technology for Flow International Corp., a waterjet machine builder in Kent, Wash., invented the AWJ by adding abrasive grit to the water stream. The abrasive gave the waterjet the ability to cut nearly any material, from steel, glass and rubber to difficult-to-machine materials such as titanium, nickel-base alloys and granite.

Control of the AWJ cutting path and speed has evolved as well. The first waterjet setups were basically liquid bandsaws. Today, AWJs are applied on gantry-style, servodriven X-Y cutting tables and even 5-axis robotic arrangements that can make complex 3-D cuts (see "3-D vision" sidebar). Also, advances in control software have boosted productivity and accuracy and simplified machine use.

AWJs offer a variety of advantages. They can cut thick (10" or more) materials as well as thin. They do not generate temperatures high enough to cause a heat-affected zone or part distortion. Machining pressures on the part are minimal—typically in the range of 1 psi—which preserves the material characteristics of the workpiece and simplifies fixturing. The AWJ's accuracy and narrow kerf enable it to follow highly detailed cutting paths, producing little or no burr. The same attributes enable AWJs to cut around parts tightly nested on a single piece of material, reducing waste. The process neither requires nor produces hazardous gases or chemicals. AWJs can cut reflective materials that pose problems for laser machining, as well as nonmetallic parts that cannot be electric-discharge-machined.

The benefits offered by AWJs are, however, accompanied by some singular peculiarities. It is difficult to accurately control the DOC of the cutting stream, and cut quality and precision are highly dependent on the traverse speed of the cutting head. While no chips or heat are generated, a shop does have to deal with used water and abrasive. And AWJ machines certainly require different, if not more intense, maintenance than conventional machine tools.

3-D vision

Bruce Kivisto, general manager for waterjet manufacturing services provider Chukar Waterjet Inc., St. Michael, Minn., said waterjet technology is relatively new and "every year we get better. It used to be a flat technology, but now we can do 3-D. We've got waterjet cutting equipment on a robot in our shop."

Chukar Waterjet

Robot fitted with an AWJ cutting head at Chukar Waterjet.

Kivisto said the cutting angles possible with the AWJ extend "as far as you can twist your robot. You'll hit a limit, depending on how you tube your water up, but basically you can run in any direction you want." The only limitations are the working range of the robot; the unit in his shop can cover about 75 cu. ft.

A typical application that illustrates its 3-D machining capacity is trimming difficult-to-machine workpiece materials to near-net shape before CNC machining or EDMing. The benefits, Kivisto said, are "faster machining cycle times and a reduction in the material you're losing in the process."

He did mention a downside to AWJ machining: the difficulty of controlling DOC. Accurate depth in blind-holes, as opposed to through-holes, is hard to achieve. Also, when cutting through one side of open materials such as pipe, the uncut side must be protected, usually with some buffer material. Kivisto said the flexibility and speed of the 3-D AWJ setup makes it a viable way to produce long and short runs of parts.

—B. Kennedy

Pieces of the Puzzle

Although equipment and applications vary greatly, AWJs share common characteristics. AWJs typically operate at 40,000 to 60,000 psi. The water pressure is generated by 2-stage intensifier pumps or single-stage, direct-drive pumps.

At the AWJ cutting head, the water travels through a 0.010"- to 0.018"-dia. orifice in a plug called a "jewel," made from ruby, sapphire or diamond. The tiny opening combined with high water pressure produce the AWJ's speed. The most common jewel material is sapphire; sapphire jewels cost $15 to $30 each and provide 50 to 100 hours of cutting life. Diamond jewels last 800 to 2,000 hours, but cost 10 to 20 times more than those made of sapphire. Diamond can be useful where continuous operation is required.

Abrasive grit is added to the water stream just below the jewel. The most common abrasive is garnet. Hard and relatively inexpensive, the grit is screened and classified in different sizes for different applications. Finer grits impart smoother surfaces, while coarser grits cut faster but impart rougher surfaces. Depending on grit size and quality, abrasive costs between 10 and 40 cents per pound.

The abrasive is released into the waterjet at 0.5 to 2 lbs. per minute, depending on the water pressure, nozzle size and other factors. The water and abrasive mix in a tube, which also focuses the cutting stream.

Early AWJ mixing tubes were made of tungsten carbide and wore out in a few hours. Today, most mixing tubes are formed from tungsten-carbide composites that contain vanadium carbide or molybdenum carbide and last 100 to 150 hours. The fine-grained composites are exceptionally hard, dense and porosity-free. But with the high hardness comes a degree of brittleness, so care must be taken not to break the approximately $150 mixing tube by running it into the workpiece or machine. The orifice at the end of the mixing-tube nozzle generally ranges in diameter from 0.015" to 0.060", and the size of the kerf where the cutting stream en-

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Blanks for these small HSS parts were cut on an AWJ machine at Arthur R. Warner Co.

ters the workpiece is about 10 percent larger than that nozzle orifice.

The effective feed rate or cutting speed for an AWJ depends on multiple variables, including the material characteristics of the workpiece, its thickness and the contour of the cut itself. As a general comparison, Flow International lists typical cutting speeds for various materials cut on an AWJ machine running a 60,000-psi cutting stream through a 0.014"-dia. jewel orifice. Nominal speeds for a ¼"-thick workpiece range from 76 ipm in aluminum to 207 ipm in graphite to 30 ipm in mild steel to 26 ipm in Inconel.

As material thickness increases, the cutting speed slows. For example, while the cutting speed for ¼"-thick mild steel is 30 ipm, it drops to 14 ipm for a ½"-thick workpiece and to 6 ipm on a 1"-thick plate. Also, a hardened workpiece cuts more slowly than one that is annealed. Flow International notes that these are maximum speeds, and to impart a high-quality surface finish, cutting speeds may need to be reduced by up to 60 percent.

Precision and the Floppy Tool

The curves and contours of the cutting path also influence cutting speed, as does the level of precision desired. That is because an AWJ is a "soft" tool, meaning it loses energy in the cut. Depending on the speed with which the cutting stream moves through the cut, the trailing end of the cutting stream lags behind the point where it enters the workpiece. This lag can cause inaccuracy in cuts that curve.

In addition, an AWJ cut tapers, or is wider at the top than at the bottom. Generally, the faster the cutting speed, the greater the taper. Too much taper is unacceptable in applications where tight tolerances are required or when it compromises workholding in secondary operations.

Continuing progress in overcoming lag and taper is the main reason for growing acceptance of AWJ technology.

Sandra McLain, marketing director for Omax Corp., a waterjet machine OEM in Kent, Wash., said the "mainstreaming" of AWJ machining "is happening because of the software. Before, you basically controlled that floppy cutting tool by G-code, which was sort of a black art." Often, numerous test pieces were required before accurate production was possible.

McLain said introduction of a PC-based expert system (a database of knowledge used to guide an application) for AWJ machining has been key to advancement of the technology.

Dr. John Cheung, Omax chairman, said the software is based on the concept of "plan first and move later." Cheung said that in the early 1990s, Dr. John Olsen, now Omax's operations vice president, developed AWJ control software. The software combined a workpiece machinability database with details about the intended cutting path. It used the information to compute how fast to move the cutting stream to achieve a desired quality of cut, minimize taper and lag, and maximize productivity and accuracy.

The software, Cheung said, permits accurate machining from the get-go. The cutting path and feed rate profile are stored in a PC and used to directly drive the servomotors that control the X-Y motion. For a given part geometry in a given material, the feed rate can change as often as every 0.0005" along the cutting path. Precision of ±0.002" to ±0.005" in material up to 2" thick is common.

Art imitates work

Tom Risser, president of U.S. Bottlers Machinery Co., uses AWJ to make his living—and also to make his art.

Risser said his artwork is "all over the map," from large-scale abstract metal sculpture to furniture and fused glass. He is affiliated with more than half a dozen galleries and also owns Eight Legs South of the Tracks Gallery in Waxhaw, N.C. (Check out his entertaining Web site at www.twisted-design.com.)

T. Risser

Among the artwork Tom Risser creates with the help of his AWJ machine are fused-glass bowls.

Risser said he does very little art completely on the AWJ machine. "I'm not a guy who wants my art to look like it's factory-produced," he said. "I occasionally blank out some butterflies or something like that, then take them home to weld and burnish them, turning them into 3-D objects."

On the other hand, he said, "you can do things with glass on the waterjet that you cannot do by hand. For fused glass, I cut spirals that nest inside each other and put them in a kiln to melt them together."

Risser even makes use of manufacturing scrap. "The cool thing about a waterjet is that every time you cut a circle or a hole, you've got a nice piece left over, a nice shape," he said. "You can reach down to the bottom of the tank and find some really interesting metal pieces. Then as an artist, you go home and turn them into furniture!"

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Mike Warner, president of Arthur R. Warner Co. (right), and Mathias Packe, shop supervisor, inspect stainless steel hose wrenches cut on an AWJ machine.

Recently, AWJ control technologies have progressed to include computer-positioned cutting heads that tilt to provide taper correction. In the Omax Tilt-a-Jet system, for example, the computer positions the cutting head so it produces a cut that is taper-free and perpendicular on one side while doubling the taper on the waste side. Cheung said that with the system "many of our customers are able to hold part accuracy somewhere between 0.001" and 0.002" on parts up to 2" thick."

However, the intrinsic precision of AWJ machining can make achieving such levels of precision unnecessary. Many shops cut a part to near-net shape with an AWJ and then grind it to final dimensions.

Tom Green, owner of Kutz Fabricating Inc., a Pittsburgh machining and fabrication shop, has two Omax AWJ machines. Kutz makes parts ranging from conveyor components to thin electrical contacts. "We cut a little bit of everything," he said. "Glass, rubber, steel, stainless, copper, aluminum—you name it, we probably cut it."

Green said his shop adjusts the accuracy of the cut to fit the job at hand. "With the waterjet, you may only have a couple thousandths taper on a ½" piece of material," he said. AWJ machine OEMs, he continued, "say you can hold ±0.005", and that's fairly true. I like to stay around ±0.010". I know we can hold that. We do thousands of parts that we just waterjet and send out."

The minimum-taper feature of the control software is effective, Green said, but it slows the AWJ machine down. "Sometimes, we use it when we are machining a keyway or the center of something that's fairly critical," he said. "It eliminates the taper to maybe 0.001" or 0.002"." However, customers are charged according to machining time and usually don't want to pay for the slower cut when higher precision isn't necessary. The extra cost becomes acceptable, though, when a more precise cut can eliminate a secondary operation.

Green said the software also enables the shop to perform operations in one setup that used to require multiple machines. Previously, when machining flanges, "we used to have to lay them out, take them over to a punch press and make holes in them, then take them to a saw or burning table (plasma cutter) and burn them. Now the waterjet does everything at once. It puts the holes in, cuts the circle, cuts the ID and cuts the OD," he said. "We lay everything out on the screen—it's Windows software—and the waterjet cuts it."

The nesting feature of the control software facilitates profitable AWJ machining of short production runs. Tom Risser is president of U.S. Bottlers Machinery Co., Charlotte, N.C., a maker of custom-designed bottle-filling and -handling machines. The plant has a 12'x12' AWJ machine from Flow International.

"Our longest runs are 20 to 30 parts," Risser said. "The waterjet is easy to program for 'onesie-twosie' stuff. You can take a sheet, slowly nest in all your different components over a week, then set it up and let it run for a couple of hours."

Risser added that fixturing a part for AWJ machining usually is simple. Compared to the tooling and fixturing issues prevalent when using a CNC milling machine, "with a waterjet, primarily all you are doing is sliding the plate into a corner, homing it, clamping it down and going," he said. "You don't have to buy special tooling or fixturing."

Why a Waterjet

Often, a shop adds AWJ capacity to replace outsourced services. "We were spending $30,000 to $50,000 a year on outside vendors for laser cutting," said Risser. "I wanted to bring that money in-house, and I discovered waterjet cutting. We used to have the steel company cut out a blank in a certain size. Now we cut everything from sheets."

The AWJ also enabled the company to eliminate sourcing of some castings from outside suppliers. Instead of spending $3,000 for pattern (mold for the casting) for a cast plate with a few radiused corners, "now we do it on the waterjet," said Risser. "We cut it and we're done. We only cut as many as we need, and we can cut anytime we want."

Mike Warner, president of Arthur R. Warner Co., Latrobe, Pa., has an Omax AWJ machine to cut HSS blanks. Warner Co. specializes in the production of thin, flat, HSS blanks, down to 0.020" thick, as well as a complete line of HSS throwaway inserts.

Before it acquired the AWJ machine, the company cut HSS sheet and bar stock with a plate saw. Seeking greater productivity, Warner investigated plasma cutters, lasers and AWJs. "You can't use plasma to cut HSS," he said. "It actually changes the chemistry of the steel at the cut and pulls the tungsten and the molybdenum toward the surface. Laser gives a heat-affected zone, and with HSS, I didn't want that." Warner settled on the AWJ machine, and found it could cut the

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Tom Green, owner of Kutz Fabricating, shows mating rubber and stainless steel conveyor components that were cut, separately, on an AWJ machine.

same material at 12 to 18 ipm that cut at only 2 ipm on the plate saw.

Warner generally cuts HSS parts to near-net shape, sends them out for heat treating and then finish-grinds them. However, the ability of an AWJ to precisely cut hardened workpieces with no heat-affected zone has helped him solve customer inventory crises. After acquiring the AWJ machine, Warner began to stock a variety of small, heat-treated HSS plates. "Now, if a customer wants to order a hundred parts, but he needs 10 real quick, we can take the heat-treated plate, put it on the waterjet, cut 10 parts and ship them to him in 4 to 5 days. It might be only 10 pieces, but it's enough to get him out of the woods," he said.

AWJ also helps Warner get the most out of raw material, an important benefit as steel prices continue to rise. Using the plate saw to cut blanks, he could make 4,500 pieces of a certain tool bit from a 2,000-lb. plate of HSS. With the AWJ, it is possible to cut 6,800 bits from the same amount of material. The narrow kerf produced and tight tolerances the AWJ meets, compared to the plate saw, minimize waste.

Job Shopping

John Dedic, marketing manager for high-pressure waterjet equipment supplier KMT Waterjet Systems Co., Baxter Springs, Kan., said versatility is the biggest appeal of AWJ machining for shops. "The variety of material they can cut with waterjet is extreme," he said, "from titanium and steel to foam, granite countertops and glass." While materials like foam and stone are not traditional fare for metalworking shops, economic pressures are driving them to find ways to diversify. AWJ capacity, he said, "has given them a lot more ways to make money when times get tough."

Duncan Murdock, regional sales manager for Flow International, called the AWJ the "Swiss Army knife of metalcutting processes" because it can cut nearly any material. He acknowledged that some materials are cut more quickly with a plasma cutter or a laser, but for others, AWJ excels.

A typical case is aluminum, he said. "Aluminum is a reflective material so lasers have problems with it. And we can cut it pretty much as fast as a laser, especially when it's over ¼" thick."

AWJ can make out-of-the-ordinary work routine. In fact, Warner said, "I allow 20 percent of the machine's time for walk-in work. The guys in town bring me stainless to cut. We've done rubber and ceramic. You name it and I've cut it." Warner said he's even cut different materials on the same job, citing work on a 46"-dia. lapping pad that consisted of a 0.078"-thick steel disk with 0.172" of rubber bonded to it. The customer wanted Warner to make 144, ⅛"-dia. through-holes in the pad, then countersink the rubber down to the steel to accommodate a ⅜" bolt head.

"It took a little bit of time to figure it out," Warner said. "First, we cut the through-holes with the waterjet, then we turned off the abrasive and cut the ⅜" countersinks at a high cutting speed. We cut the rubber but didn't cut the steel, then popped the rubber out with a screwdriver."

Many shops consider AWJ machining as a complement to other metalcutting processes rather than a straight replacement. For example, Warner said, "you can't compare EDM to waterjet. EDM cuts very accurately, but at such a slow rate. The waterjet isn't as precise, but it cuts really, really fast. It depends on what you're doing."

Maintenance and Disposal

Productivity and versatility do have their price. Kutz Fabricating's Green said, "It's probably the most maintenance-intense piece of equipment we have here. You do have to keep an eye on it." Nevertheless, he added, "I'm very happy with it—I bought another AWJ machine!"

KMT Waterjet Systems' Dedic agreed that maintenance is critical in getting maximum precision and productivity out of an AWJ machine. "It's not like other machine tools that you just set up and run," he said. "We try to be very clear with people that they must monitor these machines and keep them in good running condition."

Flow International's Murdock stressed the importance of training operators of AWJ machines. "That's the big thing. Once they are trained, they have no problems," he said.

AWJ machining is not the perfect solution for every application, but it's certainly an alternative to consider for a range of situations. Risser is a true believer. "In the next decade, if you're a job shop and you don't have a waterjet, you're going to be really hurting," he said. "Everybody needs to have one, even if it's a little 4'x8'. People are constantly coming up with new shapes that you just can't do any other way."

Dedic simply looks at the present state of supply and demand for AWJ services. "When I talk to people who aren't sure if they should buy a machine, I tell them to call a job shop in the area that does have one, and get a quote on the time to deliver a part." △

The following companies contributed to this report:

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