Water down

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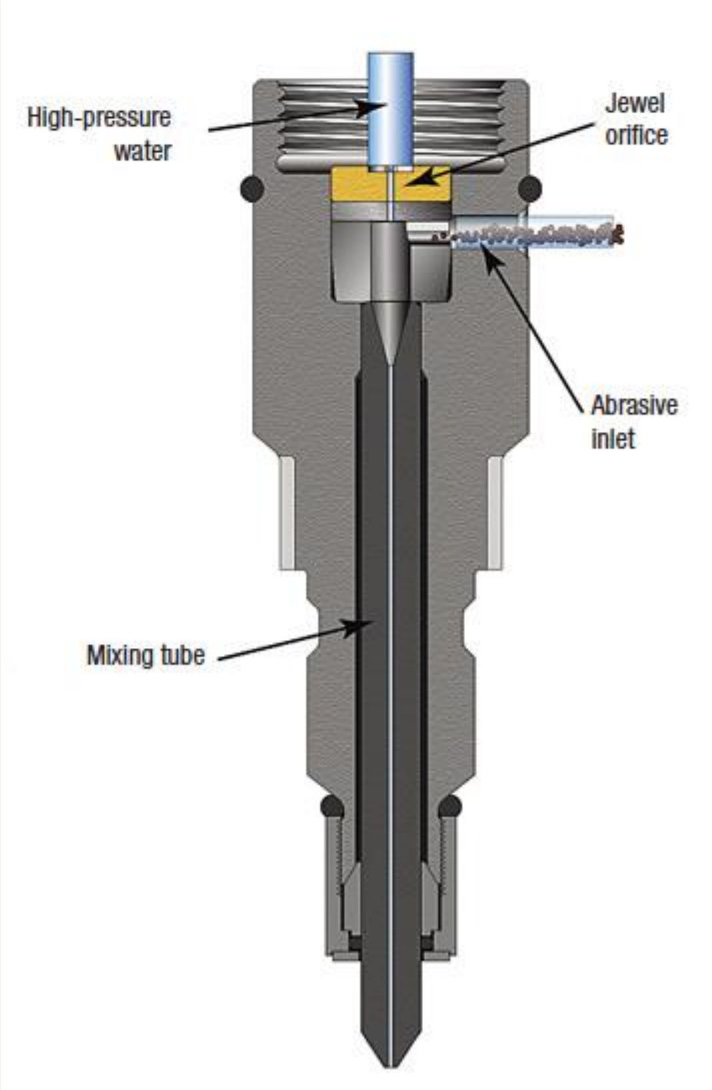
Fine tuning abrasive waterjets for micro applications

Geologists say that the Colorado River once took a hard westward turn, then trickled its way across what is now northern Arizona to form the Grand Canyon. Abrasive waterjet pioneer Don Miller predicts there is another trickle coming, this one in the world of micromanufacturing.

Miller, who heads Miller Innovations, the U.K.-based research company involved with Finecut waterjet machines made by Finepart Sweden AB, has spent the past 15 years researching and promoting a technology that turns plain tap water into a cutting-edge force to be reckoned with, one that can machine features to greater accuracy and in finer detail than previous waterjet technologies. “We’re researching systems capable of cutting reliably with nozzle diameters down to 50µm,” he said.



An abrasive waterjet nozzle. Image courtesy Omax.

That's mighty precise for equipment that works much like the power washer you use to hose down your Honda Civic on a warm day. Waterjet machines have been around for decades. They work by firing a guitar-string-wide stream of pressurized water that travels at the speed of a bullet, and are used to cut everything from frozen pizza to aluminum wing spars.

For anything tougher than a granola bar, that same waterjet receives an injection of ultrafine abrasive particles, which rip away the target material faster than Secretariat running in the Kentucky Derby. The result is a smooth, burr-free finish in titanium, Kevlar, rubber, plastic, wood … the list goes on. About the only materials an abrasive waterjet (AWJ) struggles with is diamond (too hard) and tempered glass (too brittle). For everything else, this manufacturing Goldilocks is just right.

Taking macro to micro

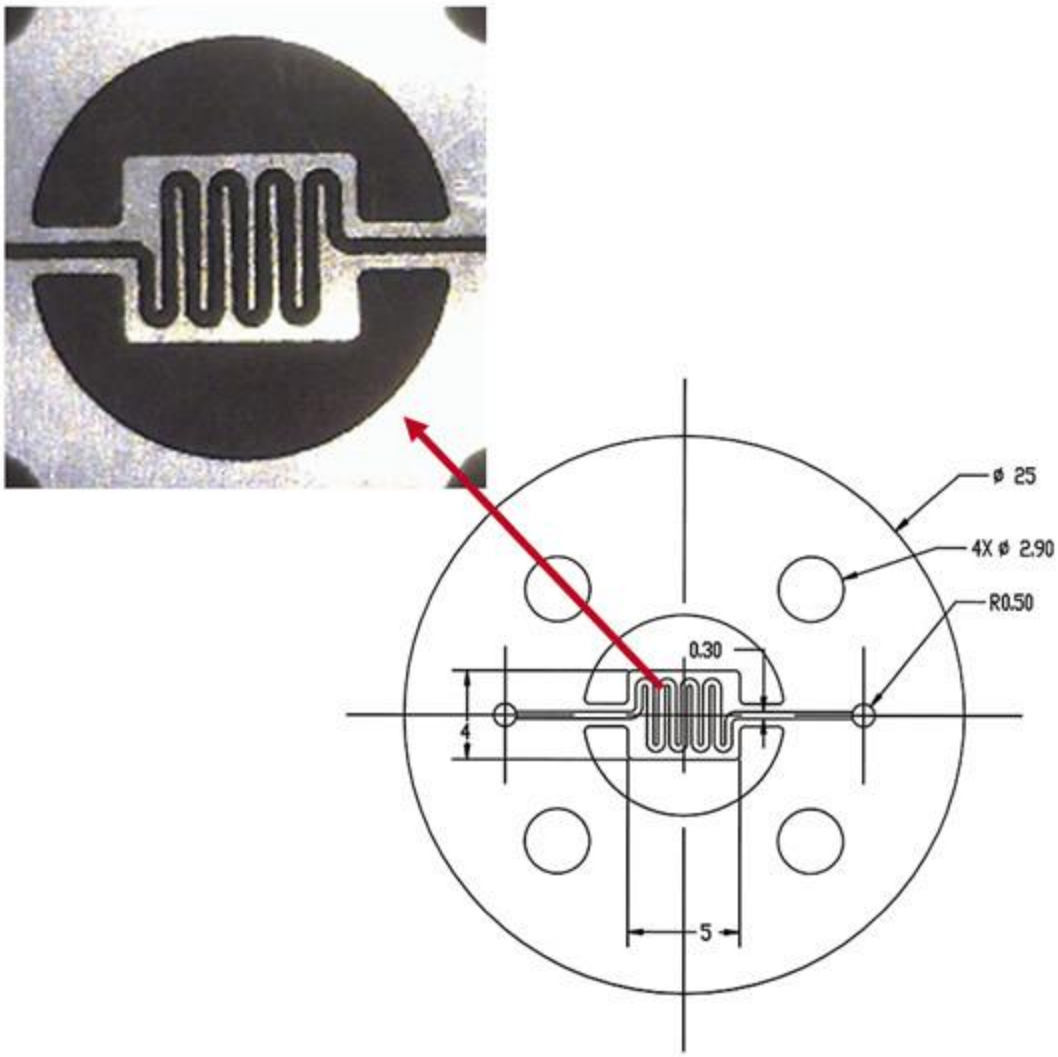
With conventional chipmaking operations, going from macroscale to microscale typically means throwing the feeds-and-speeds playbook out the window. Yet Miller explained that, from an application perspective, there's little difference in the AWJ world between cutting material thick enough for a battleship hull or thin enough for a microprocessor.

"There is essentially no change in the cutting mechanism when going from macro to microAWJ machining," he said. "If the cutting jet diameter is reduced by a factor of 10, and the material thickness is also reduced by a factor of 10, cutting speeds remain roughly the same."

The one exception to that statement is the abrasive. As the jet gets smaller, more abrasive particles per second are used relative to the amount of machining performed, and the particles become larger relative to the width of the waterjet. For example, if you were to cut 6"-thick Inconel on an industrial AWJ, you might inject abrasive particles 100µm or larger into a jet 500µm in diameter. In this situation, Miller said, the abrasive particles flow as easily as sand through an old-fashioned egg timer.

However, cutting parts for a miniature dielectric resistor out of aluminum foil requires a jet much smaller than the "firehose" just described. While Miller might be able to deliver a 50µm-dia. nozzle for the AWJ application, the finest-grain abrasive commercially available is about half that size. This scenario would be like shooting rocks through a garden hose, and raises all kinds of issues with abrasives clumping together, compaction of the particle bed and air entrapment.

"The metering and feeding of fine powders is probably the most complex and challenging of all industrial flows, and is the primary roadblock to further development of microabrasive waterjet machining," Miller said. "Because of their struggles with particle-flow systems, experts in this area have developed a rich tool bag of experience, but for the foreseeable future, minimum cutting jet diameter will be limited to about 50µm."



With features just 0.30mm wide, this medical part was less expensive to produce with microAWJ than competing technologies. Image courtesy Micro Waterjet.

While Miller and his water-loving peers continue their quest to go where no waterjet has gone before, commercially available microAWJs do a respectable job with 200µm-dia. nozzles. Christian Öjmertz, managing director of Finepart Sweden, based in Bollebygd, said it's important to get the word out to the manufacturing industry about microAWJ and what it can do today.

"Customers need to be aware of microAWJ's capabilities, as well as the part quality attainable with this process." That said, Öjmertz offered this advice: "There are a handful of microAWJ builders, and all claim the same level of accuracy and part precision. It's important to cut some test parts and determine the correct processes prior to investing in any machine tool."

Compared to micromachining processes such as lasing and EDMing, microAWJ cuts a wider range of materials and frequently delivers better results, according to Öjmertz. "We are not limited to electrically conductive materials, as is EDM, nor are we concerned with material flammability or reflectivity, as with laser processing," he said. "There is no heat accumulation with

AWJ, like with thermal processes, so the recast problem is avoided. This makes it quite easy to cut sharp edges and thin bridges while maintaining material integrity."

Despite microAWJ's benefits, Öjmertz noted the technology is still a work-in-progress. To help speed microAWJ's development, Finepart practices what it preaches, providing contract machining services using its own equipment. "It's part of our learning curve," he said. "By collaborating on our customers' parts, we gain experience with the machine tools we develop, and, at the same time, prove to our customers that this is a process that will work well for them."

Extremely long aspect ratios with very straight walls are possible with microAWJ. Image courtesy Finepart Sweden.

Machines and more

Micro Waterjet LLC is another company wearing multiple hats: equipment supplier and contract manufacturer. According to Steve Parette, managing director for the Huntersville, N.C., distributor of Daetwyler-built machines, under license of the WATERjet-Group, Switzerland, "There is a lot of work out there for microAWJ, but, at the same time, this is a technology that doesn't always lend itself to the purchase of a machine tool."

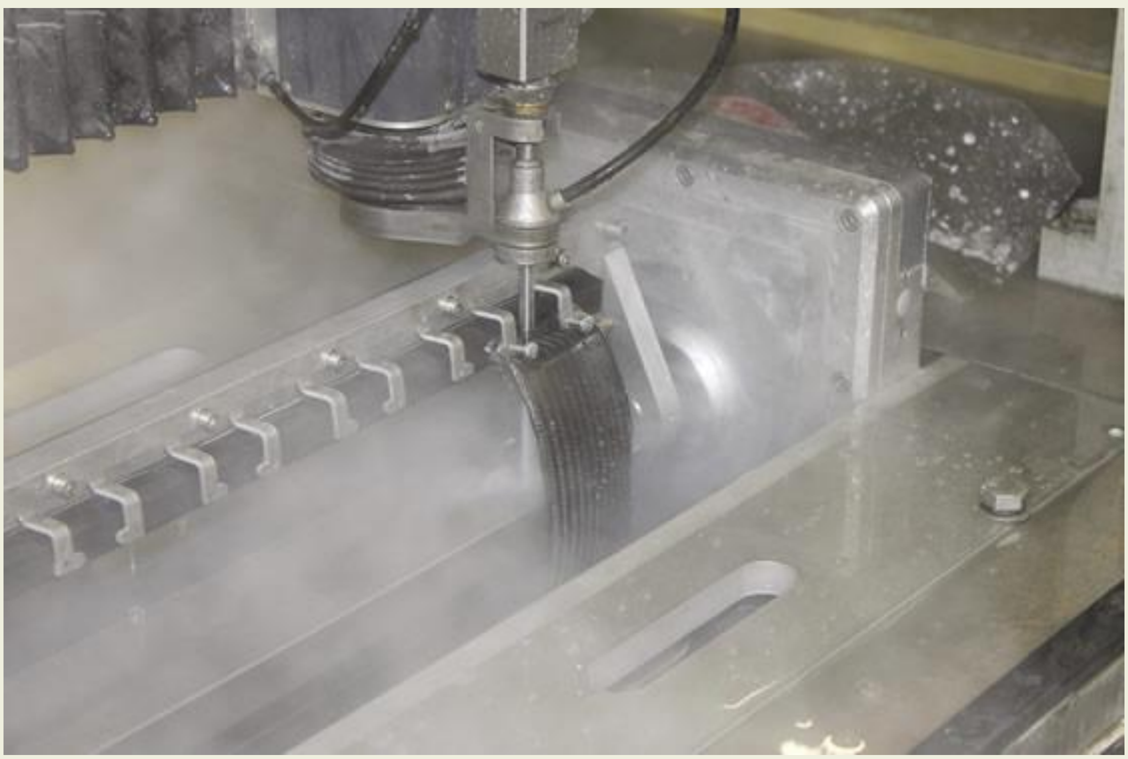
Micro Waterjet offers a 6-ton, glass-scaled machine with a 1-sq.-m work envelope. Despite the equipment's elephantine size, MWJ's bread-and-butter on the contract side is more mouse-like, primarily small, delicate work. "Even though we are cutting pieces measuring 14" across, they contain features that are ±0.001". That said, our typical workpiece is anything under a millimeter thick. There we hold tolerances to ±10µm."

Like its competition, MWJ runs waterjets with nozzles as small as 200μm in diameter. Parette said it was a long road getting to that point. “One of the big challenges comes during introduction of the abrasive. We use 300-mesh garnet, which measures a couple-thousandths of an inch in diameter. You have to feed this into the stream at a very low rate, while still creating enough acceleration that you can cut the material efficiently.”

Using Miller’s egg timer analogy, this would be like replacing the sand with flour—it can be a struggle to keep things moving. By developing the right mixing chamber and working closely with abrasive manufacturers, MWJ was able to come up with the right combination, according to Parette.

With this mix, Parette achieves cutting rates up to 2 sfm while holding tolerances of a few-thousandths of an inch. Despite these results, though, challenges remain.

Cutting straight walls and accurate dimensions is a continuous balancing act. “The longer you stay in one spot, the more material you are routing away,” Parette said. “So, if you run too slowly, you can end up with taper and the bottom flared out. We can control that a bit by the amount of abrasive that we put through, but if you speed up, you’ll reach a point where the bottom is barely broken through.”



No tool wear here—using a rotary table to cut carbon fiber with microAWJ. Image courtesy Finepart Sweden.

To further complicate matters, the abrasive particles are constantly breaking down, especially when cutting hard materials. “It’s a critical combination of workpiece material, cutting speed and feeding in enough fresh abrasive to maintain good cutting action,” Parette said.

Making parts

Micro Waterjet's first machine sale was to Incodema Inc., Ithaca, N.Y. Engineering manager Andy Jaye said the decision to purchase the waterjet equipment was a no-brainer: "Our philosophy is to always buy the latest technology available, regardless of the process. That's where we can best satisfy our customers' needs. MicroAWJ seemed like a perfect fit."

Incodema's innovative mindset has paid off. Compared to its wire EDMs, Jaye said, the company's microwaterjet can cut up to 50 times faster and has "opened up a whole new ballgame for much smaller geometries," producing a diverse range of products for the medical, consumer electronics, military and aerospace industries.

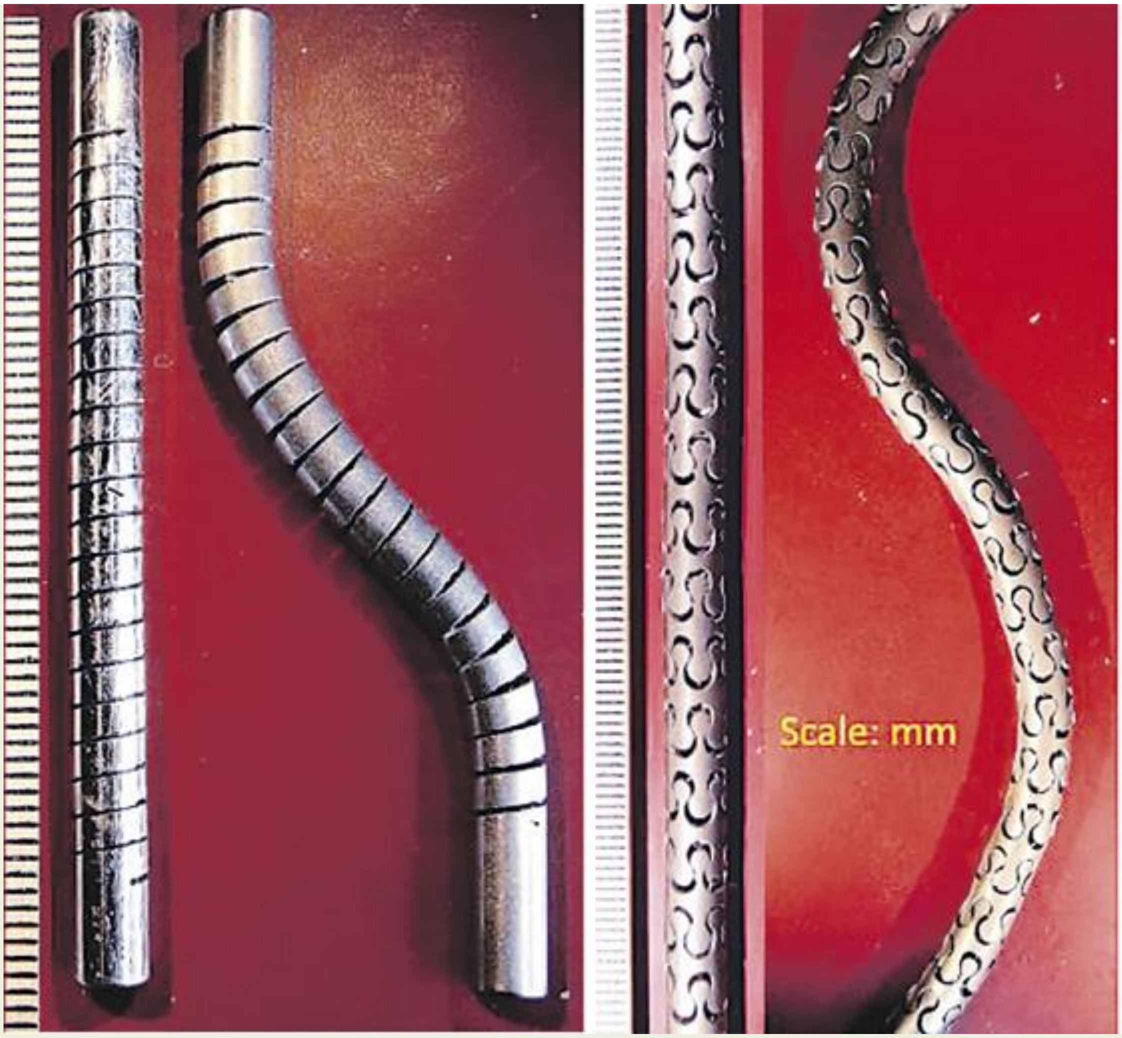
"It creates tremendous possibilities for how you design things," Jaye continued. "Assemblies can be joined together differently now. New geometries can be cut that were previously impossible to manufacture. For example, we can take a piece of $\frac{1}{8}$"-thick engineering plastic and microwaterjet complex features with wall thicknesses 3 to 5 mils [0.003" to 0.005"] across. There's no other process that can do that."

MicroAWJ proponents say the technology will change the world of micromachining—or at least a big chunk of it. The only thing holding the technology back is education.

"Designers and engineers have been limited to manufacturing processes that forced them into less-than-optimal design solutions," Jaye said. Now there's a process that cuts virtually any material, with minimal material loss, no heat-affected zones and accuracies that are hard to beat.

"With this technology, you almost have to rethink everything," Jaye said. µ

Anatomy of a microAWJ machine



These 6mm-dia. titanium spinal cages were machined with microAWJ and a rotary axis. Measurement scale (mm) is in the middle of the photo. Image courtesy Omax.

With a 20-year history as an industrial waterjet machine builder, Omax Corp., Kent, Wash., is looking to downsize—its machines, that is. Senior scientist Peter Liu said Omax is developing a "next-generation" microAWJ machine as part of a Phase IIB grant from the National Science Foundation (NSF). Called simply the "micro machining center," the new machine includes the following features:

- Sturdy machine construction. Liu said, "When you get down to waterjets less than 100µm in diameter, the stability of the machine becomes increasingly important to workpiece accuracy. This is why we have substantially increased the mass of the machine in this new design."
- Accurate motion control utilizing glass-scale feedback and linear motors that will provide positional accuracy twice that currently offered on Omax waterjet machines.

- Antivibration technology to eliminate pump vibration and environmental forces. “This has been a big issue for us,” Liu said. “We have found that mechanical vibration transfers directly into the waterjet nozzle, leading to waviness in the kerf. Therefore, we’ve isolated the cutting head from the pump and added vibration dampers to the machine foundation.”
- A refrigerated water tank to prevent machine growth because of changes in ambient air temperature, as well as heat generated by the machine tool itself.

Testing of the prototype machine is slated to begin within the next few months, and Omax plans to introduce the machine at a trade show in late 2013. Said Liu, “For anyone interested in the machine, the NSF is offering a 50 percent match toward the purchase of the machine in an effort to encourage commercialization of the technology.”

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